Carbon sequestration
Policy, science and economics

Proceedings of a COFORD seminar on Carbon Sequestration and Irish Forests, Dublin, Ireland, June 15th 2000

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FOREWORD FROM THE OPENING ADDRESS

COFORD SEMINAR: CARBON SEQUESTRATION AND IRISH FORESTS

JUNE 15TH 2000
INDUSTRY CENTRE UCD

Ladies and Gentlemen, as COFORD chairman I would like to welcome you all here this morning to our COFORD seminar on Carbon Sequestration and Irish Forests.

Forests are the world's largest store of carbon. Over exploitation has reduced forest cover in many developing countries and this, together with the growth in the use of fossil fuels, has raised global CO_2 and other greenhouse gas levels. Most scientific opinion now agrees that unless steps are taken to stabilise and reduce emissions of greenhouse gases there will be global warming with potentially devastating consequences for the environment and the human race. What is being done about these concerns? At a national level we are about to issue a greenhouse gas abatement strategy that will encompass a series of measures including, it is likely, the use of forestry to offset projected increases in CO_2 emissions. This is in keeping with our national targets as agreed at Kyoto as part of the UN Framework Convention on Climate Change.

We recognise of course, that forestry will not of itself reduce emissions but can be an important part of a series of measures aimed at offsetting and reducing greenhouse gas levels. We also recognise that there are research and development needs tied into using forests to offset increases in emissions. Not least of these is the need to develop robust models of the amounts of carbon stored above and below ground. COFORD has already published the first estimates of carbon storage in Irish forests - but we will be refining and improving on these over the coming year – it will from an important part of our new research programme.

As we have said Ireland is well placed to use forests as part of a package of measures which aim to offset and reduce rising emissions of greenhouse gases. From the early 1990s the national afforestation programme has resulted in significant areas of new forests being established each year, and Government policy is to continue to expand forest cover from 9% at present to 17% by the year 2035.

All of these developments make it is an opportune time to review and discuss the latest policy and research findings relating to carbon sequestration and Irish forestry. We have here today a distinguished panel of speakers to address technical and policy issues. I am sure that we will have a useful and productive day.

David Nevins
Chairman
COFORD

EDITORS' NOTE AND UPDATE

This compilation of papers and presentations from the COFORD conference CARBON SEQUESTRATION AND IRISH FORESTS, which was held in June 2000, is one of a number of current and planned COFORD publications which deal, and will deal, with carbon sequestration in Irish forests and related policy, scientific and economic issues.

The international process has moved forward rapidly since the COFORD seminar. COP6, held at The Hague last November put the use of forest sinks centre stage in the negotiation process. It is not an exaggeration to say that disagreement on forest sinks was the main reason for the failure of COP6. Sinks have assumed such an importance that the nature and extent of their use as stabilisers of greenhouse gas levels will be a critical part of any future international agreement on climate change. A further development has been President Bush's intervention in March, to announce that the US was opposed to the Kyoto Protocol reduction targets and to the non-inclusion of developing countries in emission reductions. However, despite some initial setback the international process is moving ahead. A new Presidency Paper from Minister Pronk of The Netherlands was issued last month. It envisages a significant contribution from sinks in helping to stabilise levels of greenhouse gases.

The EU remains firmly committed to action on climate change and proposes to ratify the Protocol in 2002. In Ireland the National Climate Change Strategy was published in October 2000. It sets the contribution of forest sinks at 1.01 million tonnes of CO_2 equivalent per year over the period 2008-2012. Overall the indicative reductions proposed in the strategy are 15.42 million tonnes of CO_2 equivalent per year. Research funded by COFORD will shortly begin to better quantify the Irish forest sink.

In the text a uniform terminology relating to sinks has been adopted, as far as possible, though this is ever changing in a rapidly developing field.

Dr Eugene Hendrick
Director
COFORD

Dr Miriam Ryan
Research Projects Officer
COFORD

June 2001

CARBON STORAGE IN IRISH FORESTS - CURRENT KNOWLEDGE AND RESEARCH NEEDS

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Abstract

Although much carbon is removed each year from the earth's atmosphere by forest growth, the CO_2 content of the air has been increasing over the past number of centuries. To calculate the rate of carbon storage in forest ecosystems a number of models have been developed. The models developed in Britain generally combine tree production functions with carbon retention curves for various products. Attempts have been made to apply these models to forest ecosystems in Ireland. However, while preliminary estimates indicate that Irish forests may, on average, fix 3.36 tonnes of carbon ha^{-1} yr^{-1}, many of the figures used to calculate this estimate, particularly that for the so-called biomass expansion factors, need much more refinement before more accurate estimates can be made available.

Introduction

The increasing concentration of carbon dioxide (CO_2) in the atmosphere has intensified interest in research on cycling of carbon (C) at the global level. Atmospheric CO_2 concentrations have increased 30% from the pre-industrial level of about 280 parts per million (ppm) to close to 370 ppm today. Forest ecosystems play an important role in the global carbon cycle. Trees remove CO_2 from the atmosphere through photosynthesis during growth and development processes. The carbon is stored in wood, bark, needles/leaves and in roots. Much of the carbon passes to the forest floor and forms a litter layer, which is composed of dead foliage and twigs (Figure 1).

As the litter layer decomposes part of it passes to the soil as organic matter. Thus, the soil is an important carbon reservoir, and accounts for a large proportion of stored carbon (Figure 2). The standing biomass and the forest products pool, at least under Irish conditions, account for smaller proportions of the carbon pool.

The rate of carbon sequestration in forests varies with species and with yield class (YC). In general, carbon storage rates increase rapidly with increasing yield class, but long-term storage levels are not as sensitive to growth rates (Table 1).

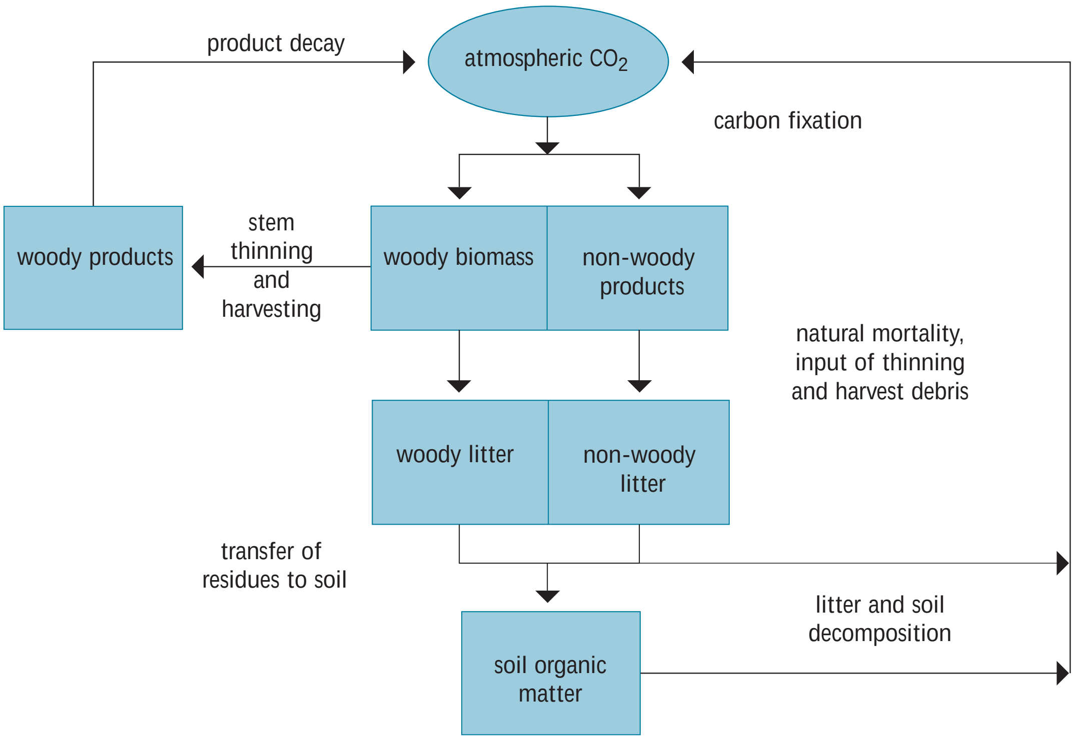

Figure 1: Carbon pools and fluxes in a plantation forest ecosystem {source Cannell (1995)}.

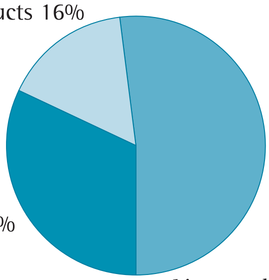

***Figure 2:** Carbon storage in forest ecosystem pools {after Dewar and Cannell (1992)}.*

Species which have the fastest growth rates, have generally also the fastest rates of carbon storage. However, they do not necessarily have the greatest total storage (Table 2). The time-averaged carbon storage in a thinned beech (*Fagus sylvatica*) plantation of YC 6, has been found to be greater than that in a thinned spruce {*Picea sitchensis*, Bong. (Carr.)} stand of YC 12. However, carbon sequestration can be maximised in the short term by growing high yield class crops (to maximise storage of carbon), felling the crops and reforesting the area, and by converting the harvested wood to long-lived products.

Carbon Storage in Irish Forests

Using the information in Table 1, Kilbride *et al.* (1999) estimated C storage in four contrasting forest types in Ireland (Table 3). They showed that the Coillte forest estate of 344,896 ha of productive forest (PFA) has the potential to store carbon at an average rate of 3.36 t C ha^{-1} yr^{-1}. This is equivalent to 1.16 million tonnes of carbon yr^{-1} (Mt C yr^{-1}).

Taking into account the fact that there are a further (ca.160,000 ha) of plantations in the private sector and assuming the same average rates of C storage adds a further 0.54 Mt C yr^{-1}, this brings the national total to 1.7 Mt C yr^{-1}.

These amounts of carbon were derived using the model developed by Dewar (1991) as modified by Dewar and Cannell (1992). This is one of the few models which encompasses the entire tree-soil-forest product system. It tracks the path of carbon from tree to products and soil in a dynamic fashion. There are, however, other models of this type, including the CO_2FIX software tool (Mohren *et al.*, 1999), the CARBMOD computer simulation model developed by Price and Willis (1993), and the Forestry Commission model developed by Thompson and Matthews (1989a).

***Table 1:** The impact of the growth rate (YC) of Sitka spruce on the rate and amount of carbon storage {after Dewar and Cannell (1992)}.*

	YC 6	YC 16	YC 24
Rate of C storage (t C ha^{-1} yr^{-1})	2.5	3.6	4.4
Carbon storage after one rotation (tC ha^{-1})	170	198	207
Carbon storage at equilibrium (tC ha^{-1})	134	192	211

***Table 2:** Carbon storage by contrasting forest types {after Dewar and Cannell (1992)}.*

Species	Yield class m^{3}ha^{-1}yr^{-1}	Rotation length years	Rate of C storage tC ha^{-1}yr^{-1}	Equilibrium C storage tC ha^{-1}
Sitka spruce	12	59	3.0	167
Beech	6	92	2.4	200
Oak	4	95	1.8	154

***Table 3:** Carbon storage over one rotation for four of the main species groups in Irish forests.*

Species	PFA ha	Mean YC m^3 ha^{-1} yr^{-1}	Rate of C storage tC ha^{-1} yr^{-1}	Total C Mt
Sitka spruce	221,557	16	3.6	35.89
Other conifers	111,032	12	3.0	14.99
Oak/beech	6,528	4	1.8	1.12
Other Broadleaves	5,779	6	2.4	0.49

The CO_2FIX model quantifies C stocks and fluxes in the forest (in whole trees), in the soil organic matter and in wood products. It has been used for even-aged monocultures, as well as other forestry and agro-forestry systems (Nabuurs and Mohren 1993). CARBMOD models the temporal sequestration of carbon for a range of tree species at different growth rates, using Forestry Commission (FC) yield tables and carbon sequestration figures. For each species, the model includes assumptions regarding the end uses of the wood to give a complete picture of the carbon dynamics of afforestation. CARBMOD was used by Clinch (1999) to estimate the contribution of carbon storage to the financial benefits of the Irish afforestation programme. The Forestry Commission model combines tree production functions based on FC yield models, with carbon retention curves for the various wood products recognised in the UK market (Thompson and Matthews 1989b).

In the Dewar and Cannell model, the amount of carbon (in kg) stored in living trees is derived from the equation:

Carbon mass = volume x d x fc

where:
volume is the accumulated biomass volume (m^3),
d is stemwood basic density (kg m^{-3}) and
fc is the proportion of carbon in wood.

Dewar and Cannell (op. cit.) derived the biomass volume (including above and below ground biomass) from the stemwood volume, using the FC yield tables (Edwards and Christie 1981), multiplied by a so-called ‘biomass expansion factor’ (BEF).

The difficulty in using this model arises because small changes in any of the model components can lead to considerable differences in the values obtained and ‘small’ changes in these components do arise for every crop. FC yield tables are used to predict crop production over the rotation in Ireland. However, there is long-standing evidence (Gallagher 1972) that forest crops in Ireland have a greater cumulative volume production for any given top height than is apparent in Forestry Commission Yield Tables. Thus, the Dewar and Cannell model may underestimate the carbon storage rates of forest plantations in Ireland. In addition it appears that BEF values may be higher under Irish conditions than that proposed by Dewar and Cannell (Table 4). In this context it has been estimated that a doubling of the BEF from 1.4 to 2.8 could lead to an increase of 73% in the estimated carbon storage values (Dewar and Cannell 1992).

Table 4: *Biomass expansion factors (BEF) for forest crops.*

Species	BEF	Source
Sitka spruce	1.5	Miller *et al.* 1980
Conifers	1.9	Johnson and Sharpe 1983
Broadleaves	2.4	
Sitka spruce (33 years old)	1.8	Carey and O’Brien 1979
Sitka spruce (6 years old)	2.8	Wills 1999
Sitka spruce (19 years old)	1.7	Wills 1999
Sitka spruce (29 years old)	1.9	Wills 1999
General	1.4	Dewar and Cannell 1992

Similarly, both carbon content and wood density are reported to vary with species. The model used by Kilbride *et al*. (1999) used standard values of 50% for the carbon content of wood and 350 kilograms per cubic metre (kg m^{-3}) for wood basic density. From available data a value of 350 kg m^{-3} may be quite accurate for conifers, however, values for oak and beech may be somewhat higher, at perhaps 550 kg m^{-3}. Similarly, the values for carbon content of wood vary and while a value of 50% was used in the estimation of carbon storage in Irish forests, Thompson and Matthews (1989b) give slightly lower estimates of 42% for conifers and 45% for broadleaves.

Research needs

Although preliminary estimates of the carbon storage potential of Irish forests are available, it is clear that much research will be necessary to refine these estimates and to produce more accurate figures for carbon storage. In this presentation only one carbon pool has been addressed in any detail and major difficulties in estimating carbon storage have been highlighted. It is also clear that the soil carbon pool, which may contain over 50% of the total carbon in the ecosystem, is the largest and most important pool. However, it is not the size of this pool which is significant, but the increase (or decrease) in size as a result of afforestation. Jenkinson (1971) found that the increase in the soil carbon pool size may be greatest as a result of the afforestation of mineral soils, while ploughing can result in a net loss of soil organic carbon in the years before canopy closure. Little information is available on carbon dynamics in forest soils or on fine root biomass turnover and decomposition. In the carbon-flow model for managed forest plantations in the UK, fractional decomposition rates for foliage; branch, stem and woody roots; fine roots;

and soil organic matter were estimated for mid-latitude UK conditions. These decomposition rate estimates were based on studies by Swift *et al.* (1979), Berg *et al.* (1984) and Vogt *et al.* (1986). Annual rates ranged from 3.0 tC tC^{-1} for broadleaf foliage to 0.03 tC tC^{-1} for soil organic matter (Table 5). It is also clear that there may be significant differences in the carbon cycle in mineral and peatland sites. Byrne *et al.* (1999) have reported that forestry development transformed a blanket peatland from a net source of methane to a weak sink, and that carbon dioxide emissions were greatly increased.

The wood products pool contains the carbon in wood that is harvested in thinnings and at final harvest. This wood is either burned as fuel or products are manufactured from it which, eventually, decay and release the stored C as CO_2 back to the atmosphere. Few data on the lifetime of wood products exist. Thompson and Matthews (1989b) constructed carbon retention curves for the various wood products recognised in the UK market, based on best estimates of the period to 95% loss of carbon. The 95% carbon loss period varied from four to five years for Sitka spruce pulpwood, pallet and packaging, to 300 years for oak construction and engineered wood products (Table 6). In several models the simplifying assumption is made that the lifetime of wood products is approximately equal to the rotation length used to produce them. However, as estimates indicate that only about 16% of the total carbon is stored in wood products (Figure 2), the sensitivity of the total carbon storage estimates to changes in product lifetimes and retention values is generally low (Dewar and Cannell 1992).

Two other effects associated with increasing atmospheric CO_2 levels require further investigation. First, the direct impact of higher CO_2 levels on tree growth (and indirectly on carbon sequestration) is not fully understood. Results from short-term experiments may not be valid over longer periods, as trees may ‘adapt’ to high CO_2 levels by producing fewer stomata per unit leaf area and by producing less photosynthetic enzyme (Eamus and Jarvis 1989) or by other physiological adaptations. (Valentini *et al.* 2000). Second, the long-term effect of climate change, especially the increase in ambient temperature, on tree growth has not been studied in sufficient detail. Initial investigations by Cannell and Cape (1991) indicated that a 1°C rise in temperature could have the effect of raising the average yield class in the UK by 2 m^3 ha^{-1} yr^{-1}. However, growth response would be dependent on soils, with forests growing on fertile soils benefiting most (Pastor and Post 1988).

Table 5: *Fractional decomposition rates of foliage; branches, stem and woody roots; fine roots; and soil organic matter {after Dewar and Cannell (1992)}.*

Species	Foliage	Branches, stem and woody roots	Fine roots	Soil organic matter
	tC tC^{-1} yr^{-1}			
Salix spp	3.0	0.10	2.0	0.03
Populus spp	3.0	0.08	2.0	0.03
Nothofagus spp	3.0	0.07	2.0	0.03
Picea sitchensis[1]	1.0	0.06	1.5	0.03
Pinus sylvestris	1.0	0.06	1.5	0.03
Pinus contorta	1.0	0.06	1.5	0.03
Fagus sylvatica	3.0	0.04	1.5	0.03
Quercus spp	3.0	0.04	1.5	0.03

[1] *All Yield Classes*

Table 6: *Estimated time to 95% loss of carbon for various wood products {after: Thompson and Matthews (1989b)}.*

Product	Softwoods		Hardwoods	
	Sitka spruce	Corsican pine	Oak	Birch
	years			
Pulpwood	5	5	5	5
Particle-board	40	40	40	40
Pallet & Packaging	4	5	5	5
Fencing	30	40	80	80
Construction & Engineering	150	200	300	40

Finally, an aspect of forest carbon sequestration studies that has generally not received much attention, is the emission of carbon as a result of associated forestry and wood processing operations. Forest nursery operations (including the use of chemicals and fertilisers), wood harvesting and transportation, wood processing and transportation of wood products to the customers, all require energy inputs. The quantities of carbon that are released as a result are not well established and further life-cycle analysis research is required to integrate production processes in carbon sink estimation models.

It is clear that before it is possible to refine estimates of carbon sequestration in Irish forests, much detailed research will be necessary on all carbon stocks, sinks and fluxes.

References

Berg, B., Jansson P.E and Meentegeyer V. 1984. Litter decomposition and climate - regional and local models. In *State and Change of Forest Ecosystems - Indicators in Current Research*. Ed. Agren G.I., Swedish University of Agricultural Sciences, Uppsala, pp 389-404.

Byrne, K.A., Farrell, E.P., Papen, H. and K. Butterbach-Bahl. In press. Carbon dioxide and methane fluxes in forested and virgin blanket peatland in the west of Ireland. Verh. Internat. Verein Limnol. 27(1-4)

Cannell, M. and Cape J. 1991. Forestry expansion: a study of technical, economic and ecological factors. Paper No 2: *International environmental impacts: Acid rain and the greenhouse effect*. Forestry Commission, Alice Holt, Surrey.

Cannell, M.G.R. 1995. Forests and the global carbon cycle in the past, present and future. European Forest Institute, Research Report 2.

Carey, M.L. and O'Brien D. 1979. Biomass, nutrient content and distribution in a stand of Sitka spruce. *Irish Forestry* 36(1): 25-35.

Clinch, J.P. 1999. *Economics of Irish Forestry: Evaluating the Returns to Economy and Society*. COFORD, Dublin.

Dewar, C.R. 1991. Analytical model of carbon storage in the trees, soils and wood products of managed forests. *Tree Physiology* 8: 239-258.

Dewar, R.C. and M.G.R. Cannell. 1992. Carbon sequestration in the trees, products and soils of forest plantations: an analysis using UK examples. *Tree Physiology* 11: 49-71.

Eamus, D. and P.G. Jarvis. 1989. Direct effects of CO_2 increases on trees and forests in the UK. In *Advances in Ecological Research*, Vol. 18. Academic Press, London/New York.

Edwards, P. N. and Christie, J.M. 1981. Yield models for forest management. Forestry Commission Booklet 48. HMSO, London.

Gallagher, G. 1972. Some patterns in crop structure and productivity for unthinned Sitka spruce. Irish Forestry 29(2): 33-52.

Jenkinson, D.S. 1971. The accumulation of organic matter in soil left uncultivated. Annual Report Rothamsted Research Station, UK, pp 113-137.

Johnson, W.C. and Sharpe D.M. 1983. The ratio of total to merchantable forest biomass and its application to the global carbon budget. Can. J. For. Res. 13: 372-383.

Kilbride, C.M., Byrne K.A. and Gardiner J.J. 1999. Carbon sequestration and Irish forests. COFORD, Dublin.

Miller, H.G., Miller J.D. and Cooper J.M. 1980. Biomass and nutrient accumulation at different growth rates in thinned plantations of Corsican pine. *Forestry* 53: 23-39.

Mohren, G.M.J., Garcia Caligaris J.F., Masera O., Kanninen M., Karjalainen T. and Nabuurs G.J. 1999. *CO2FIX for Windows: a dynamic model of the CO_2 fixation in forest stands*. Institute for Forestry and Nature Research (IBN-DLO), Wageningen.

Nabuurs, G.J. and Mohren G.M.J. 1993. Carbon fixation through forestation activities. A case study of the carbon sequestering potential of selected forest types commissioned by the FACE foundation. *IBN Research Report* 93/4. Institute for Forestry and Nature Research (IBN-DLO), Wageningen.

Pastor, J. and Post W.M. 1988. Response of northern forests to CO_2-induced climate change. *Nature* 334:55-58.

Price, C. and Willis R.W. 1993. Time, discounting and the valuation of forestry's carbon fluxes. *Comm. For. Rev*. 72: 265-271.

Swift, M.J., Heal O.W. and Anderson J.M. 1979. *Decomposition in terrestrial ecosystems*. Blackwell Scientific, Oxford.

Thompson, D.A. and Matthews R.W. 1989a. The storage of carbon in trees and timber. *Research Information Note* 160, Forestry Commission, Alice Holt, Farnham, Surrey.

Thompson, D.A. and R.W. Matthews. 1989b. CO_2 in trees and timber lowers greenhouse effect. *Forestry and British Timber*, October 1989:19-22.

Valentini, R., Matteucci G., Dolman A.J., Schulze E.D., Rebmann C., Moors E.J., Granier A., Gross P., Jensen N.O., Pilegaard K., Lindroth A., Grelle A., Bernhofer C., Grünwald T., Aubinet M., Ceulemans R., Kowalski A.S., Vesala T., Rannik Ü., Berbigier P., Loustau D., Gumundsson J., Thorgeirsson H., Ibrom A., Morgenstern K., Clement R., Moncrieff J., Montagnana L., Minerbi S. and Jarvis P.G.. 2000. Respiration as the main determinant of carbon balance in European Forests. *Nature* 404: 861-865.

Vogt, K.A., Grier C.C. and. Vogt D.J. 1986. Production, turnover and nutrient dynamics of above and below ground detritus of world forests. In: *Advances in Ecological Research*, Vol.15. Academic Press, London/New York, pp 303-377.

Wills, J.M. 1999. *The development of Sitka spruce crops on wet mineral soils following site cultivation*. Unpublished Ph.D. thesis, National University of Ireland, Dublin.

GREENHOUSE GAS BALANCES IN PEATLAND FORESTS

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Abstract

The current threat of climate change has stimulated considerable interest both in the role of forests in the global carbon cycle, and in their potential to sequester carbon dioxide (CO_2) and thereby offset greenhouse gas emissions from fossil fuel combustion. The role of peatland forests in sequestering atmospheric CO_2 remains uncertain. In the virgin state, peatlands are net carbon storing ecosystems. They capture CO_2 from the atmosphere and release methane. Forestry development exerts a considerable influence on the peatland carbon balance. Drainage and lowering of the water table leads to a cessation of methane emissions. The increased aeration associated with drainage leads to a change in soil microbial populations and an increase in CO_2 emissions. As a result of these changes peatlands may change from being net sinks of carbon to net sources. However these losses may be offset by CO_2 sequestration by the forest crop. This paper describes the carbon balance in virgin and forested peatlands and discusses the results of relevant national and international studies.

Introduction

The ability of forests to store and sequester atmospheric CO_2 is well known. Carbon is stored in biomass (above- and below-ground), litter and soil. The soil carbon store is the largest pool (Dewar and Cannell 1992, Dixon *et al*. 1994). Given the current concern about rising levels of greenhouse gases in the atmosphere and the threat of climate change there is an increasing need to understand the dynamics of carbon in forest ecosystems in order to understand how best to manage forests so as to maintain and enhance their carbon stores. The signing of the Kyoto Protocol in 1997 (UNFCCC 1997) has added impetus to this issue. Under this agreement, Ireland is committed to limiting its greenhouse gas emissions to 13% above 1990 levels by 2008-2012 (Department of the Environment and Local Government 2000). The Kyoto Protocol allows for some land use change and forestry activities, which sequester atmospheric CO_2, to be offset against greenhouse gas emissions.

The rate of carbon sequestration in forest ecosystems is controlled by the delicate balance between uptake (photosynthesis) and loss (respiration). They show strong diurnal, seasonal and annual variability. The carbon balance in peatland forests is also characterised by uptake and loss but its investigation presents researchers with many complex questions. This is because one must first consider the carbon balance in virgin peatlands and how it changes following soil preparation for afforestation and subsequently, as the forest grows and matures.

Peatlands in the boreal and temperate zones store some 0.5 x 1018 g of carbon (Gorham 1991), which is equal to about one third of the world's pool of soil carbon (Post *et al*. 1982). For example, in Great Britain 46% of the total soil carbon pool is in Scottish peats (Milne and Brown 1997). In Northern Ireland peatlands cover 12.4% of the land area (Hammond 1981) and are estimated to account for 42% of the soil carbon pool (Cruickshank *et al*. 1998). Given that peatland occupies 17.2% of the land area in the Republic of Ireland (Hammond 1981) it is reasonable to assume that a large proportion of the soil carbon there is also held in peat soils.

Some 15 million ha of peatlands in the boreal and temperate zones have been developed for commercial forestry (Laine *et al*. 1995). The majority of this activity has taken place in the Nordic countries and the former Soviet Union. Peatland utilisation for forestry in Ireland and the United Kingdom is quite different to that in northern Europe. Peatlands in northern Europe usually have a natural tree cover, the productivity of which is increased through drainage and fertilisation. In Ireland and the United Kingdom, on the other hand, peatlands are generally treeless and forestry development not only involves drainage and fertilisation but also afforestation with exotic tree species (e.g. Zehetmayr 1954, Farrell 1990).

Peatland forestry began in the Republic of Ireland in the mid to late 1950's. While some planting took place on raised bogs in the midlands, most was concentrated on the low-level blanket peatlands of the west and on high-level blanket peatlands, which occur on mountain ranges throughout the country (Farrell 1990). No accurate figures are available, but in 1990 there were estimated to be at least 200,000 ha of forest established on peat (Farrell and Boyle 1990), the majority of which was blanket peat. Despite the fact that the state sector no longer purchases large areas of blanket peatland for afforestation (Lowery 1990), the area of peatland forestry has increased significantly since 1990, given the expansion in private sector afforestation (COFORD 1994). A recent study by Gillmor (1998) found that most private afforestation during the period 1987-96 occurred in western counties; it is reasonable to assume that a large proportion of this was on peatland.

Carbon balance in virgin peatlands

The high water table and consequent poor aeration in virgin peatlands shifts the balance of growth and decay towards the accumulation of organic matter as peat. The rate of carbon accumulation is determined by the dynamic interaction between landscape, substrate, vegetation and climate (Harden *et al*. 1992, Korhola 1992, Korhola *et al*. 1995). Most peat-forming systems consist of two layers: an upper aerobic layer, the acrotelm, 0-50 cm deep, of relatively high hydraulic conductivity; and a lower anaerobic layer, the catotelm, much thicker, of lower conductivity and a lower rate of decay (Clymo 1984).

Carbon dioxide is taken from the atmosphere by the actively growing vegetation layer. Part of this is returned to the atmosphere through plant respiration. The remaining CO_2 is fixed in the growing vegetation and is subsequently deposited as plant litter, in, or on, the soil. Some 80-95% of this litter is decomposed by aerobic bacteria and released as CO_2 before it is transformed into peat under the influence of anaerobic conditions (Reader and Stewart 1972, Pakarinen 1975, Clymo 1984, Reinikainen *et al*. 1984, Bartsch and Moore 1985). Moore *et al*. (1975) estimated the rate of accumulation in an Irish blanket bog as 32 g C m^{-2} yr^{-1} or 6% of net primary productivity. Given that the rate of carbon accumulation is small it is clear that a small change in the delicate balance between growth and decay could shift the system from being a carbon source to a sink. The potential influence of climate change on this balance should not be overlooked. A climate-induced alteration in the carbon balance of natural peatlands, perhaps tiny in percentage terms, could have a very significant impact on the global carbon balance.

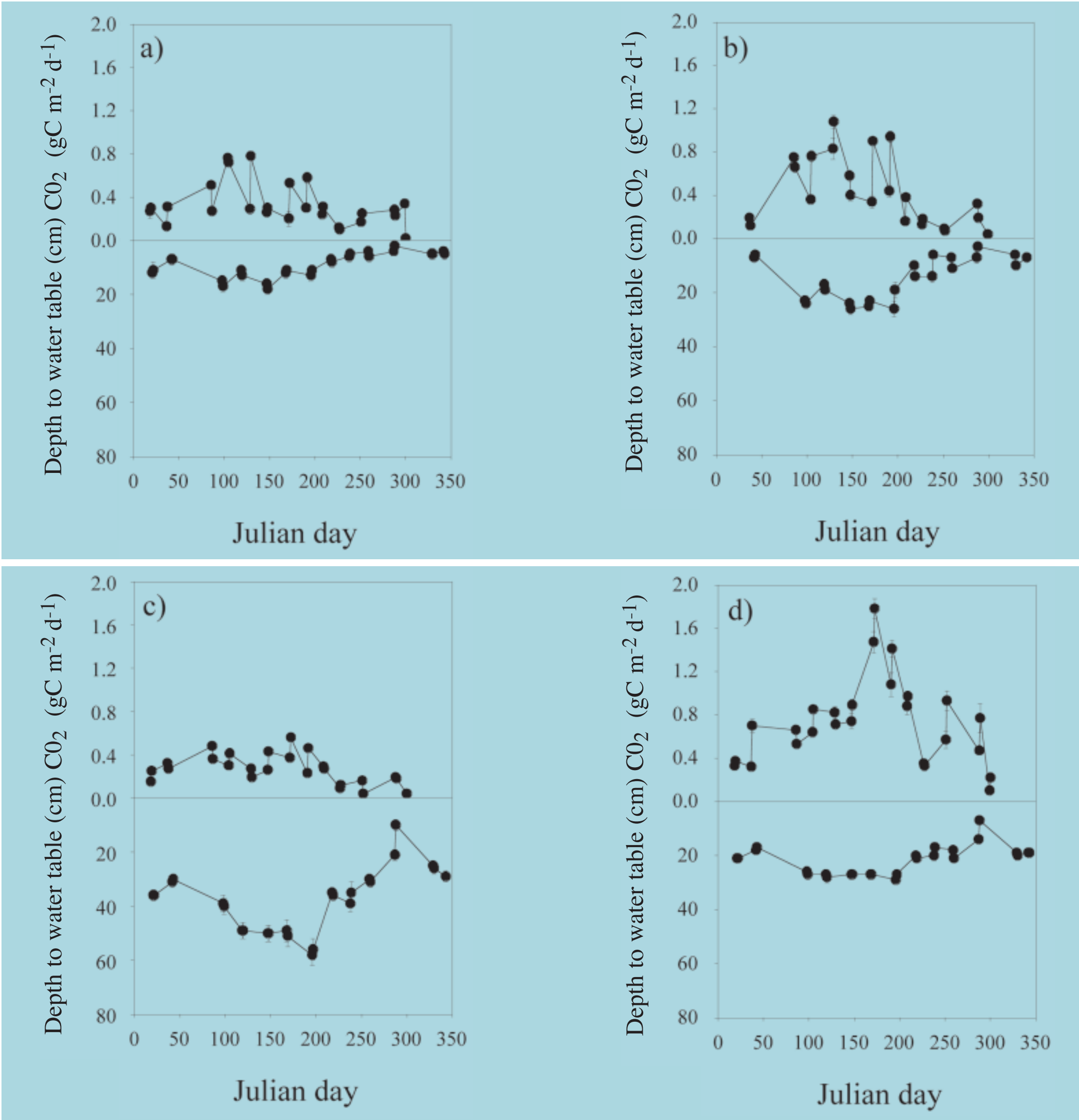
Methane producing bacteria live in the permanently saturated, anaerobic conditions found in peat below the water table. However, most of the methane formed has its origin in newly assimilated plant carbon (Whiting and Chanton 1993, Schimel 1995) which is translocated to the anaerobic peat layer via the roots of hydrophilic plants such as sedges (Saarinen 1996). This means that most of the methane is produced in the zone just below the water table. As it passes through the upper aerobic layer it may be oxidised to CO_2 (Sundh *et al*. 1995). Methane flux is also influenced by those vascular plants which have large intercellular spaces which allow both the movement of oxygen into the roots (Armstrong 1979) and the diffusion of methane from anaerobic layers to the atmosphere (Sebacher *et al*. 1985). The methane flux will be positive or negative depending on the balance between methane production below the water table, and oxidation above it. The principal factors controlling methane emissions are depth to water table (Roulet *et al*. 1993), soil temperature (Moosavi *et al*. 1996), microtopography (Bubier *et al*. 1993) and soil pH (Moore and Knowles 1989).

Nitrous oxide is produced in soils by the processes of nitrification and denitrification. These processes are primarily regulated by the oxygen status of the soil, which in turn is affected by soil water content (Robertson and Tiedje 1987). Lowering of the water table in peatlands has been found to increase N_2O emissions, although more in minerotrophic than ombrotrophic sites (Martikainen *et al*. 1993, Regina *et al*. 1996). Other factors which influence emissions are pH, temperature, nutritional status and nitrification activity (Regina 1998).

Carbon balance in peatland forests

Following drainage for afforestation the depth of the aerobic layer in peat is increased. As a result decomposition rates, and therefore soil CO_2 emissions increase. Such an increase occurs very soon after drainage where it results in a lowering of the water table. For instance, in studies at a range of virgin and drained peatland sites in Finland, Silvola *et al*. (1996a) found that where the effect of drainage on the water table was small (5-9 cm increase in depth) there was little increase in soil CO_2 emissions. In contrast where drainage resulted in a 12-40 cm increase in water table depth, soil CO_2 emissions were doubled. Studies on blanket peat in the west of Ireland (Byrne 1999) have produced similar findings. Soil CO_2 emissions during 1997, at a blanket peat site afforested three years previously with Sitka spruce (*Picea sitchensis*), were not consistently higher than in a nearby virgin site (Figure 1). This was attributed to the failure of drainage to lower the water table sufficiently to stimulate a significant increase in soil CO_2 emissions.

One would expect that following closure of the forest canopy the increase in evapotranspiration (Farrell *et al*. 1993) would have a drying effect on the surface peat (Burke 1978). Such drying will increase the population of aerobic decomposers (Chmielewski 1991) and consequently the rate of organic matter decay (e.g. Lieffers 1988, Bridgham *et al*. 1991). This manifests itself as increased soil CO_2 emissions (Silvola *et al*. 1985, Silvola *et al*. 1996a, Nykänen *et al*. 1997). However, this is not always the case. Byrne (1999) monitored soil CO_2



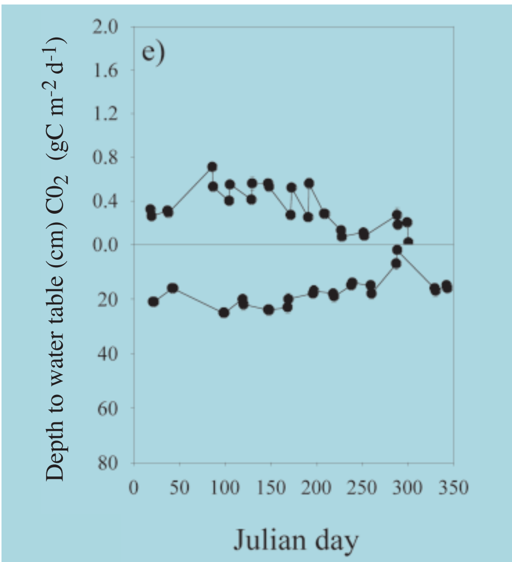


Figure 1: *Soil CO_2 emmissions and depth to water table during 1997 in: a) virgin peat, b) Sitka spruce (three years old), c) lodgepole pine (27 years old), d) Sitka spruce (39 years old) and, e)Sitka spruce clearfell.*

emissions during 1997 at four lodgepole pine (*Pinus contorta*) sites with closed canopy and found that although the depth to the water table was generally greater than in nearby virgin blanket peat, there was no increase in soil CO_2 emissions.

The similarity in CO_2 emissions between the lodgepole pine sites, despite a considerable difference in the depth to water table is probably due to two factors. First, the main source of CO_2 emissions is the surface peat layer. It has been reported elsewhere that the enhanced microbial activity as a result of forestry development is limited to the surface layer (0-10 cm) even where the depth to water table remains greater than 50 cm throughout most of the growing season (Paarlahti and Vartiovaara 1958, Karsisto 1979). Studies indicate that the peat from lower layers may be more resistant to decay. For instance, in a laboratory experiment using peat cores, Byrne (1999) found that CO_2 emissions from peat taken from the surface layers were on average 4.3 times higher than from cores taken at 45 cm depth. Further evidence is provided by Hogg *et al*. (1992) who found that deeper peat strata were more resistant to decay than surface peat. This may be due to the accumulation of substances such as lignins, phenols and humic acids in the deeper layers which are unfavourable to microbial activity (Ivarson 1977). The pH of the surface peat is known to decrease after drainage (Kelly 1993, Minkkinen *et al*. 1999) which may retard decomposition processes (Ivarson 1977, Laine *et al*. 1995) and so contribute to the resistance of the peat to decay. Another contributory factor could be a poorly developed fine root biomass which limits the availability of substrate for aerobic decomposition and the amount of root respiration.

In a study conducted by the authors at Cloosh Forest, Co Galway (Byrne 1999), soil CO_2 emissions in mature Sitka spruce during 1997 were 2.0-2.4 times higher than in virgin blanket peat. The depth to the water table during that period varied between 15 and 30 cm which suggests that the surface peat layers are the source of emissions (Figure 1). This site has a well developed fine root biomass and root respiration probably accounts for a large proportion of the CO_2 emissions. The only study on peat soils that has attempted to measure this is by Silvola *et al*. (1996b). They estimated that root respiration represented 35-45% of CO_2 emissions. Oxidation of new photosynthates, derived from fine root biomass, will also contribute to emissions. The contribution of roots to soil CO_2 emissions, through root decay and respiration, will vary depending on site and species. It is also likely to vary spatially depending on the soil preparation technique used in afforestation. For instance, Farrell and Mullen (1979) found at a site which had been double mouldboard ploughed that 40% of the roots were in the plough ribbon where there was also the greatest density of rooting.

A reduction in methane emissions following drainage, with net uptake in some cases, has been observed in a number of studies (Moore and Roulet 1993, Glenn *et al*. 1993, Roulet *et al*. 1993, Fowler *et al*. 1995, Martikainen *et al*. 1995, Roulet and Moore 1995, Laine *et al*. 1996). A study in a Sitka spruce stand on blanket peat found that afforestation can lead to the conversion of peatland from a source to a sink for atmospheric methane (Byrne *et al*. In press). Lowering of the water table reduces methane emissions by increasing the depth of aerobic peat and therefore the potential for methane produced below the water table to be oxidised before emission to the atmosphere. Another contributory factor is that when the water table is lowered methane production is restricted to more highly humified peat, which is not easily decomposed, consequently a reduction in methane production is likely. An increase of just 10 cm in the depth to the water table has been found to be sufficient to prevent methane loss to the atmosphere (Roulet *et al*. 1993). Site trophic status has also been found to influence the change in CH_4 emissions following drainage (Laine *et al*. 1996).

Drains can be a source of methane (Roulet and Moore 1995, Minkkinen *et al*. 1997). This methane may originate from (i) *in situ* production of methane from organic matter leached from the peat profile or, (ii) organic matter derived from plant and algal photosynthetic activity in the drains, or (iii) transport of methane in soil water from the peat to the drains.

As has been discussed, the carbon balance in virgin peatlands depends on the predominance of either carbon accumulation or loss. In peatland forests the same situation exists except that the primary productivity of the ecosystem is much higher than in virgin peatlands. Atmospheric carbon is sequestered in the growing tree through photosynthesis. It is then partitioned between stemwood, branchwood, foliage, and roots. Much of the carbon is transferred either to the forest floor (branches, needles and harvest debris) or to the peat soil (coarse and fine roots). The carbon which accumulates in stemwood {≈ 50% of the above-ground biomass (Carey and O'Brien 1979)} is mostly harvested and finds its way into forest products.

The rate of carbon storage in a forest plantation is primarily determined by the rate of growth of the forest, which depends on the species, site and management (Cannell 1995). On this basis the annual amount of carbon stored will be a proportion of the current annual increment. A model of carbon accumulation in forest plantations was developed by Dewar and Cannell (1992). They calculated that an increase in Yield Class (YC) (potential maximum mean annual volume increment, Edwards and Christie 1981) from 6 to 24 m^3 ha^{-1} yr^{-1} for Sitka spruce would increase total carbon storage by 60%. The average increase in total carbon storage per unit increase in YC (1 m^3 ha^{-1} yr^{-1}) was 4.3 Mg C ha^{-1} for thinned stands and 5.6 Mg C ha^{-1} for unthinned stands. They also found that trees contained a larger proportion of the total carbon pool and soil a smaller proportion as yield class increased. They also found that given similar yield classes, Sitka spruce will not store substantially more carbon than Scots pine (*Pinus sylvestris L.*) or lodgepole pine. It should be pointed out however, that these models do not adequately describe changes in soil carbon stores, particularly in peat soils.

As described, drainage accelerates the rate of peat decomposition and leads to a reduction in the peat carbon store. This loss may be offset by fresh inputs of organic matter through root biomass turnover and litterfall. Annual litterfall increases until canopy closure, thereafter remains relatively constant before decreasing, along with the reduction in stand density or productivity, in older stands (Bray and Gorham 1964). The rate of litterfall varies within and between species and is controlled by factors such as climate, site fertility and productivity (Bray and Gorham 1964). Carey and Farrell (1978) found that the average litterfall value for Sitka spruce stands was 5,500 kg ha^{-1} yr^{-1} and suggested that accumulation of litter far exceeded its decomposition. Working in a Scots pine stand on a bog, Finér (1996) found that the mean annual litterfall over a nine year period was 1995 ± 272 kg ha^{-1} and estimated that this would compensate for 17-20% of the carbon loss from peat.

Studies in Finland have found that fine root production and decomposition is also a significant component of the carbon balance in peatland forests. Finér *et al*. (1992) calculated that fine root production would account for 10-40% of total biomass production. Laine *et al*. (1996) found that although there was an increase in soil CO_2 emissions after drainage, largely caused by the enhanced decay of organic matter, the change in the peat carbon store was relatively small. The authors attributed this to increased carbon flow into the peat via litter production (including roots). More recently, Finér and Laine (1998) found that root production in Scots pine increased with increasing water table depth, suggesting that the role of fine root production in carbon cycling will be greater on well drained sites.

A number of studies have attempted to quantify the change in the peat carbon store following drainage for forestry. Working at a site representative of median nutrient levels of drainage areas in Finland, Laine and Minkkinen (1996) found that the net change in the original carbon store over 30 years since drainage was -14 g C m^{-2} yr^{-1}. Also in Finland, Minkkinen and Laine (1998) carried out an extensive survey of undrained and drained (ca. 60 years) sites and found an increase in the carbon store associated with the poorest sites types in the south of the country. Possible reasons for this are higher post-drainage fine root biomasses and production (Vogt *et al*. 1986, Finér and Laine 1998), a slower decomposition rate (Farrish and Grigal 1988) at nutrient-poor sites and a small postdrainage increase in CO_2 emissions from organic matter decay at these sites (Silvola *et al*. 1996a). Studies in the former Soviet Union have found similar changes in the carbon store of peatlands drained for forestry (Vompersky and Smagina 1984, Sakovets and Germanova 1992, Vompersky *et al*. 1992). Studies from Norway (Braekke 1987) and Scotland (Anderson *et al*. 1994) report much higher losses. These losses may be attributed to thermoclimatic differences (Meentmeyer 1978) since microbial decomposition activity has been shown to increase with increasing temperature. The variation in results between studies may also be due to the difficulty in measuring the changes in the carbon store, which are very small with respect to the total store, or the lack of a universally accepted method for measuring them (e.g. Laine *et al*. 1992).

While very little qualitative information is available about the impact of clearfelling on the carbon balance in peatland forests, it is likely to be substantial. The most immediate impact of the removal of the forest crop (with the transfer of carbon to the product and litter/debris pools), is to stop carbon sequestration. Until a new forest crop, or ground vegetation, is established there will be no input of carbon to the ecosystem. While renewal of carbon accumulation will depend both on the productivity and composition of the newly established forest crop and the rate of decomposition of organic matter (Trettin *et al*. 1996) it is unclear how long this will take. Furthermore, since there are changes in the factors controlling decomposition, a change in both CO_2 and methane emissions is possible.

A reduction in soil CO_2 emissions following clearfelling of Sitka spruce (Figure 1) was found by Byrne (1999). The most likely cause was the cessation of root respiration. The decline of root respiration following clearfelling has been observed in other studies (Edwards and Ross-Todd 1983, Ewel *et al*. 1987) although increased CO_2 emissions have also been reported (Ewel *et al*. 1987, Gordon *et al*. 1987, Hendrickson *et al*. 1989, Lytle and Cronan 1998). A rise in the water table following clearfelling (e.g. Roy *et al*. 1997) will reduce the depth of aerobic peat which may in turn reduce aerobic decomposition and consequently CO_2 emissions. On the other hand, organic matter decomposition may be enhanced by increased microbial respiration in response to higher soil temperatures and greater availability of carbon, disturbance of the forest floor during harvesting operations and, increased availability of organic matter from harvest residues.

The forest operations used in reforestation on peatland may have an impact on CO_2 emissions. Prior to reforestation the usual practice is first to move the harvest residues into 'windrows' spaced at 10 -15 m. A mound drain is then excavated between them and planting mounds from the drain are distributed at 2 m centres. The creation of windrows may make the harvest residues more amenable to decomposition, although coarse harvest residues have slow decomposition rates. An increase in soil CO_2 emissions is likely following drainage particularly if the newly aerated peat contains poorly decomposed roots from the previous rotation.

The effect of clearfelling on methane emissions is poorly known. After clearfelling the water table rises with the possible consequence of a reduction in methane oxidation and/or a net emission. Nieminen *et al*. (1996) made measurements at two clearfelled sites (and controls) in southern Finland. One site became a weak source for methane and uptake rates were reduced in the other. The clearfelled sites had a higher availability of mineral nitrogen, especially ammonium, in the peat which may be associated with the lower methane uptake. This is because mineral nitrogen has been reported to inhibit methane oxidation in drained and forested peat (Crill *et al*. 1994, Nykänen *et al*. 1996).

Future work

Many questions remain unanswered before a clear assessment can be made of the net effect of forestry on the carbon balance of Irish peatlands. One could establish this by comparing measured soil CO_2 emissions with published estimates of carbon uptake by forest crops, such as those of Dewar and Cannell (1992). However this approach has limitations. Carbon sequestration rates based on rotation lengths to maximum mean annual increment (mai), as used by Dewar and Cannell (1992), are not applicable here as rotations are generally below the age of mai (the rotation length for Sitka spruce used by Coillte is 80% of the age of maximum mai). The same applies to lodgepole pine, except that current practice is to clearfell prematurely, at less than the age of financial maturity. It is clear that the actual rates of carbon sequestration and transfer to the litter and soil pools will be less than that estimated by Dewar and Cannell (1992). What are required are site specific studies which measure all major components of the carbon balance. Some of the key tasks of a research programme should be:

- to estimate carbon stores and the greenhouse gas balance at virgin peatland sites and their relationship with environmental factors; this would establish a baseline against which the effects of forestry development could be assessed;
- to estimate the carbon store and greenhouse gas balance in peatland forests and the impacts of environmental factors and management on them;
- to develop models which would allow upscaling from site specific studies to regional and national level.

The future management of our peatland forests will greatly impact on the carbon store and greenhouse gas balance. Examples of issues which need to be addressed are:

- what happens to carbon budgets after clearfelling?
- what is the impact of site preparation, such as mounding and windrowing?
- what if clearfelled areas are not reforested but allowed to regenerate naturally?
- what if forest areas are not clearfelled but are allowed to grow on?

It should be remembered that carbon cycling is a key component of the dynamics of forest ecosystems. Increased understanding of carbon cycling and related processes will provide greater insights into how our forests function and therefore contribute to their sustainable management.

References

Anderson, A.R., Anderson, H.A. and Pyatt, D.G. 1994. Carbon loss from afforested peat. Poster paper presented at the conference: Greenhouse Gas Balance in Forestry, Forest Research Coordination Council, The Royal Geographic Society, London, 9-10 November, 1994.

Armstrong, W. 1979. Aeration in higher plants. *Advances in Botanical Research* 7: 226-333.

Bartsch, I. and Moore, T.R. 1985. A preliminary investigation of primary production and decomposition in four peatlands near Schefferville, Québec. *Canadian Journal of Botany* 63: 1241-1248.

Braekke, F.H. 1987. Nutrient relationships in forest stands: effects of drainage and fertilization on surface peat layers. *Forest Ecology and Management* 21: 269-284.

Bray, J.R. and Gorham, E. 1964. Litter production in forests of the world. *Advances in Ecological Research* 2: 101-157.

Bridgham, S.D., Richardson, C.J., Maltby, E. and Faulkner, S.P. 1991. Cellulose decay in natural and disturbed peatlands in North Carolina. *Journal of Environmental Quality* 20: 695-701.

Bubier, J., Costello, A., Moore, T.R., Roulet, N.T. and Savage, K. 1993. Microtopography and methane flux in boreal peatlands, northern Ontario, Canada. *Canadian Journal of Botany* 71: 1056-1063.

Burke, W. 1978. Long-term effects of drainage and land use on some physical properties of blanket peat. *Irish Journal of Agricultural Research* 17: 315-322.

Byrne, K.A. 1999. *Studies on the Carbon Balance in a Blanket Peatland Forest.* Unpublished Ph.D. thesis, National University of Ireland, Dublin.

Byrne, K.A., Farrell, E.P., Papen, H. and Butterbach-Bahl, K. In press. Carbon dioxide and methane fluxes in forested and virgin blanket peatland in the west of Ireland. *Verh. Internat. Verein. Limnol.* 27(1-4).

Cannell, M.G.R. 1995. *Forests and the Global Carbon Cycle in the Past, Present and Future.* Research Report 2, European Forest Institute, Joensuu.

Carey, M.L. and Farrell, E.P. 1978. Production, accumulation and nutrient content of Sitka spruce litterfall. I*rish Forestry*, 35(1): 35-44.

Carey, M.L. and O'Brien, D. 1979. Biomass, nutrient content and distribution in a stand of Sitka spruce. *Irish Forestry* 36(1): 25-35.

Chmielewski, K. 1991. The effect of habitat conditions on microbiological activity of peat soils. *Polish Ecological Studies* 17: 143-153.

Clymo, R.S. 1984. The limits to peat bog growth. *Philosophical Transactions of the Royal Society of London* B 303: 605-654.

COFORD. 1994. *Pathway to Progress: A Programme for Forest Research and Development.* COFORD, Dublin.

Crill, P.M., Martikainen, P.J., Nykänen, H. and Silvola, J. 1994. Temperature and N fertilization effects on methane oxidation in a drained peat soil. *Soil Biology and Biochemistry* 26(10): 1331-1339.

Cruickshank, M.M., Tomlinson, R.W., Devine, P.M. and Milne, R. 1998. Carbon in the vegetation and soils of Northern Ireland. *Biology and Environment: Proceedings of the Royal Irish Academy* 98B(1): 9-21.

Department of the Environment and Local Government. 2000. *National Climate Change Strategy Ireland.* The Stationery Office, Dublin.

Dewar, R.C. and Cannell, M.G.R. 1992. Carbon sequestration in the trees, products and soils of forest plantations: an analysis using UK examples. *Tree Physiology* 8: 239-258.

Dixon, R.K., Brown, S., Houghton, R.A, Solomon, A.M., Trexler, M.C. and Wisniewski, J. 1994. Carbon pools and flux of global ecosystems. *Science* 263: 185-190.

Edwards, N.T. and Ross-Todd, B.M. 1983. Soil carbon dynamics in a mixed deciduous forest following clear-cutting with and without residue removal. *Soil Science Society of America Journal* 47: 1014-1021.
Edwards, P.N. and Christie, J.M. 1981. *Yield Models for Forest Management.* Forestry Commission Booklet 48, Forestry Commission, Edinburgh.

Ewel, K.C., Cropper, Jr., W.P. and Gholz, H.L. 1987. Soil CO_2 evolution in Florida slash pine plantations. I. Changes through time. *Canadian Journal of Forest Research* 17: 325-329.

Farrell, E.P. 1990. Peatland forestry in the Republic of Ireland. In *Biomass Production and Element Fluxes in Forested Peatland Ecosystems.* Ed. Hånell, B., Proceedings of a seminar held at Umeå, Sweden, Department of Forest Site Research, Swedish University of Agricultural Sciences, pp 13-18.

Farrell, E.P. and Boyle, G. 1990. Peatland forestry in the 1990s. 1. Low-level blanket bog. *Irish Forestry* 47(2): 69-78.

Farrell, E.P. and Mullen, G.J. 1979. Rooting characteristics of *Picea sitchensis* and *Pinus contorta* on blanket peat in Ireland. *Journal of Life Sciences* Royal Dublin Society, 1: 1-12.

Farrell, E.P., Cummins, T., Boyle, G.M., Smillie, G.W. and Collins, J.F. 1993. Intensive monitoring of forest ecosystems. *Irish Forestry* 50(1): 53-69.

Farrish, K.W. and Grigal, D.F. 1988. Decomposition in an ombrotrophic bog and a minerotrophic fen in Minnesota. *Soil Science* 145(5): 353-358.

Finér, L. 1996. Variation in the amount and quality of litterfall in a *Pinus sylvestris* L. stand growing on a bog. *Forest Ecology and Management* 80: 1-11.

Finér, L. and Laine, J. 1998. Root dynamics at drained sites of different fertility in southern Finland. *Plant and Soil* 201: 27-36.

Finér, L., Laine, J. and Halko, L. 1992. Fine root dynamics on two drained peatland sites. *Suo* 43(4/5): 207-210.

Fowler, D., Hargreaves, K.J., MacDonald, J.A. and Gardiner. B. 1995. Methane and CO_2 exchange over peatland and the effects of afforestation. *Forestry 68(4): 327-334*.

Gillmor, D.A. 1998. Trends and spatial patterns in private afforestation in the Republic of Ireland. *Irish Forestry* 55(1): 10-25.

Glenn, S., Heyes, A. and Moore, T. 1993. Carbon dioxide and methane fluxes from drained peat soils, southern Quebec. *Global Biogeochemical Cycles* 7(2): 247-257.

Gordon, A.M., Schlentner, R.E., Van Cleve, K. 1987. Seasonal patterns of soil respiration and CO_2 evolution following harvesting in the white spruce forests of interior Alaska. *Canadian Journal of Forest Research* 17: 304-310.

Gorham, E. 1991. Northern peatlands: role in the carbon cycle and probable responses to climatic warming. *Ecological Applications* 1(2): 182-195.

Hammond, R.F. 1981. *The Peatlands of Ireland*. Soil Survey Bulletin No. 35, An Foras Talúntais, Dublin.
Harden, W.H.E.T., Sundquist, R.F., Stallard, R.F. and Mark, R.K. 1992. Dynamics of soil carbon during deglaciation of the Laurentide ice sheet. *Science* 258: 1921-1924.

Hendrickson, O.Q., Chatarpaul, L. and Burgess, D. 1989. Nutrient cycling following whole-tree and conventional harvest in northern mixed forest. *Canadian Journal of Forest Research* 19: 725-735.

Hogg, E.H., Lieffers, V.J. and Wein, R.W. 1992. Potential carbon losses from peat profiles: effects of temperature, drought cycles and fire. *Ecological Applications* 2(3): 298-306.

Ivarson, K.C. 1977. Changes in decomposition rate, microbial population and carbohydrate content of an acid peat after liming and reclamation. *Canadian Journal of Soil Science* 57: 129-137.

Karsisto, M. 1979. Maanparannustoimenpiteiden vaikutuksista organista ainetta hajottavien mikrobien aktiivisuuteen suometsissä. Osa I. Pohjavden etäisyyden ja NPK-lannoituksen vaikutus Vilppulan ja Kivalon rämmeellä ja korvessa. Summary: Effect of forest improvement measures on activity of organic matter decomposing micro-organisms in forested peatlands. Part I. *Suo* 30: 49-58.

Kelly, A.M. 1993. *The Impact of Coniferous Afforestation on the Physical and Chemical Properties of Blanket Peat*. Unpublished M.Agr.Sc. thesis, National University of Ireland, Dublin.

Korhola, A. 1992. Mire induction, ecosystem dynamics and lateral extension on raised bogs in the southern coastal area of Finland. *Fennia* 170: 25-94.

Korhola, A., Tolonen, K., Turunen, J. and Jungner, H. 1995. Estimating long-term carbon accumulation rates on boreal peatlands by radiocarbon dating. *Radiocarbon* 37: 575-584.

Laine J. and Minkkinen, K. 1996. Effect of forest drainage on the carbon balance of a mire: a case study. *Scandinavian Journal of Forest Research* 11: 307- 312.

Laine, J., Silvola, J., Tolonen, K., Alm, J., Nykänen, H., Vasander, H., Sallantaus, T., Savolainen, I., Sinisalo, J. and Martikainen, P.J. 1996. Effects of water-level drawdown on global climatic warming: northern peatlands. *Ambio* 25(3): 179-184.

Laine, J., Vasander, H. and Puhalainen, A. 1992. A method to estimate the effect of forest drainage on the carbon store of a mire. *Suo* 43(4/5): 227-230.

Laine, J., Vasander, H. and Sallantaus, T. 1995. Ecological effects of peatland drainage for forestry. *Environmental Reviews* 3: 286-303.

Lieffers, V.J. 1988. Sphagnum and cellulose decomposition in drained and natural areas of an Alberta peatland. *Canadian Journal of Soil Science* 68: 755-761.

Lowery, M. 1990. Forestry-its part in rural development. In *The Right Trees in the Right Places*. Eds. Mollen C. and Maloney, M., Royal Dublin Society, Seminar Proceedings No. 4, pp 35-41.

Lytle, D.E. and Cronan, C.S. 1998. Comparative soil CO_2 evolution, litter decay, and root dynamics in clearcut and uncut spruce-fir forest. *Forest Ecology and Management* 103: 121-128.

Martikainen, P.J., Nykänen, H., Crill, P. and Silvola, J. 1993. Effect of a lowered water table on nitrous oxide fluxes from northern peatlands. *Nature* 366: 51-53.

Martikainen, P.J., Nykänen, H., Alm, J. and Silvola, J. 1995. Changes in fluxes of carbon dioxide, methane and nitrous oxide due to forest drainage of mire sites of different trophy. *Plant and Soil* 168-169: 571-577.

Meentmeyer, V. 1978. Macroclimate and lignin control of litter decomposition rates. *Ecology* 59(3): 465-472.

Milne, R. and Brown, T.A. 1997. Carbon in the vegetation and soils of Great Britain. *Journal of Environmental Management* 49: 413-433.

Minkkinen, K. and Laine, J. 1998. Long-term effect of forest drainage on the peat carbon stores of pine mires in Finland. *Canadian Journal of Forest* Research 28: 1267-1275.

Minkkinen, K., Laine, J., Nykänen, H. and Martikainen, P.J. 1997. Importance of drainage ditches in emissions of methane from mires drained for forestry. *Canadian Journal of Forest Research* 27: 949-952.

Minkkinen, K., Vasander, H., Jauhiainen, S., Karsisto, M. and Laine, J. 1999. Post-drainage changes in vegetation composition and carbon balance in Lakkasuo mire, Central Finland. *Plant and Soil* 207: 107-120.

Moore, T.R. and Knowles, R. 1989. The influence of water table levels on methane and carbon dioxide emissions from peatland soils. *Canadian Journal of Soil Science* 69: 33-38.

Moore, T.R. and Roulet, N.T. 1993. Methane flux: water table relations in northern wetlands. *Geophysical Research Letters* 20(7): 587-590.

Moore, J.J., Dowding, P. and Healy B. 1975. Glenamoy, Ireland. *Ecological Bulletin* (Stockholm) 20: 321-343.

Moosavi, S.C., Crill, P.M., Pullman, E.R., Funk, D.W., Peterson, K.M. 1996. Controls on CH_4 flux from an Alaskan boreal wetland. *Global Biogeochemical Cycles* 10(2): 287-296.

Nieminen, M., Nykänen, H. and Martikainen, P.J. 1996. Changes in fluxes of N_2O and CH_4 after clearfelling of drained spruce mires in southern Finland. In *Northern Peatlands in Global Climatic Change*. Eds. Laiho, R., Laine, J. and Vasander, H., Publications of the Academy of Finland, 1/96, pp 122-126.

Nykänen, H., Alm, J., Silvola, J. and Martikainen, P.J. 1996. Fluxes of methane on boreal mires with different hydrology and fertility in Finland. In *Northern Peatlands in Global Climatic Change*. Eds. Laiho, R., Laine, J. and Vasander, H., Publications of the Academy of Finland, 1/96, pp 127-135.

Nykänen, H, Silvola, J., Alm, J. and Martikainen, P.J. 1997. The effect of peatland forestry on fluxes of carbon dioxide, methane and nitrous oxide. In *Northern Forested Wetlands: Ecology and Management*. Eds. Trettin, C.C., Jurgensen, M.F., Grigal, D.F., Gale, M.R., and Jeglum, J.K., Lewis Publishers, New York, pp 325-339.

Paarlahti, K. and Vartiovaara, U. 1958. Havaintoja luonnontilaisten ja metsäojitettujen soiden pieneliöstöistä. Summary: Observations concerning the microbial populations in virgin and drained bogs. *Communicationes Instituti Forestalis Fenniae* 50: 5-38.

Pakarinen, P. 1975. Bogs as peat producing ecosystems. *International Peat Society, Bulletin* 7: 51-54.

Post, W.M., Emanuel, W.R., Zinke, P.J. and Stangenberger, A.G. 1982. Soil carbon pools and world life zones. *Nature* 298: 156-159.

Reader, S.J. and Stewart, J.M. 1972. The relationship between net primary production and accumulation for a peatland in southeastern Manitoba. *Ecology* 53: 1024-1037.

Regina, K., Nykänen, H., Silvola, J. & Martikainen, P.J. 1996. Fluxes of nitrous oxide from boreal peatlands as affected by peatland type, water table level and nitrification capacity. *Biogeochemistry* 35: 401-418.

Regina, K. 1998. *Microbial Production of Nitrous Oxide and Nitric Oxide in Boreal Peatlands*. PhD thesis, University of Joensuu, Publications in Science No. 50.

Reinikainen, A., Vasander, H. and Lindholm, T. 1984. Plant biomass and primary production of southern boreal mire-ecosystems in Finland. In *Proceedings of the 7th International Peat Congress*, Dublin, International Peat Society, Vol. 4, pp 1-20.

Robertson, G.P. and Tiedje, J.M. 1987. Nitrous oxide sources in aerobic soils: nitrification, denitrification and other biological processes. *Soil Biology and Biochemistry* 19: 187-189.

Roulet, N.T., Ash, R., Quinton, W. and Moore, T. 1993. Methane flux from drained northern peatlands: effect of a persistent water table lowering on flux. *Global Biogeochemical Cycles* 7(4): 749-769.

Roulet, N.T. and Moore, T.R. 1995. The effect of forestry drainage practices on the emission of methane from northern peatlands. *Canadian Journal of Forest Research* 25: 491-499.

Roy, V., Jeglum, J.K. and Plamondon, A.P. 1997. Water table fluctuations following clearcutting and thinning on Wally Creek wetlands. In *Northern Forested Wetlands: Ecology and Management*. Eds. Trettin, C.C., Jurgensen, M.F., Grigal, D.F., Gale, M.R., and Jeglum, J.K., Lewis Publishers, New York, pp 239-251.

Saarinen, T. 1996. Biomass and production of two vascular plants in a boreal mesotrophic fen. *Canadian Journal of Botany* 74: 934-938.\

Sakovets, V.V. and Germanova, N.I. 1992. Changes in the carbon balance of forested mires in Karelia due to drainage. *Suo* 43(4/5): 249-252.

Schimel, J.P. 1995. Plant transport and methane production as controls on methane flux from arctic meadow tundra. *Biogeochemistry* 28: 183-200.

Sebacher, D.I., Harriss, R.C. and Bartlett, K.B. 1985. Methane emissions to the atmosphere through aquatic plants. *Journal of Environmental Quality* 14(1): 40-46.

Silvola, J., Alm, J., Ahlholm, U., Nykänen, H. and Martikainen, P.J. 1996a. CO_2 fluxes from peat in boreal mires under varying temperature and moisture conditions. *Journal of Ecology* 84: 219-228.

Silvola, J., Alm, J., Ahlholm, U., Nykänen, H. and Martikainen, P.J. 1996b. The contribution of plant roots to CO_2 fluxes from organic soils. *Biology and Fertility of Soils* 23: 126-131.

Silvola, J., Välijoki, J. and Aaltonen, H. 1985. Effect of draining and fertilization on soil respiration at three ameliorated peatland sites. *Acta Forestalia Fennica* 191: 1-32.

Sundh, I., Mikkelä, C., Nilsson, M. and Svensson, B.H. 1995. Potential aerobic methane oxidation in a Sphagnum dominated peatland - controlling factors and relation to methane emission. *Soil Biology and Biochemistry* 27: 829-837.

Trettin, C.C., Davidian, M., Jurgensen, M.F. and Lea, R. 1996. Organic matter decomposition following harvesting and site preparation of a forested wetland. *Soil Science Society of America Journal* 60: 1994-2003.

UNFCCC. 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change. UNFCCC Secretariat, Bonn.

Vogt, K.A., Grier, C.C. and Vogt, D.J. 1986. Production, turnover, and nutrient dynamics of above- and belowground detritus of world forests. *Advances in Ecological Research* 15: 303-377.

Vompersky, S.E. and Smagina, M.V. 1984. The impact of hydroreclamation of forests on peat accumulation. In *Proceedings of the 7th International Peat Congress*, Dublin, International Peat Society, Vol. 4: 86-95.

Vompersky, S.E., Smagina, M.V., Ivanov, A.I. and Glukhova, T.V. 1992. The effect of forest drainage on the balance of organic matter in forest mires. In *Peatland Ecosystems and Man: An Impact Assessment*. Eds. Bragg, O.M., Hulme, P.D., Ingram, H.A.P. and Robertson, R.A., British Ecological Society/International Peat Society, Dundee, pp. 17-22.

Whiting, G.J. and Chanton, J.P. 1993. Primary production control of methane emmission from wetlands. *Nature 364*: 794-795.

Zehetmayr, J.W. L. 1954. *Experiments in Tree Planting on Peat*. Forestry Commission Bulletin 22, HMSO, London.

MARKET OPPORTUNITIES FOR CO_2 CREDITS FROM FORESTRY PROJECTS

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Introduction

The Conferences of the UN Framework Convention on Climate Change (UNFCCC) have resulted in the Kyoto Protocol, under which countries have made commitments to carbon dioxide reduction measures. Countries with commitments, called Annex 1 countries, are the OECD members plus countries with economies in transition (Eastern Europe). Countries without commitments, called non-Annex 1 countries, are the OPEC members and developing nations. With regard to a 'business-as-usual' scenario and the first commitment period 2008-2012, the potential market for carbon credits is estimated at 24 billion tonnes of CO_2 equivalents per annum.

Cost efficiency of CO_2 measures

The forestry sector is generally considered to be an unattractive investment opportunity. However, the introduction of a market for carbon credits from CO_2 sinks, will probably make afforestation more attractive to investors. For example the cost efficiency of a number of CO_2 reduction options, in both the energy and the forestry sectors is shown in Figure 1. The graph is based on a Joint implementation Model from Jepma and Lee (1995). It can be seen that investments in CO_2 emission reductions in forestry are the most cost effective, particularly in developing countries. In options 2 and 4 investments in OECD countries appear to be the best, while with option 5 it is Eastern Europe. All the options have similar efficiencies at the lowest reduction level (0-100 million t CO_2). The costs remain the same, while the CO_2 reductions increase strongly. However, after a certain reduction level, all the options are faced with increasing costs. Through the depletion of all the attractive investment opportunities in one option, only the more expensive remain.

The cost of forestry projects in developing countries is relatively low and with an increase in the size of such projects, the rise in cost remains low. This is the result of a number of factors:

- large tracts of land are still available in these countries;
- the mean annual increment is relatively high (especially in tropical countries);
- labour is relatively cheap.

There is, however, a certain amount of risk involved with investments in such countries. These concern conditions at a project level, at a national level and even currency fluctuations.

Three types of forestry investment

The CO_2 storage capacity of forests (as 'carbon sinks') has been recognised for quite some time. During the Kyoto climate conference in 1997, there was an important breakthrough for the forest industry. Afforestation and reforestation (as defined by the International Panel on Climate Change is, for all intents and purposes afforestation in the Irish context - reforestation in the Irish context is

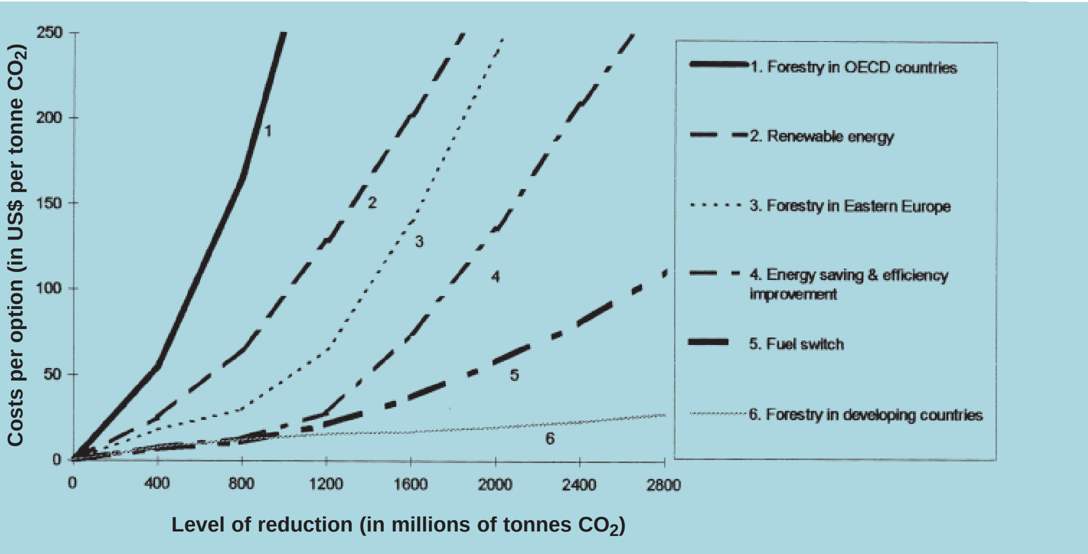

Figure 1: *The cost efficiency of a number of different CO_2 emmission reduction mechanisms world wide.*

excluded under Article 3 of the Kyoto protocol) were explicitly highlighted as greenhouse gas reduction measures.

Three types of forestry activity may be considered for CO_2 emission reduction measures:

- Type 1: Afforestation/reforestation, essentially new forests.
- Type 2: Harvested wood that can be used as building material or for energy purposes.
- Type 3: Forest protection and other management activities over and above business-as-usual, which increase carbon stocks on a unit land area.

The potential of these forestry measures has been estimated in a number of different studies. The estimates range from 345 million (Nilsson and Schopfhauser 1995) to some 3,200 million ha (MikeRead Associates 1998).

Afforestation/reforestation (type 1)

The allowance of CO_2 fixation in forests in calculating countries' compliance with their assigned amount of greenhouse gas is presented in article 3.3 of the Kyoto Protocol. Afforestation, reforestation (IPPC definition) and deforestation are to be included. The Protocol only allows carbon credits for forests planted after 1990 and a subtraction of credits for deforestation since 1990.

However, there are as yet no standard definitions of the terms afforestation, reforestation and deforestation. An important stumbling block with all three of the definitions is the crown projection of the tree on the soil surface. The FAO defines closed, productive forest as forest with a minimum of 20% closure for temperate forests and a minimum of 10% closure for the tropics. The trees must be able to attain a minimum height of 7 m (Institute for Forestry and Forest Products 1995). In general the following definitions apply:

- decrease in forest surface area is deforestation;
- planting of areas that formerly carried forest is reforestation;
- planting of areas without forest or where forest has been absent for several generations is considered afforestation.

The difference between reforestation and afforestation is not always clear as some countries utilise different definitions of a longer period of time varying from five years to several centuries (Lund 2000).

Harvested wood (type 2)

The potential for wood lies in the possibility of using it to replace fossil fuel, through its use as a source of energy and/or the replacement of energy intensive materials with durable wood products.

- Fuels - In the IPCC guidelines the position is that CO_2 emissions from biofuels (including wood) should not be included in calculating emissions, whereas emissions from fossil fuels should be. In other words, the use of wood as a fuel is considered to be CO_2 neutral. However, the Kyoto Protocol did not make any definite statement on the potential for CO_2 credits from fuel wood.
- Building materials - Another possibility is the increased use of wood based building materials in place of concrete, steel and aluminium. There are currently no international agreements on the use of these products to mitigate CO_2 emissions. It may be possible that an extra opportunity for carbon sequestration in wood products, also covered through article 3.4 ("other human induced activities"), will be included (Nabuurs and Sikkema 2000). The role of harvested wood products will be discussed in 2001 at COP-7 in Marrakech, Morocco.

Forest protection (type 3)

This refers to activities aimed at maintaining current carbon stocks. This can be achieved by means of reducing deforestation, improved harvesting techniques or the protection of forests. CO_2 is released by the decomposition of wood and forest litter. Local emission reductions can be achieved by ensuring that trees are not unnecessarily felled, are optimally used for wood products and by a reduction in ground disturbance. Reduced Impact Logging (RIL) techniques are an example of such measures. These techniques include harvesting activities such as directional felling, and post-harvest activities such as the closure of harvesting roads/tracks, followed by reforestation/regeneration of the logging roads.

No international agreements have yet been concluded on the reduction of emissions from forests. There is currently a debate (WBGU, 1999) as to whether such activities should be included in article 3.4 of the protocol. Deforestation since 1990 has been included as a source of carbon emissions in the IPCC guidelines but it still remains unclear if reductions in deforestation or the rehabilitation of degraded land will be accepted under the Protocol. Furthermore, there are no active policy agreements on different types of forest management, such as natural regeneration, thinning or harvesting. More clarity on the issue is required. A step in this direction is the IPCC Special Report on Land Use and Land Use Change and Forestry (LULUCF) which indicates the pros and cons of different forest management activities (IPCC 2000). It is also likely that Joint Implementation pilot projects (Activities Implemented Jointly or AIJ) will develop practical insights.

State of the art 2000 (Pre the Sixth Conference of the Parties to the UNFCCC COP-6[1])

On the basis of the current situation regarding the Protocol a tentative overview of the potential for forestry credits has been attempted (Table 1).
The following conclusions emerge from Table 1:

- up until now only investments dealing with afforestation/ reforestation ('new forests') in Annex 1 countries have been included in the Kyoto Protocol;
- the use of renewable energy, including wood, is indirectly stimulated via the IPCC guidelines, as the use of biofuels is CO_2 neutral;
- national measures are of interest with regard to the stimulation of use of wood based building products;
- forest protection measures ('existing forests') are currently a possible option, included under article 3.4 of the Kyoto Protocol.

The potential for carbon credits from forestry projects (including renewable energy) will depend on the international trade allowance and opportunities for these credits. There are currently no international agreements for these.

Experience of costs in carbon related forestry projects

Dutch experience
To give an impression of the cost of implementing a type 1 project, take the afforestation of one ha of Norway spruce, based on a 45-year rotation. The costs are comprised of the land, soil preparation, planting, management and preparation for the return of the land to agricultural production. Harvesting costs are not relevant as the trees are sold standing. Besides the profit from selling the wood, a farmer in the Netherlands is eligible for government subsidies, from the Management Program (Ministry of LNV 1999). These subsidies have not been included in the current calculation. Without subsidies, the costs are 36 EURO t^{-1} CO_2.

To give an impression of the cost of a type 2 project, take the economic feasibility of a district heating plant at Lelystad, The Netherlands. The pre-tax costs of such a project consist of investment, exploitation and fuel. The fuel costs have been calculated on the basis of the amount of wood (in chipped and dried form) delivered to the plant. These costs are 107 EURO t^{-1} CO_2. After subtraction of the benefits from heat and electricity the costs are 37 EURO t^{-1} CO_2 (Sikkema and Heineman 1997).

World wide experience
According to the IPCC Special Report an assessment of AIJ LULUCF projects is constrained by, inter alia, the small number of projects and their uneven geographic distribution (IPCC 2000). Furthermore, an internationally agreed set of guidelines is absent, as well as methods to determine project baselines and to quantify emissions uptake by the project. Moreover, projects generally do not report all greenhouse gas (GHG) emissions nor estimated leakage. Few have independent review. Of the 21 AIJ projects analysed, ten are forest management related, such as avoiding deforestation and improved management. The remaining eleven deal with afforestation/reforestation. Forest conservation projects are carried out on a land area of 2.86 million ha, which is about 80% of the total area of AIJ LULUCF projects.

Recognising the different calculation methods used, the undiscounted costs and investment estimates range from US\$ 0.03 to US\$ 7.5 t^{-1} CO_2. These estimates have been obtained simply by dividing project costs by their total reported accumulated carbon uptake or estimated emissions avoided, assuming no leakage outside the project boundaries (IPCC 2000).

Establishing carbon projects

Based on an international framework for CDM transactions in developing nations (Hassing and Mendis 1999), the following steps may be involved in establishing carbon projects in OECD countries.

Table 1: *Forestry and CO_2 credits - June 2000*

	Ireland (International emissions, transfer of national budget)	Annex 1 countries (JI) e.g. Eastern Europe	Non-Annex 1 countries (CDM) e.g. developing countries
Type 1 Afforestation/reforestation	+	+	±
Type 2.1. Fuel wood	+	+	+
Type 2.2. Building materials	±	±	-
Type 3. Forest protection	-	±	±

Legend: + possible; ± relevant, but under discussion; - less relevant

[1] *This conference will be held at The Hague in late November, 2000.*

Project development

The first and most important step in a project cycle, is the identification and formulation of potential projects. There is a broad spectrum of project proponents and parties involved in the project identification and formulation stage. The key players include but are not limited to: private sector project developers, emission reduction prospectors, green corporations, environmental development NGO's, carbon investment funds, national development agencies and bilateral or multilateral development agencies.

Approval from the host country

A necessary but not sufficient pre-condition for attracting investments in projects is a legal environment that fosters general project investments. The host country needs to approve the project.

Determination of baselines and additionality

A baseline defines a level of emissions if the project would not be implemented. This is called the 'without project situation' or the 'reference scenario'. The project scenario is the expected emission reduction to reach the new mitigation performance. The difference between with - and without project situation is called additionality. The principal responsibility for defining the baseline associated with a specific project will lie with the project developer/investor. However, the underlying assumptions and data that support a baseline definition must be derived from national or international authorities. Some methodologies for defining baselines exist: project specific, technology matrix and benchmarking (Hassing and Mendis 1999).

Baseline validation

A critical element of the validation process is the assessment of the assumed baseline and the estimated emission reduction resulting from the proposed project. The responsibility for validation must lie with the host country and can be done by an independent third party. Criteria for validation of projects should be, at a minimum, designed to determine if the project:

- meets national development priorities;
- contributes to the sustainable development of a country;
- has real, measurable and long term benefits related to the mitigation of climate change;
- reduces GHG emissions that are additional to any that would occur in the absence of the project;
- has an acceptable process for monitoring, reporting and verifying of associated emission reduction.

Project financing (accountancy check)

Financial closure is achieved when all contractual arrangements related to project financing, construction, fuel supply, operation and maintenance, performance monitoring and product sales are put in place. From the perspective of a project emission reduction (carbon credit), it is important that this credit purchase agreement covers all of the relevant aspects related to its financial value. These include:

- protocols for measurement, reporting and verification;
- quantity, quality, price and delivery date of credits;
- responsibilities and liabilities in case of non performance with regard to credits;
- required approval from the host government;
- implications of a change in the status of the project's validation and baseline reference;
- procedures to resolve impacts of future changes in the regulatory environment or baseline definition.

Project implementation and execution

Upon achieving financial closure, a project moves quickly to the project implementation and operation phase. For (forestry) projects, an important element is ensuring that monitoring and reporting are implemented according to agreed or required protocols. This is particularly important if the resulting carbon credits are to verified and certified at a later date.

Internal monitoring and documentation

The project owner/operator has the primary responsibility for the monitoring of credits. He/she is the initial seller of credits and therefore must put the required procedures and measures for monitoring the project's resulting credit in place. The owner may contract an external party to conduct the monitoring.

Verification and certification

Within the Kyoto Protocol, it is explicitly stated that projects in developing (non-Annex 1) countries (CDM) must be certified (Certified Emissions Reduction Units or CERs). Independent third party auditors may do this certification. But to date nothing has officially been agreed. With regard to Emission Reduction Units (ERUs) from projects in Annex 1 countries (JI), the EU may propose that certification of JI projects be required as well. With regard to forestry projects, SGS is currently the only certifier doing third party certification. Its activities are described in the following section.

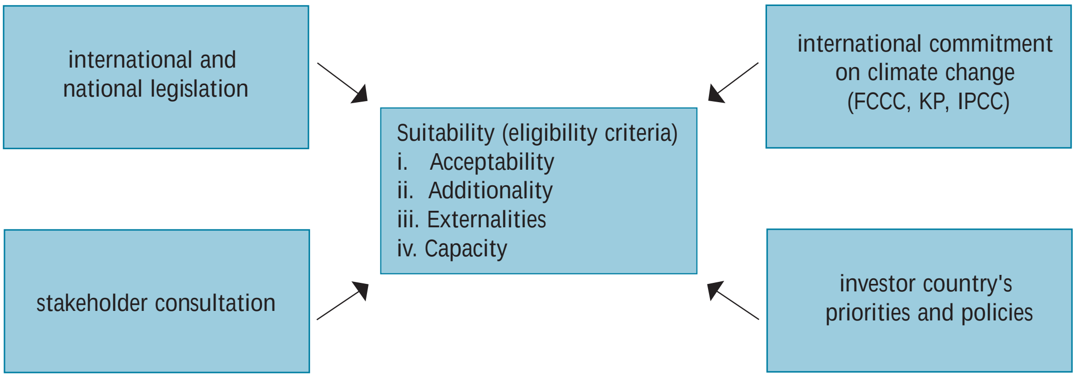

Figure 2: Assessment criteria for forestry carbon SGS projects (2000)

International project certification

A provisional certification standard has been developed by SGS, based on existing criteria promulgated by the FCCC and national regulatory bodies for joint implementation. They are drawing on their own expertise on best forest management practices. Certification programmes assess projects against such a standard and subsequently quantify the project's performance in terms of achieved ERUs or CERs. The risks and uncertainties associated with the project are also assessed based on scientific methods. This provides a mitigation mechanism by placing all the affected ERUs or CERs into a buffer, which is non-tradable. Both the criteria used and the assessment procedure are transparent (Sikkema and Simula 2000).

Interested certification bodies will set up their own carbon offset verification services. SGS (AgroControl), is currently the only certifying company dealing with the certification of carbon credits from forestry projects. The description that follows draws extensively on the SGS Carbon Offset Verification service. Such services initially focused on forestry projects (plantation establishment, sustainable forest management practices, reduced impact logging, forest protection, etc.). However, verification services have also been extended in 2000 to other sectors, such as energy (renewable energy, energy efficiency improvement, fuel switching, etc.) and waste management (for example wastewater treatment). The process of certification of carbon offset projects can be divided into three main phases which are related to the requirements of the Kyoto Protocol.

Project design

A qualitative analysis must be carried out for validation to verify that the project design meets the eligibility criteria set by the FCCC, the Kyoto Protocol, and GHG regulatory agencies. The Kyoto Protocol requires projects to "promote sustainable development" (Article 2) and that they result in benefits "additional to any that would otherwise occur" (Article 6.1b). Benefits of a project must be quantifiable in "a transparent and verifiable manner" (Article 3.1). Figure 2 shows the eligibility criteria.

Quantification and risk assessment

The GHG benefits of a project must be quantifiable and reliable. Consequently certification must include a verification of the methods used for quantification as well as a risk and uncertainty assessment.

Surveillance visits

The third phase consists of periodic verification of carbon achievements, concentrating on field implementation and field data gathered by the project's internal and monitoring programme. This will include field inspections, emission reduction calculations, and review of documentation and records.

Dutch policy on climate investments

The Dutch government has launched The Netherlands Climate Policy Implementation Plan. Part I (June 1999) deals with reduction measures in the Netherlands while part II (March 2000) deals with those abroad. The Netherlands has chosen to accomplish 50% of its reduction policy (50 million t CO_2 equivalents per year during the commitment period 2008-2012) within the country and 50% outside, using Kyoto mechanisms.

50% emission reduction within the Netherlands

- Forest certificates: The contribution of afforestation in The Netherlands is foreseen as about 0.1 million t CO_2 (annually). This estimate is based on 45,000 ha of new forests being established between 1995 and 2010 (Ministry of Environment 1999). The Ministry of Agriculture, Nature and Fisheries (LNV) has opted for the setting-up of a system of tradable forest certificates. The certificates, intended to encourage establishment, are intended to come into practice at the end of 2000. The proposal has first to be approved by the European Commission. The Ministry expects that investors will pay forest owners about 4500 EURO ha^{-1} in the first year of establishment (23 EURO t^{-1} CO_2). The National Green Fund Foundation will be responsible for project execution. Although it is a well-prepared initiative, according to a KPMG study (1998), potential Dutch investors are sceptical about the cost efficiency of (carbon) certificates for Dutch forests. They claim afforestation/reforestation and will be cheaper abroad.

- Renewable energy: At an earlier stage, electric power companies agreed to an input of 10% renewable energy sources (RES). This is referred to as the base scenario. The Ministry of Environment (VROM) proposes an extra input of 1.8%. This means an additional reduction of about 2.0 million t CO_2. However, the use of RES is more expensive than fossil fuels. Therefore, the price of electricity is currently being reduced by a voluntary payment by consumers (3.6 EURO cents kWh^{-1}) or a regulatory energy tax for fossil fuels (maximum of 2.6 EURO cents kWh^{-1}). The total (relative) price reduction is about 16 EURO t^{-1} CO_2.

- Domestic greenfunds: The Dutch Decree for Green Investments was launched in July 1994. It was meant to enhance environmental investments, amongst them nature, forestry and sustainable energy projects. All projects should have a minimum cost of about 23,000 EURO. By January 2000 only two green afforestation projects (total 60 ha) had been implemented within The Netherlands. The amount of Green projects, based on the use of wood for energy production, is unknown. Currently green assets of private investors are fully free from taxes until April 2001. However, in May 2000 the new Belastingwet 2001 ('Fiscal Policy 2001') was launched that will result in a change to this policy. This will come into effect in 2001 and assumes an average return on all new green investments of 2.5%. A partial tax exemption will result in a net 1.25% return for green investors that have their income in the 50% taxation bracket.

50% emission reduction outside the Netherlands

- Eastern Europe: On 15 May 2000 the Dutch government opened the first tender for acquiring credits resulting from projects under Article 6 of the Kyoto Protocol (JI). Through the tender, the Dutch government invites private sector entities in the EU, the EU associated member states, Canada and the USA to submit project proposals aimed at GHG abatement (including afforestation/reforestation) in Annex 1 countries, especially in a number of Central and Eastern European countries. The Dutch government intends to purchase the credits achieved via such projects (Ministry of Economic Affairs 2000).
- Developing countries: Due to the fact that the decisions on the rules concerning the Kyoto mechanisms will not be made until COP-6, the Dutch climate plan is incomplete. The Dutch government is currently preparing a document on the issue of sinks (forests) within the CDM. This document will be used for the preparation of COP-6. The final Dutch climate policy will be based on decisions at COP-6 or a later date (Joint Implementation Quarterly 2000).
- Green investments abroad: The Decree for Green Investments was broadened to include investments abroad in September 1998. This was based on positive experience with the Decree for Green Investments in the Netherlands. Possible areas for investment include Eastern Europe as well as some developing countries. It aims at the enhancement of JI projects (Eastern Europe) and renewable energy (developing countries). The project budget may lie between 23,000 and 4,500,000 EURO. Due to the new Fiscal Policy (Belastingwet 2001), including the discussion of Green Investments, potential investors have been reluctant to make use of the Decree for Green Investments abroad.

International policy on climate investments

PCF fund of World Bank

On 18 January 2000 the World Bank launched the Prototype Carbon Fund (PCF) in an attempt to experiment with the creation of a market in project based emission reductions. The PCF, established with contributions from governments and private companies, will invest in cleaner technologies in developing countries and countries with economies in transition, thus reducing their GHG emissions under the CDM and JI, respectively. It will include, for example, renewable energy projects.

EBRD

On the 15th of February 2000 the European Bank for Reconstruction and Development (EBRD) and the French-Belgian banking group Dexia announced the launch of a fund to reduce energy consumption and GHG emissions in Central and Eastern Europe. According to EBRD and Dexia the fund offers investors the opportunity to earn emission reduction credits to be used for achieving investor's commitments under the Kyoto Protocol (Joint Implementation Quarterly 2000).

Conclusions

Experience so far

- Pre-financing facilities for afforestation within the Netherlands still have to be approved by the EU. The system is built up with forest certificates for CO_2 capture, which are estimated to be sold at about 23 EURO t^{-1} CO_2.
- Tendering procedures for carbon projects, amongst them those dealing with afforestation/reforestation, in Eastern Europe have been set up in the Netherlands, since June 2000. The system (ERUPT) has set pre-financing project conditions at about 5 to 10 EURO t^{-1} CO_2.
- The World Bank has launched the Prototype Carbon Fund, aiming at pre-financing of carbon projects for JI and CDM.

Future feasibility

- The feasibility of carbon credits from forestry depends on the outcome of the Kyoto Protocol, which will further be discussed at the Conference of Parties (COP-6).
- At the moment only aboveground biomass is used for accountancy purposes. The inclusion of, and accounting methods to be used for other ecosystem carbon pools (roots and soil carbon) and for wood products is one of the major issues.
- With regard to the right type of projects to be selected for the Kyoto Protocol, the input and practical experience from the professional forestry sector are highly recommended.

Post COP-6 footnote

Having been unable to reach agreement on some of the key outstanding issues, the Climate Conference in The Hague formally concluded with a decision by Parties to suspend COP-6 and reconvene in May/June 2001 in Bonn. The President of COP-6 distributed, on the final day, a Note to all the delegates (International Institute for Sustainable Development 2000). The Note, which is relevant for LULUCF, states that it addresses key unresolved issues of COP-6. The Note proposes:

- Article 3.3 Parties apply the FAO definition for ‘forest’ and apply the IPCC definition for afforestation, reforestation and deforestation;
- Article 3.4 In terms of additional activities under 3.4 in the first commitment period, the note suggests that Annex 1 Parties be allowed to include grazing and cropland management, forest management and revegetation. To address problem of scale, an upper limit of credits amounting to 3% of a Party’s base year’s emissions would be set. This item is especially relevant for the National carbon budget of Parties with a big area of forest and agricultural land, such as the USA, Canada, Japan and Australia.
- CDM Parties allow afforestation and reforestation projects. Forest protection projects would not be allowed, but would be prioritised under the adaptation fund.

References

Hassing, P. and Mendis M.S. 1999. An international market framework for CDM transactions. In *The UN Framework Convention on Climate Change. Activities Implemented Jointly (AIJ) Pilot: experiences and lessons learned*. Ed. Dixon R.K., Kluwer, Dordrecht.

Institute for Forestry and Forest Products (SBH). 1995. Country based information on Forest and Wood Products. Basic figures for 24 countries around the world (*Landenoriëntatie Bos en Hout*). SBH, Wageningen.

International Institute for Sustainable Development (IISD). 2000. Earth Negotiations Bulletin 12 (162): 1-4.

IPCC. 2000. Special Report on Land Use, Land-use Change and Forestry. Summary for Policymakers. IPCC, Bonn.
On www.grida.no/climate/ipcc/land_use/index.htm

Jepma, C.J. and Lee C.W. 1995. The feasibility of JI. In *Carbon dioxide emissions: a cost-effective approach*. Ed Jepma, C. J., Kluwer, Dordrecht, pp 59-68.

Joint Implementation Quarterly (JIQ). 2000. Vol. 6 (1-2). Stichting JIN, Paterswolde.

KPMG. 1998. The introduction of system and organisation structure for CO_2 certificates (in Dutch). First draft. Ministry of Agriculture, Nature and Fisheries, The Hague, 6 May 1998.

Lund, H.G. 2000. Definitions of Forest, Deforestation, Afforestation and Reforestation. Unpublished Report. Manassas, VA. On http://home.att.net/~gklund/DEFpaper.html.

Ministry of Economic Affairs (EZ). 2000. Emission Reduction Unit Procurement Tender (ERUPT). On www.senter.nl/erupt.

Ministry of Agriculture, Nature and Fisheries (LNV). 1999. Temporary Agreement for Nature Conservation (Tijdelijke Regeling Natuurbeheer). On www.minlnv.nl.

Ministry of Environment (VROM). 1999. Climate Change Policy. Part *I*. Domestic Measures. VROM, Distribution Centre, The Hague.

Ministry of Environment (VROM). 1998. Decree for Green Investments Abroad. In Staatscourant 11 September 1998 (available in English version).

MikeRead Associates. 1998. Sink or swim? How can forestry be used to mitigate climate change? On www.geocities.com/rainforest/canopy/5632/index.html.

Nabuurs, G.J. and. Sikkema R. 2000. International trade in wood products: its role in the land use change and forestry carbon cycle. *Climatic Change* In press.

Nationaal Groenfonds. 1999. Annual Report 1998. Nationaal Groenfonds, Hoevelaken. On www.groenfonds.nl.

Nilsson, S. and Schopfhauser W. 1995. The carbon sequestration potential of a global afforestation program. *Climatic Change* (30): 267-293.

Nuon International/DE. 2000. Annual Report renewable energy 1999. Arnhem.

SGS. 2000. Carbon Offset Verification (COV) Service. Book 1. Background. SGS AgroControl, Spijkenisse.

Sikkema, R. and Simula M. 2000. Assessing forest-based carbon sinks in the Kyoto protocol - Interpretation and verification issues for the flexibility mechanisms. Indufor, Helsinki. In preparation.

Sikkema, R. and Heineman A.M. 1997. Summary project '*Flevo energiehout*'. Centrum voor Plantaardige Vezels (CPV), Wageningen.

WBGU. 1999. *Special report: the accounting of biological sinks and sources under the Kyoto Protocol*. German advisory council on global change (WBGU), Bremerhaven. On www.avi-bremerhave.de/wbgu.

World Bank. 2000. *Prototype Carbon Fund*. On www.prototypecarbonfund.org.

VALUING THE BENEFITS OF GREENHOUSE GAS REDUCTIONS

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Abstract
Carbon storage is, perhaps, the most widely recognised external benefit of forestry. The net amount of carbon that has been sequestered by forests planted since 1990 can be credited as a contribution towards meeting national and EU-wide assigned amounts under the Kyoto Protocol. However, without intervention by the government, the market will not provide an optimal level of forests in which carbon can be stored. This is because the benefits of carbon sequestration by trees accrue to wider society rather than to the forest owner. In order to construct an appropriate method of compensation (such as a grant scheme or emissions trading system), it is necessary to estimate the monetary value of carbon sequestration. This paper explores the approaches to valuing the benefits of carbon sequestration by Irish forests and appropriate incentive methods to promote this sequestration function. Particular attention is paid to developing an agenda to facilitate such research.

Introduction
Perhaps the most widely recognised external benefit of forestry is carbon storage. Trees absorb (sequester) carbon dioxide (CO_2) and store it in the wood. This carbon is released when the wood, or the products that have been made from the wood, decay. In this way forests delay the release of CO_2 to the atmosphere. This storage function of trees is of potential value to society in a number of ways. First, there are the long-term benefits in terms of avoided damage from the global warming that would have resulted if the carbon had not been sequestered by the trees. The more imminent benefits that may arise are as a result of Ireland being a signatory to the Kyoto Protocol on greenhouse gas emissions. Ireland has already exceeded its Kyoto quota and, if it is still in over its quota by 2012, the country will, most likely, be subject to legal action. However, without intervention by the government, the market will not provide an optimal level of afforestation for carbon storage. This is because the benefits of carbon sequestration by trees accrue to wider society rather than to the forest owner. This provides the rationale for subsidies (or some other method of compensation such as via an emissions-trading scheme) to compensate the wood grower for the value of the sequestration benefits that their forest provides. However, before an appropriate grant scheme can be constructed, it is necessary to estimate the monetary value of carbon sequestration by forests. In this paper we discuss approaches to valuing the benefits of carbon sequestration by Irish forests. Particular attention is paid to developing an agenda to facilitate such research.

Valuation methods
There are three approaches to placing a monetary value on the benefits of greenhouse gas reductions (Clinch, 1999).

1. The Damage-Avoided Approach values a tonne of carbon not emitted by the cost of the damage that would have been done by global warming in the event that it had been emitted.
2. The Offset Approach measures the value of not emitting a tonne of carbon using one method, by the next cheapest alternative method.
3. The Avoided-Cost-of-Compliance Approach measures the above tonne of saved carbon by the avoided cost of compliance with a global/regional CO_2 emissions' reduction agreement.

1. The Damage-avoided approach.
One problem with this approach is the high levels of uncertainty associated with the estimates. As the science and the associated modelling evolve, the margin of error can be expected to narrow, but in the meantime, policy makers and investors have to face the uncertainty, and make decisions. The issue is crystallised by the evolution of estimates emerging from the ExternE research project[1]. The initial estimates derived in 1997/98 had a mean value around €20 t^{-1} of CO_2. More recent amendments by Tol (2000) have reduced the estimates sharply, as shown in Table 1.

Table 1: Revised marginal damage costs from carbon dioxide {Tol (2000)}.

	Estimated Marginal Damage Costs per tonne of CO_2 equivalent reduction (€)
Minimum	0
Low	1
Mid	2
High	4
Maximum	16

[1] *ExternE was an EU funded research project with the objective of estimating the external costs associated first with electricity production, and subsequently with transport. It estimated willingness to pay to avoid adverse effects on life, health (comprising over 80 per cent of total estimated effects), agriculture and forestry and buildings.*

The substantial reduction in value is a product of a number of developments in methodology, including:

- New insights and associated values as regards benefits of global warming, including reduced energy costs in winter, and positive effects on crop production;
- A higher discount rate, a consequence of adopting the latest convention in the neo-classical literature, namely, the pure rate of time preference and the real per capita growth rate combined; these differ by region.

This is, of course, by no means the final word, and much research remains to be done. It simply highlights the oscillations in values emerging as new knowledge accretes and gets incorporated into the models. This leads us to our first recommendation regarding socio-economic research on carbon sequestration by forests in Ireland (Box 1).

Box 1. Irish Carbon Sequestration Valuation Research 1

Damage costs are global in scope, and therefore an Irish study per se does not make sense. However, it is important that the Irish policy process be kept up-to-date on emerging trends, and develop an understanding of the underlying assumptions and protocols that drive such damage cost modelling, since the findings will be one of the drivers of policy at EU level.

2. Offset Approach: marginal costs of abatement

The Luxembourg burden sharing agreement provides an assigned amount to each Member State; Ireland's amount is 64.25 million t of CO_2 equivalent to be achieved by 2008-2012. Projections of expected emissions under business as usual indicate that Ireland will overshoot its target by 8 to 11 million t. The measures needed to bring emissions down to the assigned amount can be ranked from the most to the least costly. The offset approach values a tonne of reduction achieved by a forest by the cost of the last increment of abatement that just achieves the objective. These costs have been estimated for Germany at 19 t^{-1} of CO_2 equivalent (Friedrich 2000). Our recommendations for research on the offset approach to valuing sequestration benefits are set out in Box 2.

Box 2. Irish Carbon Sequestration Valuation Research 2

Rank order the abatement opportunities available in Ireland, on the basis of the unit costs per tonne of CO_2 equivalent abatement. A start has already been made in ERM (1998) on the opportunities available for such action in Ireland. Two key issues will need to be addressed:

- The scope of the marginal cost exercise - should it be confined to Ireland, to the EU, to Annex 1 signatories, to the world? The flexible mechanisms of Joint Implementation (Annex 1 signatories) and the Clean Development Mechanism (global) respectively in the Kyoto Protocol provide a vehicle for drawing in such opportunities in meeting the Irish assigned amount;

- How political constraints are handled. For example, in ERM, it is proposed that, if the peat-fired plants were replaced by combined cycle natural gas fired plants, the ensuing CO_2 abatement costs would be negative. However, there are substantial political constraints limiting such action.

3. Avoided cost of compliance: values emerging from emissions trading etc.

There is provision in the Kyoto Protocol to allow countries to meet their targets by trading in emissions. That is to say, a signatory that does not meet its target from its own efforts has the option of buying in credits from a signatory whose emissions are below its assigned amount. This provision was included in the Protocol at the insistence of the US, which has had considerable success in using emissions trading to reduce emissions of SO_2 from power plants at minimum cost. Power plants for whom it was very expensive to reduce emissions to meet their assigned amount bought credits from plants that could, at modest cost, reduce emissions below their quota. A price per tonne of SO_2 emerges from these transactions (see Market trading below).

Summary of valuation approaches - willingness to pay by the Irish public to achieve a reduction in greenhouse gas emissions

Clinch (1999) suggests that the Damage-Avoided Approach is the appropriate measure of global carbon sequestration benefits. However, in terms of global emissions, Ireland, being a small economy, is a relatively small polluter (0.1% of global emissions of CO_2). All else being equal, if Ireland were to reduce its emissions of CO_2 by, say 20%, the impact on the total damage of global warming to Ireland would be insignificant. Therefore, if Ireland acts in its own self-interest, it will not reduce its emissions in the absence of an international agreement. With an international agreement, the Avoided-Cost-of-Compliance Approach would be the most appropriate method of valuing reductions in greenhouse gases. However, the appropriateness of the various measures depends very much upon the preferences of the Irish population. The Irish public may (or may not) be willing to pay to achieve reductions in Ireland's greenhouse gas emissions, for a variety of reasons, both on the basis of their self interest and a willingness to pay to reduce the risk of global disruption and ecological dysfunction. An estimate of such willingness to pay would provide a value at the margin that could be used to value carbon sequestered by afforestation (Box 3).

Box 3. Irish Carbon Sequestration Valuation Research 3

Undertake a contingent valuation of Irish residents to assay their willingness to pay to achieve a reduction in greenhouse gas emissions.

Market trading

The European Commission has issued a Green (discussion) paper on how emissions trading might be implemented in the EU, and the Minister for the Environment and Local Government in Ireland has established a working group to advise him on how Ireland should position itself in this regard (Consultation Group on Greenhouse Gas Emissions Trading, 2000). The outcome and operational implications of these deliberations are not yet clear, but it is likely that a trading scheme will be in place by 2005 where carbon equivalent credits will be bought and sold, and a market clearing price will emerge as a result. If the market is highly restricted as regards volumes traded - as has been proposed by the European Commission - and limited to particular sectors, this will influence the price. The wider the geographical scope of the market, the lower will be the market-clearing price. (Convery, 2000). Peter Bohm (1999) has conducted research on the potential for a Nordic market in greenhouse gasses, and estimated the savings and possible market clearing prices. A key pre-requisite for effective trading is unambiguous assignment of rights; the assigned amounts agreed in Luxembourg will need to be given some form of legal status and enforceable mechanism in the event of default. This leads us to our fourth recommendation regarding socio-economic research on carbon sequestration by forests in Ireland (Box 4).

Box 4. Irish Carbon Sequestration Valuation Research 4

To examine the market clearing price that is likely to emerge if and when emissions trading develops, under different scenarios as regards market structure, scope and function. To assess whether it is likely or desirable that offsets be permitted, whereby forest owners who qualify could be paid for carbon sequestration on the basis of the reduction they effect. In formulating an appropriate grant scheme or trading scheme, particular attention must be paid to the relationship between the greenhouse abatement benefits and the other environmental impacts of forestry so that the appropriate balance can be struck.

Conclusion

The net amount of carbon which has been sequestered by forests planted since 1990 can be credited as a contribution towards meeting national and EU-wide assigned amounts under the Kyoto Protocol. This raises key questions as to the measurement and estimation of the amounts of carbon so sequestered, and how it is credited etc. The net amount of carbon sequestered annually and over time varies depending on site type, species, and silviculture, and these, in turn, affect the commercial and environmental services provided. Thus, for example, a Sitka spruce plantation grown on a 35-year rotation, thinned every five years from year 15 will have quite different commercial, environmental and carbon sequestration characteristics and performance relative to an oak plantation which has an 120-year rotation, and is thinned every 10 years from year 25. These choices are fundamentally economic in the broadest sense, in that the choices affect the private financial returns to the forest owner, the value of the contribution to mitigation of global warming, and value of non-global warming environmental benefits yielded.

The research agenda set out in this paper is of great importance if the carbon sequestration function of trees and forests is to be fully valued. If it is, it will greatly assist in ensuring that the full potential that forests have to assist in reducing Ireland's greenhouse gas emissions is realised.

References

Bohm, P. 1999. International Greenhouse Gas Emission Trading - with special reference to the Kyoto Protocol, Nordic Council of Ministers.

CEC. 1999. Preparing for Implementation of the Kyoto Protocol. *Commission Communication to the Council and the Parliament*, Com (1999) 230 final, 19 May 1999.

Clinch, J. P. 1999. *Economics of Irish Forestry: Evaluating the Returns to Economy and Society*. COFORD, Dublin.

Consultation Group on Greenhouse Gas Emissions Trading. 2000. Report of the Consultation Group on Greenhouse Gas Emissions Trading. Department of the Environment and Local Government, Dublin.

Convery, F. J. 2000. Insights into Climate Policy in Europe. *Environmental Modelling and Assessment* 1:165-176.

Friedrich, R. 2000. Marginal Energy-related External Costs of Transport. Paper presented at *External Costs of Energy Conversion - Improvement of the ExternE Methodology and Assessment of Energy-related Transport Externalities*, Vlaams Europees Conferentiecentrum, Brussels, May 10, 2000.

Tol, R. 2000. External Costs of Emissions of Greenhouse Gasses. Paper presented at *External Costs of Energy Conversion - Improvement of the ExternE Methodology and Assessment of Energy-related Transport Externalities*, Vlaams Europees Conferentiecentrum, Brussels, May 10, 2000.

POWERPOINT PRESENTATION 1

Kyoto Protocol:
National Greenhouse Gas Strategy and Forestry

Donal Enright
Dept. of the Environment and Local Government

Key Points

- Provisions of Kyoto Protocol
  - Forestry
  - Other Sinks
- IPCC Special Report
- Current State of Negotiations
- Implications for Ireland
  - Forestry
  - Other Sinks
- National Greenhouse Gas Abatement Strategy

1

Provisions of Kyoto Protocol
Forestry

- Article 3.3
  - "Direct human-induced afforestation, reforestation and deforestation since 1990"
  - "Verifiable changes in carbon stocks"
- Irish afforestation programme tailor made
- Limited to ensure environmental outcome at Kyoto

2

Provisions of Kyoto Protocol (2)
Other Sinks

- Article 3.4
  - Parties to decide on "Additional activities" in the
  - "Agriculture soils, Land-use change and forestry" sectors
  - Must apply to post-2012 commitments
  - Optional for 1st Commitment Period
- Potential to weaken global commitment to reduce emissions

3

IPCC Special Report

- Asked for Report on LULUCF
  - Implications of Art 3.3
  - What additional activities for Art 3.4
  - Project-based sequestration
- Report May 2000
- Designed to inform negotiations
- Highlighted
  - Complexities
  - Difficulties

4

IPCC Special Report Findings Art 3.3 - Forestry

- Sequestration / Emissions (-)
  - (Parties with Targets) -849 to 483 MtC yr^{-1}
  - (Global) -1204 to -1591 Mt C yr^{-1}
- Problems
  - Definitions and uncertainties
  - Reversibility
  - Scale
  - Accounting
    - Activity-Based vs Land-Based
    - Biomass, Soil, Litter, Products
  - Leakages
  - Sustainable Development Obligations

5

IPCC Special Report Findings (2) Article 3.4 - Additional Activities

- Limited Data
- Incomplete Sequestration totals
  - (Parties with Targets) 300 MtC yr^{-1}
  - (Global) 1,000 MtC yr^{-1}
- Problems
  - Same as Forestry, but intensified

6

IPCC Special Report Findings (3) Project-based Sequestration

- Limited Experience
  - Cost $0.10 - $28 per Tonne C
- Problems
  - Baseline determination
  - Leakage/displacement

7

Current State of Negotiations - Forestry

- Important for Ratification for some Parties
- Definitions
- Inventory Methodologies
  - Linked to other inventory questions
- In or out of CDM – EU says out
- Timescale
  - Nov 2000 to set parameters
  - Final Decisions post-Entry into Force

8

Current State of Negotiations (2) - Additional Activities

- Which (if any)
  - Most EU against use before 2012
- Timescale
  - Nov 2000 may see political decisions
  - Decisions post-Entry into Force

9

Implications for Ireland - Forestry

- Clear environmental benefit
  - need for compatibility with other environmental objectives
- Support for afforestation programme
- Requires integration with agriculture
- Pre-1990 planting irrelevant except deforestation

- Other Sinks

- Agriculture – Abandonment to Natural Systems
  - Rough Grazing
  - 15 - 25 Mt CO_2 yr^{-1}
- Forestry Management Practices

10

National Greenhouse Gas Abatement Strategy

- To Government shortly
- Sinks
  - Forest Strategy
  - Important in agriculture sector
- Conservative approach to counting
  - Above Ground Biomass only
  - To be reviewed

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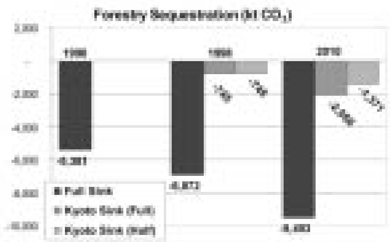
Size of Sink



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POWERPOINT PRESENTATION 2

Wood in construction
Carbon storage and environmental impact

Peter Bonfield
Building Research Establishment, UK

Carbon storage

- Locked
- Life of building

Increasing market

- Re-engineering
- Adding value
- Upgrading

- Carbon just one issue

1

Life cycle assessment

- Why LCA?
- Relevance to buildings
- Benefits
- Available tools

2

Definition of LCA

"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle"

ISO 14040

3

LCA process

- Two Stages
  - Life cycle inventory analysis
  - Life cycle impact assessment

Life cycle inventory analysis

- Aims and objectives
- Rules
- Functional unit
- Boundaries
- Inputs and outputs

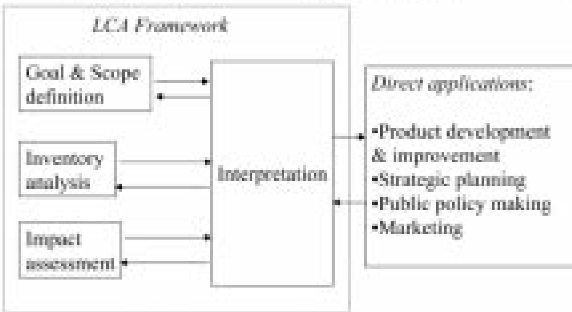
4

Life cycle impact assessment

- Characterisation
  - Contribution to issue (eg global warming)

5

Stages of LCA



6

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Stage 1: Goal & Scope definition

- Why doing study?
- How will results be used?
- What will be looked at & why?
- What information needed?

7

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Stage 2: Inventory Analysis

- Data collection
- Data processing

"Inventory Table"

Input/Output	*Environmental Measure*
Electricity	Resource extraction Emissions

8

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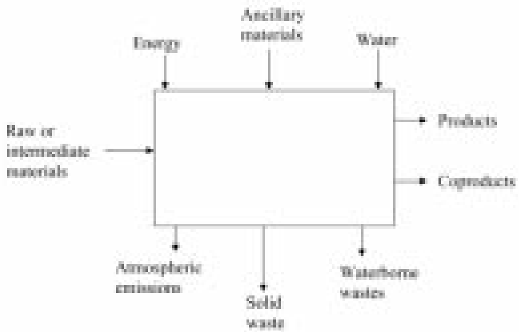
Life Cycle Inventory Template



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Stage 3: Impact Assessment

- Classification
- Characterisation
- Valuation

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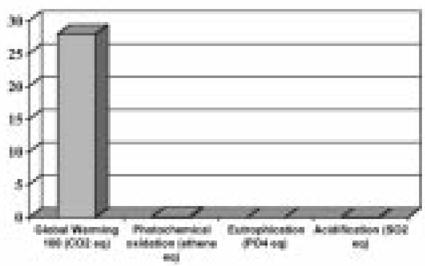
Environmental Profile *Characterised*



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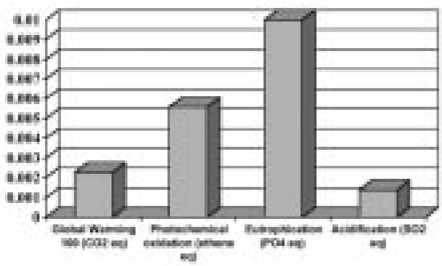
Environmental Profile *Normalised*



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Valuation

- What's important to you?
  - Global
  - Local
- Weighting Factors
  - Environmental Index

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Tools

- BRE environmental profiles
- BRE UK timber LCA
- Green Guide
- BREEAM/EcoHomes
- ENVEST

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BRE

BRE environmental profiles

- National database
- Materials, components and buildings
- Inventory and characterised
- www.bre.co.uk/envprofiles

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BRE

UK Forestry, panel products and sawn timber LCA

- Cradle to gate
- Modular approach
- Compatible with BRE environmental profiles
- Improvement opportunities
- Complete summer 2000
- Bonfieldp@bre.co.uk

16

BRE

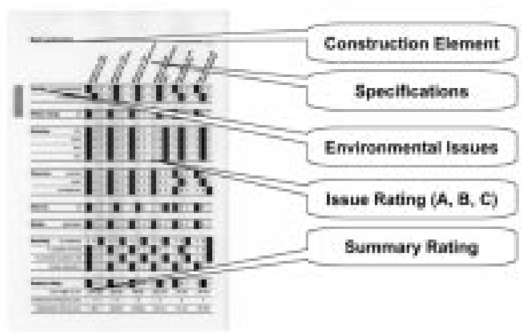
Green Guide to Specification

- **Sponsored by The Post Office**
- **Component based**
- **Simple to use**
- **Part of the BREEAM portfolio**

17

BRE

Green Guide to Specification



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Green Guide to housing specification

- Launched May 2000

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BREEAM

- BREEAM widely used for offices
- Credits system
- EcoHomes to be launched April 2000
- Http://products.bre.co.uk/breeam

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BRE

ENVEST

- LCA tool for architects/designers
- Can change specifications and design life
- Includes operational impacts (eg energy and water use)
- Single 'Eco-points' ratings
- Launch date April 2000
- www.bre.co.uk/envest

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What about timber?

- Windows
  - Hardwoods A
  - Softwoods A
  - PVC C
  - Aluminium B

22

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What about timber?

- Upper floor
  - Timber joists (plywood) A
  - Composite floor B
  - In-situ concrete C

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Conclusions

- Several tools available
- Comprehensive knowledge base
- Timber does well!
- Edwardss@bre.co.uk
- bonfieldp@bre.co.uk

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