

IEA Bioenergy

Task 38
**Greenhouse Gas Balances of Biomass
and Bioenergy Systems**



Proceedings of the Workshop
Carbon accounting and emissions trading related to bioenergy, wood products and carbon sequestration

26–30 March 2001
Canberra, Australia

B. Schlamadinger, S. Woess-Gallasch and A. Cowie (eds.)
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Foreword by the Editors

IEA Bioenergy is an international collaborative agreement under the auspices of the International Energy Agency (IEA), aiming at the use of biomass as an environmentally sound, cost-competitive, and sustainable energy source to provide a substantial contribution to meeting future energy demands. It was set up in 1978 in order to improve the international co-operation and exchange between national research, development and demonstration (RD&D) projects on bioenergy. The work within IEA Bioenergy is structured into a number of Tasks which have well defined objectives, budgets and time frames.

IEA Bioenergy Task 38 (Greenhouse Gas Balances of Biomass and Bioenergy Systems), which succeeds Task 25 (1998-2000) and Task XV (1995-1997), aims to investigate, on a full fuel-cycle basis, all processes involved in the use of biomass, and bioenergy systems, in order to establish overall greenhouse gas balances, and to make a comparison with fossil energy systems. The work of Task 38 is designed to be supportive for decision makers in selecting mitigation strategies that optimize GHG benefits, and to assist in the implementation of forestry, land-use and bioenergy options through methodological work and development of standards. The duration of Task 38 is from 1 January 2001 to 31 December 2003.

The Task 38 workshop in Canberra, Australia, is part of a series of workshops planned within Task 38, and the preceding Tasks 25 and XV, taking place every 6 to 12 months. The next workshop of the Task is scheduled for 12-16 November 2001 in or near Edinburgh, UK. For more details on the Task and its history, visit the Task 38 website at <http://www.joanneum.at/iea-bioenergy-task38>.

The proceedings contain most of the presentations that were given at the workshop, and we would like to take this opportunity to express our gratitude to all authors who managed to submit their manuscripts in the short time provided, and also to thank all the presenters. Each and every participant in the workshop contributed to the success of the event, particular thanks go to those who actively provided valuable feedback to the speakers, either during the sessions, or in the course of the breaks and/or social events.

We would like to thank Kimberly Robertson for all her work in organising the workshop. We would also like to thank the local organisers, especially Kate Düttmer, who assisted Annette Cowie and without whom this workshop would not have been such a success. We are very grateful for the support received from the local workshop co-organizers (State Forests of NSW, CSIRO Forestry and Forest Products, Bioenergy Australia, and Bureau of Rural Sciences), and we particularly wish to thank John Raison, Margaret Borucinski, Gordon Everitt and Glenn Taylor of CSIRO FFP for workshop arrangements. Thanks also to the following people who hosted the site visits for the field trip:

- Ken Epp at Visy Pulp and Paper, Tumut,
- Phil Polglase at the CSIRO Wagga effluent irrigation project,
- Ross Dickson and Jason Vincent at the State Forests Bondo pine plantation,
- and to Bishop George Browning, who delivered a stimulating after dinner speech.

From an editorial aspect, we are very grateful to Anton Stachl for his help with the design of the cover pages. The photographs on the title page are courtesy of State Forests of New South Wales.

Bernhard Schlamadinger, Susanne Woess-Gallasch and Annette Cowie

July 2001

Presentations

The *FullCAM* Carbon Accounting Model: Development, Calibration and Implementation

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ABSTRACT

In developing Australia's National Carbon Accounting System (NCAS) the Australian Greenhouse Office (AGO) has undertaken ambitious national resource and activity inventories within an accounting framework that benefits from a comprehensive and integrated suite of remote sensing and carbon modelling activities. The result is a fine scale spatial application of a comprehensive carbon cycle model which is an integration of a range of existing models.

The model developed, named *FullCAM*, is an integration of biomass, decomposition, soil carbon models and accounting tools to provide a single model capable of carbon accounting in transitional (e.g. afforestation, reforestation and deforestation) and mixed (e.g. agroforestry) systems.

The *FullCAM* model can be run in point, estate (a mix of areas by age by activity types) and a spatial mode which will integrate information drawn from the remotely sensed land-cover-change program, productivity and climate surfaces and other ancillary data to perform the various accounting routines capable of meeting the various reporting requirements of the UN Framework Convention on Climate Change, and more specifically, the Kyoto Protocol.

Keywords: FullCAM, NCAS, carbon

INTRODUCTION

The National Carbon Accounting System (NCAS) has been established by the Australian Government to provide a complete carbon accounting and projections capacity for land based (agricultural and forestry) activities.

Early in the development of the NCAS it was recognised that carbon accounting at both continental and project scales was going to rely on both the collation and synthesis of resource information and the calibration and verification of a model framework. The vast land areas in Australia under extensive forest and agricultural management demand an approach founded on modelling. Purely measured approaches were shown to be impractical, particularly for differential land based accounting systems such as Article 3.3 of the Kyoto Protocol.

An overall system framework (AGO, 2000a) guided the development of data gathering, projects and programs which could then be integrated using spatial modelling approaches. Various models were selected calibrated and verified through these programs, and a range of related projects were undertaken to provide the additional data needed to operate the models continent-wide at a fine resolution. *FullCAM* is an integrated compendium model that provides the linkage between the various sub-models.

FullCAM has components that deal with the biological and management processes which affect carbon pools and the transfers between pools in forest, agricultural, transitional (afforestation,

reforestation, deforestation) and mixed (eg. agroforestry) systems. The exchanges of carbon, loss and uptake, between the terrestrial biological system and the atmosphere are also accounted for.

The integrated suite of models that comprise *FullCAM* are: the physiological growth model for forests, *3PG* (Landsberg and Wareing, 1997; Landsberg *et. al.*, 2000; Coops *et. al.* 1998; Coops *et. al.*, 2000); the carbon accounting model for forests developed by the Australian Greenhouse Office (AGO), *CAMFor* (Richards and Evans, 2000a), the carbon accounting model for cropping and grazing systems – *CAMAg* (Richards and Evans, 2000b), the microbial decomposition model *GENDEC* (Moorhead and Reynolds, 1991; Moorhead *et. al.*, 1999) and the Rothamsted Soil Carbon Model – *Roth C* (Jenkinson, *et. al.*, 1987, Jenkinson *et. al.*, 1991).

These models have been independently developed for the various purposes of predicting and accounting for:

- soil carbon change in agriculture and forest activities (in the case of *Roth C*);
- the determination of rates of decomposition of litter (in the case of *GENDEC*); and
- the prediction of growth in trees (in the case of *3PG*).

CAMFor and *CAMAg* are carbon accounting tools developed by the Australian Greenhouse Office through which it is possible to apply management impacts such as fire, harvest, cropping, and grazing, to externally generated growth and decomposition rate inputs.

To prepare these models for integration into *FullCAM*, each model (except for *CAMAg*) was translated to a common Microsoft Excel spreadsheet format. The Excel workbooks used only sheet based formula. No ‘Macros’ or other code were applied. This provided a consistent and transparent model platform from which to review and integrate the various models. This developmental Excel version was named GRC3. Having a consistent structure and format for the models allowed for the independent calibration of various models while providing for ease of later integration. The transparency of the development process also facilitates review at a detailed level.

The integration of the models serves two primary goals. The first is to provide a capacity to be able to operate at a level of conservation of carbon at a site or other specified area. This includes all pools and transfers (net of atmospheric uptake and emissions) between pools to ensure that there are no significant instances of double counting or omissions in accounting. Potentially, this could occur if each of the dominant carbon pools – soil carbon, biomass and litter – were considered independently. The second is to provide the capacity to run the model continentally as a fine resolution grid-based spatial application. A single efficient model is required to analyse the large input data sets in a spatial context.

MODEL SELECTION

The need to develop an integrated model was highlighted during the International Review of the NCAS Implementation Plan for Phase 1 of the 1990 Baseline. The Review report is contained in the NCAS Technical Report No. 11 (AGO, 2000b). Most germane among the Review recommendations was a need to take a holistic approach, with modelling and measurement continuous across all carbon pools and cognisant of the transfers between pools.

Other recommendations from the Review which had direct implications for the development of the NCAS, and therefore *FullCAM* were:

- the adoption, within the NCAS suite of tools, of a generic and widely applicable physiological growth model;
- the adoption of a microbial litter decomposition model, with a direct suggestion to consider the *GENDEC* model of Moorhead *et. al.* (1999); and,
- support for the national calibration of the *Roth C* soil carbon model.

The selection and development of the models for integration to *FullCAM* arose from early analysis carried out in developing the system framework for the NCAS. Various strategies for data accumulation and assimilation into models capable of continental and project scale carbon accounting (largely directed at satisfying the requirements of the Kyoto Protocol) were developed. Strategies were developed to guide the fundamental data collections, research program and model calibration.

The rationale for the selection of the models that were integrated in *FullCAM* can be found in the various NCAS Technical Reports (Turner *et. al.*, 1999; AGO, 2000a–c; Webbnet, 2000).

CAMFor (carbon accounting model for forests) (Richards and Evans, 2000a) was developed within the NCAS to provide capacity for both project and continental scale accounting. *CAMFor* is an Excel based model which has its conceptual foundations in the *CO₂ Fix* model of Mohren and Goldewijk (1990).

CAMAg (carbon accounting model for agriculture) was also developed for the NCAS (Richards and Evans, 2000b). *CAMAg* performs similar functions to *CAMFor*, but operates in agricultural systems. *CAMAg*, unlike *CAMFor*, was developed with direct integration of the *Roth C* model.

Copies of the original models and User Manuals can be found in the following publications or distributed on the following websites:

- *CAMFor* User Manual - <http://www.greenhouse.gov.au/ncas>
- *Roth C* - <http://www.iacr.bbsrc.ac.uk/res/treshome.html>
- *3PG* - <http://www.landsberg.com.au>

MODEL DEVELOPMENT

The component models are being independently calibrated for the NCAS through a variety of programs. This activity provides for considerable investment into the calibration of each of the models for the range of conditions and management practices present throughout Australia. Over a 2–3 year period, the total investment in the data collection and process understanding for model calibration will be the order of \$9M.

Model calibration includes the collation of a series of previous (quality audited) site measurements and the undertaking of additional field work and laboratory analyses. Independent data sets are maintained for the model calibration and verification of model results. The subsequent integration of the range of calibrated models into a spatial version of *FullCAM* will rely on interpolation across a range of spatially continuous input data layers. This includes data such as that on climate, soil type, biomass and land cover change.

Such a comprehensive approach to carbon accounting was made possible by the NCAS having sole responsibility for the development of carbon budgets across the forest and agriculture sectors, including both the biomass and soil carbon pools. This allowed for alignment of program activities for the calibration of each component model. Data collection and model calibrations could then be easily transferred into the calibration and verification of the *FullCAM* model in both its plot and spatial versions.

THE COMPONENT MODELS

3PG

The adopted version of *3PG* is that described as Version 3-PGpj 1.0 (Sands, 2000). In its original form, this is an Excel version of the model supported by Visual Basic Macros. This was translated into a consistent sheet based and formula driven (no Macros) model. Subsequent

changes were made to this model to enable spatial application reflecting the previous version development by Coops and Wareing (2000) and Landsberg and Kesteven (2001).

The principal work required to implement this model was the compiling of the fundamental input data. This entailed:

- the development of a slope and aspect corrected solar radiation surface on a 250m grid;
- the use of Digital Elevation Model (DEM) of AUSLIG – Geodata 9 second DEM (version 2);
- the provision of access by CSIRO Division of Land and Water to their Fertility and Soil Moisture Continental Surfaces (Mackenzie *et. al.*, 2000);
- the derivation of soil surfaces from the Atlas for Australian Soils (Northcote, 1979);
- use of the rainfall, temperature and radiation surfaces from ANUCLIM (software package) (McMahon *et. al.*, 1995);
- derivation of a Normalised Difference Vegetation Index (NDVI) 10-year average by ERIN for the NCAS; and
- development of a frost surface by the NCAS.

CAMFor

CAMFor has its origins in the 1990 *CO₂ Fix* Model of Mohren and Goldewijk (1990). The published Fortran code for this model was converted to an Excel spreadsheet (sheet based, formula driven) format as reported in Richards and Evans (2000a). A subsequent series of modifications were made including:

- the introduction of an inert soil carbon pool recognising the nature of the carbon in Australian mineral soils, the high charcoal content and the potential long term protection of fine organic matter through encapsulation and absorption by clays;
- a fire simulation capacity was added to the model that could deal with stand replacing and/or regenerating fires, being either forest floor fires largely removing litter or crown fires affecting the whole tree;
- the wood product pool structures and lifecycles were modified to reflect those cited in the NCAS Technical Report Number 8 (Jaakko Pöyry, 1999);
- greater resolution was added to the component distinctions of the standing tree material, splitting coarse and fine roots, branch and leaf material;
- the potential to override the soil carbon model component by directly entering either field data or externally modelled inputs, and
- an added capacity to account from a primary data input of above-ground mass increment as an alternative to stem volume increment.

Within *FullCAM*, the *CAMFor* sub-component can take its growth information from any one of three sources:

- net primary productivity (NPP) derived from *3PG* with feedback from management actions (thinnings, etc.) specified in *CAMFor*;
- information entered from external models; and
- measures of either above-ground mass increment or stem volume increment.

Material entering the debris pool (that is the above-ground coarse and fine litter) and the decay (the root material below ground shed by live biomass) is accounted in either a decomposable or resistant fraction, with the potential to apply separate decomposition rates to each.

A series of defaults were developed for *CAMFor* using the growth rates and management descriptions drawn from the work of Turner and James (1997). Under contract to the AGO, Turner and James converted wood flow estimates for typical silvicultural regimes, growth rates and harvest rates – prepared through survey of forest growers for the National Forest Inventory (NFI) – to

standing volumes and volume increments. Wood densities were available from the work of Ilic *et al.* (2000).

The information flowing from *3PG* to *CAMFor* is simply that of total NPP, as reflected in whole tree productivity/growth. Rules for the allocation to various tree components and for the turnover rates that will affect the standing mass increment at any one time (change in mass as opposed to a total productivity change) are either specified within a *CAMFor* table or driven by formula common to *3PG* and *CAMFor*.

Neither *CAMFor* nor *3PG* (in this form) deal with a number of stems, but work on proportional change to mass per unit area. Thinning activities, such as harvest or fire, which are specified in *CAMFor* are treated as a proportional decrease of biomass and are reflected as an equivalent proportional decrease in canopy cover within *3PG*.

CAMAg

Within *FullCAM*, *CAMAg* serves the same roles for cropping and grazing systems as *CAMFor* does for forests. The *CAMAg* model reflects the impacts of management on carbon accumulation and allocates masses to various product pools within plants and to decomposable and resistant organic residues. Yields need to be prescribed in the model – as either above-ground, total or product mass – as do above- and below-ground turnover rates.

With both *CAMFor* and *CAMAg* embedded within *FullCAM*, it is possible to represent the transitional afforestation, reforestation and deforestation (change at one site) or mix of agricultural and forest systems (discrete activities at separate sites). Under afforestation and reforestation there is a gradual change from the characteristics of the original pasture or cropping system, with the mass of organic matter derived from those systems decomposing and decreasing with declining input. For deforestation, the same applies, but with a large residual of decomposing woody material being the primary change remaining within *CAMFor*.

Within *FullCAM*, *CAMFor* and *CAMAg* can be proportionally represented (as under afforestation, reforestation and deforestation) according to the relative proportions of canopy cover under each of the woody (*CAMFor*) and non-woody (*CAMAg*) categories. This provides capacity for ongoing mixed systems such as agroforestry.

GENDEC

GENDEC is a microbial decomposition model, developed by Moorhead *et al.* (1999), which considers the environmental and biological drivers of microbial activity, namely temperature, moisture and substrate quality.

GENDEC addresses both carbon and nitrogen, relying on nitrogen to carbon ratios throughout the decomposition process, and using available nitrogen as a factor which may constrain the rate of microbial activity. When *GENDEC* is brought into operation with *FullCAM*, it can replace the empirical decomposition routines which deal with the resistant decomposable fraction of each above-ground tree component embedded within either or both the *CAMFor* and *CAMAg* components of the model.

The inclusion of *GENDEC* within the NCAS suite of models, and its subsequent inclusion in *FullCAM*, arose from the recommendations of the International Review Panel of the NCAS (AGO, 2000b). The rationale of this recommendation was that the calibration to Australian conditions of a generic decomposition model such as *GENDEC* would allow for extrapolation and interpolation over a broad range of environmental situations and forest types.

A particular constraint to understanding of decomposition rates is that long-term field trials are not possible given the need to produce initial results for the NCAS by mid to end 2001. This period of

time is far too limited to develop any long term temporal trials and only allows for the development rates of change in mass through chronosequence investigations. The inherent limitations that lie within that approach are recognised and will be addressed over time through long term trials.

The impact of invertebrate activities on the breakdown of debris is addressed within *FullCAM*, whereby the microbial decomposition of *GENDEC* is paralleled by a breakdown factor which can account for losses in above-ground litter due to factors such as macro-invertebrate activity. Root material is incorporated directly into the soil carbon pools, and therefore is subject to the decomposition activities of the *Roth C* component of the *FullCAM* model.

Roth C

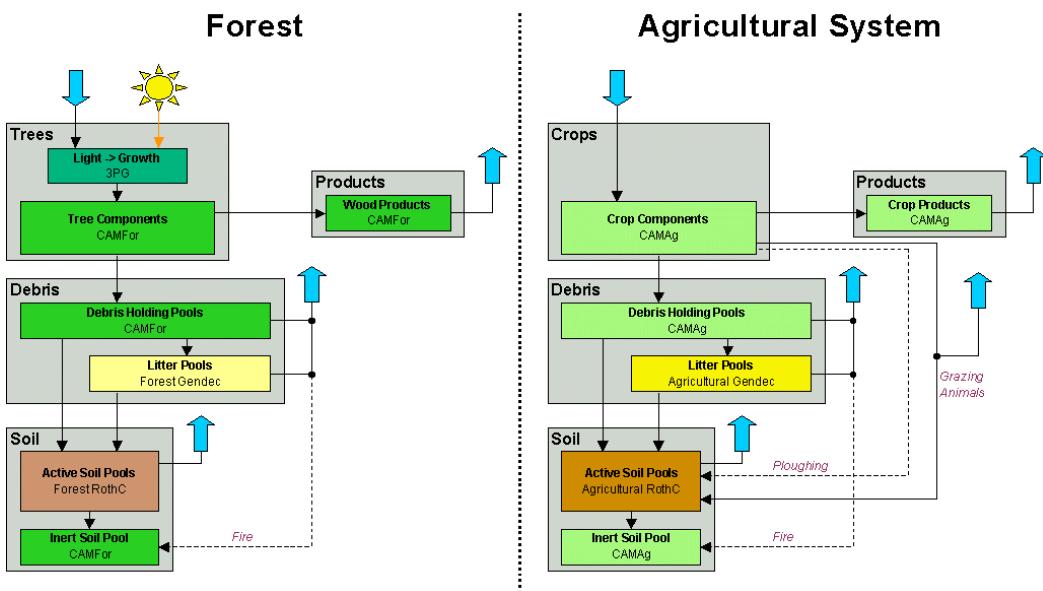
The Rothamsted soil carbon (*Roth C*) model accepts pre-determined masses of plant residues which are then split into decomposable and resistant plant material. Required model inputs include the fractionation of soil carbon into various soil carbon pools, generally defined by classes of resistance to decomposition. Turnover rates for each fraction are determined by rainfall, temperature, ground cover and evaporation. The *Roth C* source code was made available to the NCAS in two versions, 26.3 and 26.5. Version 26.3 is the more recent ‘release’ version while 26.5 is a developmental version yet to be fully tested.

It is recommended that, if calibration data is available, then the *Roth C* model should be used in conjunction with *CAMFor*. It is a more robust soil model than the soil carbon routines contained within *CAMFor*. As calibration data is more readily available for agricultural systems, *Roth C* has already been directly integrated into *CAMAg*. *CAMAg* must be operated in conjunction with the *Roth C* model.

MODEL INTEGRATION

The initial integration was performed on a Microsoft Excel developmental version of the forest component of *FullCAM* and linked with the Excel versions of the models *3PG*, *CAMFor*, *GENDEC* and *Roth C*. The resultant developmental model named *GRC3*, was used to test and refine the linkages between the models. It formed a 10 megabyte Excel workbook, which could be used for developmental purposes, but was not a realistic option for general or routine application.

No equivalent developmental Excel version of *CAMAg* and its integration with *GENDEC* and *RothC* in the agricultural suite of models was created because the linkages in this integrated model would mirror those in the forest sector model being tested in *GRC3*. As the developmental work on linkages was not required specifically for the agricultural suite of models, and with the Excel based models being unsuited to general application, a decision was taken to move directly to the C code based application of the agricultural component of *FullCAM*. This is far more efficient and transportable (e.g., Mac, PC or Unix environments), and is capable of continental scale spatial application.

Figure 1. Overview of the *FullCAM* model

MODEL CALIBRATION

FullCAM provides a mix of accounting tools and empirical and process modelling. Many of the options are at the discretion of the user and reflect management decisions, such as forest harvest and ploughing. A further set of required inputs, particularly in *CAMFor* and *CAMAg*, determine the empirical rates of transfer between pools or to the atmosphere. Unlike the ‘process’ elements of the model, these components need to be user-defined, based on rates determined from sources such as field trial, literature or third party models.

The final components of the model are the process elements, generally contained within the *3PG*, *GENDEC* and *Roth C* model components. The distinguishing feature of the process and empirical components is that the empirical rates are static in that they do not respond to changes in environment. Each of the process components of the model (*3PG*, *GENDEC* and *Roth C*) are dependent on inputs such as temperature and rainfall in various ways.

Soil Carbon

Agricultural Soils

One of the most significant calibration exercises being pursued is that for the *Roth C* model in land clearing systems. A full description of this exercise can be found in the NCAS Technical Report No. 2 (Webbnet, 1999) and Swift and Skjemstad (1999).

The calibration (as opposed to preparing data inputs) is concentrated around defining the various soil fractions, and determination of rates of decomposition under a range of climates, soil types and management actions. Model calibration is largely provided for through a series of chronosequence paired sites and through changes measured in long-term field trials. Paired sites, independent of the calibration sites, are also being used to verify modelled results. There are a range of projects in place for the calibration and verification of the model. This includes approximately 70 new paired sites, sampled according to a standardised protocol (McKenzie *et. al.* 2000).

In addition to the soil pairs, soil fractionation is required to establish the inert, resistant and decomposable fractions of various soils. This project involves the analysis of soil samples from a variety of Commonwealth and State soil archives.

Related projects include the development of correction factors to standardise data to a single analytic method. The standard chosen for this project is the LECO dry combustion method. The results of this project are reported in the NCAS Technical Report No. 15 (Skjemstad *et. al.*, 2000).

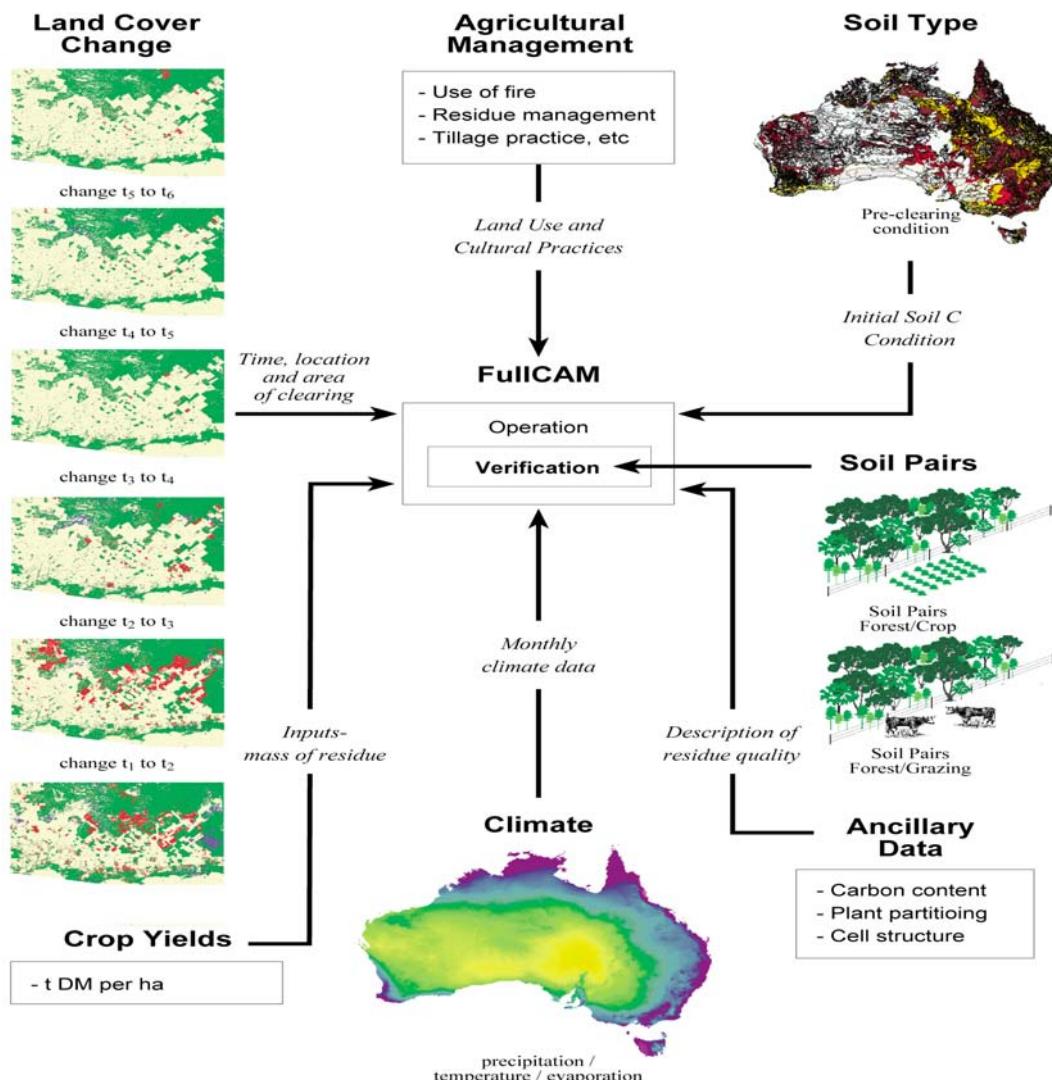
Pre-clearing (initial) soil carbon condition is also a required model input. To obtain this, an extensive program involving various State and Territory Governments was coordinated by Webbnets Land Resource Services Pty Ltd for NCAS Technical Report No. 12 (Webbnets, in prep). The best available soil landscape units were mapped and attributed with the pre-clearing soil carbon condition according to the best available soil carbon data, supplemented with expert judgement to infer across soil types where no data is available.

Various management actions are applied post land clearing and this is often closely related to soil type and climate. Acting for the NCAS, CSIRO Land and Water, through a variety of agents dispersed through the States and Territories, prepared a detailed report on the management actions (type and preparation) applied to various soil types for each land use within each Interim Biogeographic Regions of Australia (IBRA) (Thackway and Cresswell, 1995) over time intervals between 1970–2000 (Swift and Skjemstad, 2001).

This survey work by Swift and Skjemstad included estimates of the residue inputs for each activity over time. However, little information on pasture production was provided in this report and further yield modelling, plus the collection of yield data, will be carried out for the NCAS by CSIRO Sustainable Ecosystems using the *APSIM* model.

To provide climate data for a fine scale spatial operation of the *Roth C* model, monthly rainfall and temperature surfaces for the continent are being prepared. These monthly surfaces will cover the years 1970–2000 and be derived using the *ANUCLIM* software (McMahon *et. al.*, 1995)

The enormity of the information management task involved in presenting this data to a spatial model led to the development of the *CAMAg* component of the *FullCAM* model. The spatial components of the input data, rainfall, temperature, pre-clearing soils carbon condition can be automatically extracted as relevant to a particular grid. However, yield and management tabular information will need to be assigned according to a series of ‘rules’ to allocate various actions such as ploughing.

Figure 2. The Agricultural Soil Carbon Program

A series of long-term and **Soil Paired** sites will be used in model calibration and verification. The **Land-Cover-Change** results will provide the time, location and area of clearing. The 'initial' soil carbon description for that location will be drawn from the **Soil Type Pre-clearing Condition** map. Monthly climate data/rainfall, temperature and evaporation will be extracted from **Climate** surfaces. Residue inputs will be estimated from modelled or measured **Crop Yields**. **Agricultural Management** information will be drawn from the tables of the NCAS land use and management survey. **Ancillary Data** such as carbon content, plant partitions, etc., will be drawn from a variety of sources. The FullCAM modules of CAMAg and RothC will be used in conjunction to model carbon budgets at a 1ha resolution, extracting information from the above-mentioned surfaces and tables relevant to each 1ha grid within a model run.

Forest Soils

A program has also been developed for the modelling of soil carbon change under afforestation, reforestation and forest management. Conceptually, the program has many similarities to the previously described land use change soils program, relying on measured changes in long-term trials or differences between paired sites to calibrate and verify model results. However, there are some significant differences brought about by a need to understand more about above- and below-ground

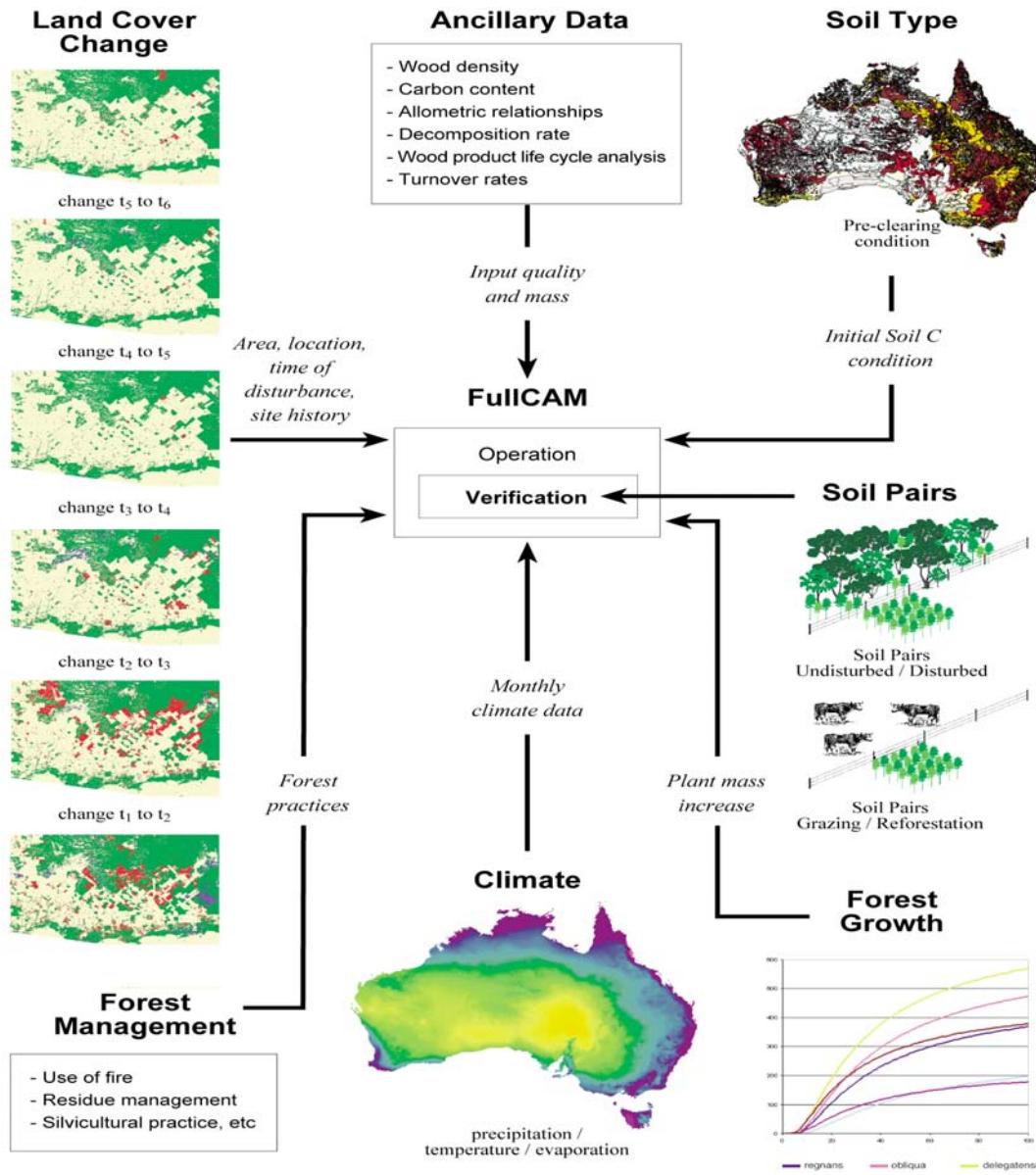
plant turnover (and the fate of each pool of material). These are far more difficult to quantify and there is a paucity of data compared to the residue estimation required for cropping systems.

Another complexity is the fact that afforestation and reforestation systems may have many years in a transitional state between the residual effect of the original crop or pasture system and the eventual tree system (Polglase et. al. 2000). *FullCAM* has been designed to operate parallel agricultural and forest versions of soils and decomposition models in conjunction with *CAMFor* and *CAMAg* to allow for the separate calibration of models for each type of system. The proportion of the ‘area’ designated for agricultural and forest inputs will be determined on the basis of percent canopy. Outputs will reflect the ‘lag’ in changed input regimes and will be the sum of carbon attributable to each system. The proposed forest soil carbon program contains elements that will detect, via isotope analysis, the components of soil carbon input from C3 and C4 plants (non-woody, woody) in a variety of transitional (afforestation and reforestation) systems.

The forest soils program also contains proposals to determine the decomposition characteristics of coarse and fine litter to calibrate and verify the *GENDEC* model across a range of systems. In addition, the project contains elements of physiological growth modelling in order to derive rates of turnover of above- and below-ground plant material. This work will be carried out using the *3PG* model component of *FullCAM*.

Access to a ‘whole-of-system’ model like *FullCAM* provides an opportunity to model changes in soil carbon from growth, through turnover and decomposition within the one framework. Much of the calibration data for models provides considerable additional information and already exists through other, related NCAS projects. For example, the land use change soils project will provide pre-clearing soil carbon contents and soil landscape mapping, the ‘condition’ of soil at the time of transition from agriculture to forest use, the soil fractionation and rainfall and temperature data.

Work has already been completed for the NCAS carbon contents (NCAS Technical Report No. 7; Gifford, 2000a) and on C:N ratios of a variety of forest materials (NCAS Technical Report No 22; Gifford, 2000b). NCAS Technical Report No. 6, (Mackensen and Bauhus, 1999) provides a state-of-knowledge assessment on the decomposition of coarse woody debris. A set of three NCAS Technical Reports No.s 5a, 5b and 17 (Eamus et. al., 2000; Keith et. al., 2000; Snowdon et. al., 2000) are studies on allometry that provide assessments of the allocation of mass to various tree components. When combined with information obtained from a detailed forest management practices study (eg., post harvest burn, wood chip) this information will be capable of determining the amount of material entering litter pools due to forest harvest activities. The *CAMFor* components of the *FullCAM* model will play a needed information management role capable of interfacing the tabular and formula based information, such as allometric equations, with the *GENDEC* and *Roth C* model components.

Figure 3: The Forest Soil Carbon Program

A series of long term and **Soil Paired** sites will be used in model calibration and verification. The **Land-Cover-Change** results will provide the area, location and timing of disturbances as well as site history. The 'initial' soil carbon description for the site will be drawn from the **Soil Type Pre-clearing Condition** map. Monthly climate data (rainfall, temperature and evaporation) will be extracted from **Climate** surfaces. Inputs will be determined via **Growth** estimates and turnover rates. **Forest Management** will be extracted from relevant NCAS surveys. **Ancillary Data** will be drawn from a number of sources. The FullCAM modules of CAMFor and Roth C will be used in conjunction to model carbon budgets at a 1ha resolution, extracting information from the above-mentioned surfaces and tables relevant to each 1ha grid in the model run.

The final required element for the use of FullCAM within the NCAS soils work is the timing of the activity. This information can be drawn from the NCAS multi-temporal land-cover-change

analyses. *FullCAM* will interface with the spatial layers (1ha grids) to determine the timing of afforestation, reforestation and deforestation events.

Biomass

As described in the approaches to biomass estimation for the NCAS (Richards, 2001) there are multiple constraints to consider in terms of accounting requirements. The following sections review approaches to data collation and collection and model calibration for the *FullCAM* model in response to this complex accounting requirement.

The most significant accounting requirement variation is that a continental account is the only requirement for the 1990 Baseline. This demands quite different data and methods from those used for the activity (project) scale accounting required post-1990. The following discussion describes the use of *FullCAM* as separate implementations for the 1990 and post-1990 accounting. Despite the differences in overall approach, there is much common data, and therefore considerable commonality in data sources and proposed programs.

Plantations

Carrying on from the work of the Forest Resources Committee (1989) the National Forest Inventory (NFI) has maintained a record of plantation areas by State (1995–99) and by region across State borders (1990–94). This record provides approximate age classes and areas of plantations from 1940. Since the work of the Forest Resources Committee, the record of plantation ages and areas (in total by region) has been maintained by periodic survey of public and private growers with estates of larger than 1,000ha. A report of these areas can be found in NFI (1997, 2000).

Turner and James (1997) developed indicative wood yield estimates for major plantation types and silvicultural regimes for each of the NFI's 14 regions. The AGO subsequently commissioned Turner and James (2001) to convert this information into current annual increments (CAI) for each possible permutation of plantation type, silvicultural regime and region. This included typical responses in growth and management to differing site qualities.

The indicative yields (CAI) of Turner and James (2001) and the age class and area data of the NFI were used as inputs to develop a national account for the plantation sector using the *CAMFor* (Excel version) of Richards and Evans (2000a), Brack and Richards (2001). This Excel version of the national account in *CAMFor* will be translated into the *CAMFor* component of *FullCAM* and provides the basis of a continental baseline estimate for 1990.

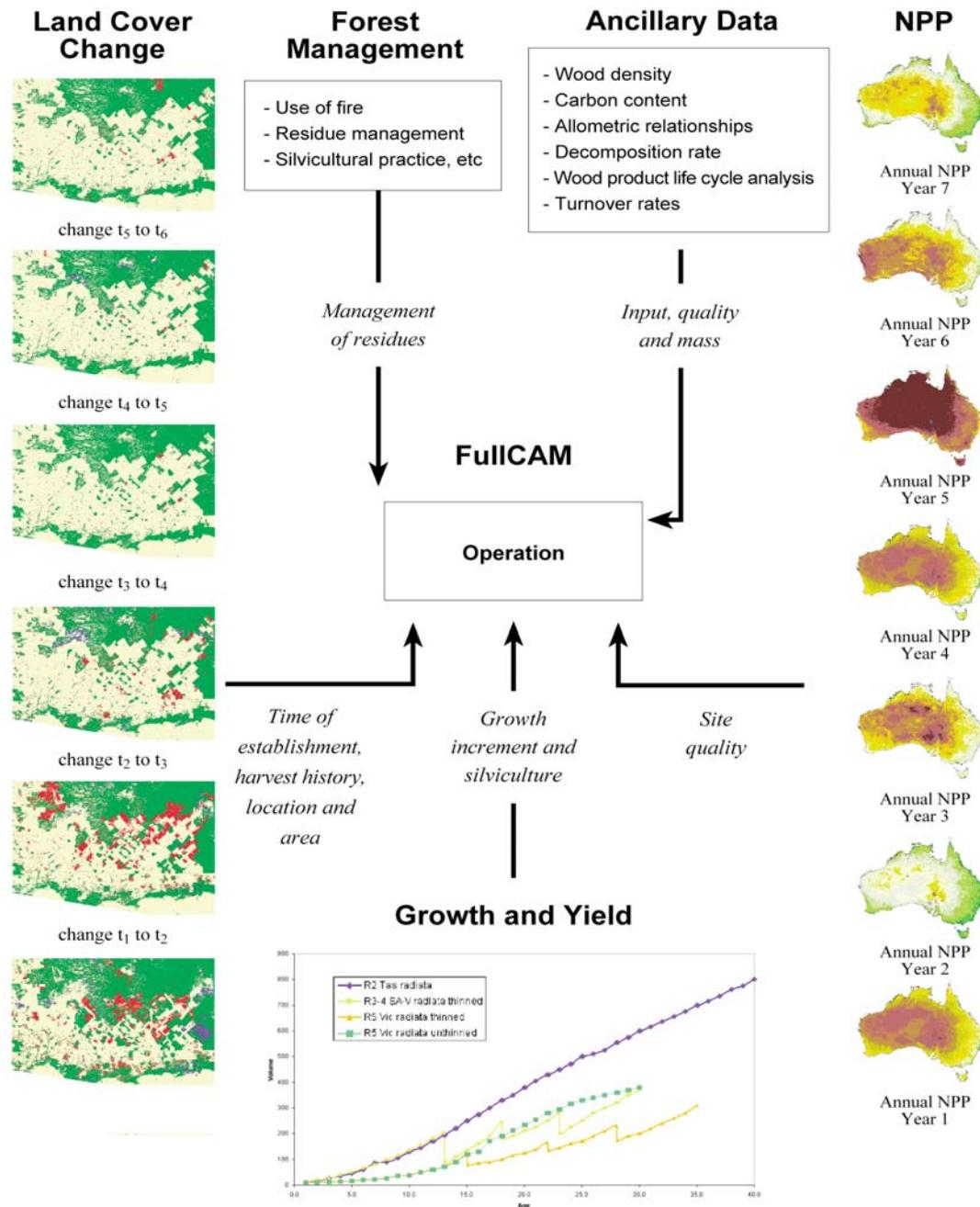
To develop this national model, considerable ancillary data, beyond that of age class, area, growth and silvicultural regime, is also required. Wood density information was drawn from the NCAS Technical Report No. 18 (Ilic *et. al.*, 2000) and carbon contents from the NCAS Technical Reports Nos. 7 and 22 (Gifford, 2000a and 2000b). Calculations for the ratios of commercial to non-commercial tree components were drawn from NCAS Technical Reports 5a, 5b and 17 (Eamus *et. al.*, 2000; Keith *et. al.*, 2000; Snowdon *et. al.*, 2000)

The *CAMFor* based analysis of Brack and Richards (2001) represents the integration of the best available national understanding and state of knowledge on allometry, wood density, growth, carbon contents, and age and area of plantations and their management.

The greatest uncertainty in the areas of established plantations lies in the non-commercial species and areas belonging to estates of less than 1000ha that have not been considered in the NFI. These are largely environmental and small commercial plantings that form only a small component of the total plantation area and are generally slower to accumulate carbon than commercial species. Regional sub-sampling of the establishment of non-commercial species will be extracted from the NCAS remote sensing multi-temporal land-cover-change analyses. This will provide the area and age of plantings in a range of systems. The limited contribution of these types of plantings to the

national carbon account, especially prior to 1990, would make full census (as opposed to sub-sampling) a potentially unnecessarily time consuming and expensive exercise (Turner *et. al.*, 1999). To provide more resolution in terms of age of planting and areas of planting than is currently available, the age and area of commercial species (mostly coniferous pre-1990) will be extracted from the land-cover-change analyses. When prepared this enhanced information can be used in the national forest model developed by Brack and Richards (2000).

Figure 4. The Plantations Program



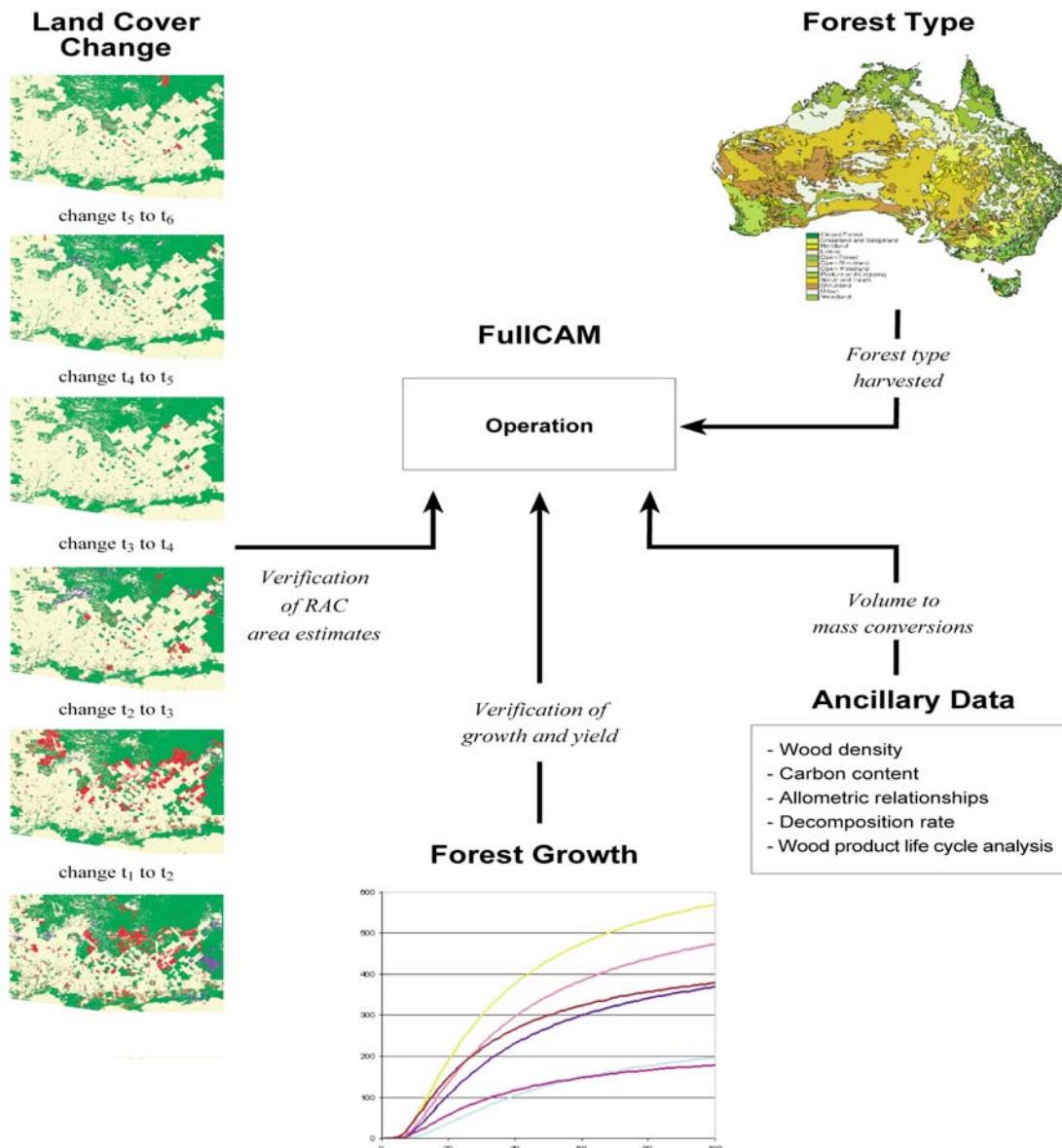
The time of establishment, harvest history, location and area can be taken from the **Land-Cover-Change** results. Relevant site quality can be taken from the long-term (250m) **NPP Surface**. **Growth and Yield** can be taken from the results of Turner and James (2000) and residue management from the **Forest Management** survey of the NCAS. **Ancillary Data** such as carbon content etc. can be drawn from a variety of sources. As soil carbon is not reported here, only the CAMFor module of FullCAM will be used.

Managed Native Forests

Much of Australia's knowledge of native forests and their management arises from the work of the Resource Assessment Commission's (RAC) Forest and Timber Inquiry (1991). This represented a major national undertaking in the collection and synthesis of forest related information. Work was largely completed between 1989 and 1991, with the publication of results in 1992.

Information of particular importance to carbon accounting includes the areas, harvest intensities and growth rates of various commercially exploited forest types in each State and Territory. This information from the RAC has been combined with the ancillary data extracted from the same sources as presented in the preceding discussion on plantations. The *CAMFor* model (in its Excel version) was again used by Brack and Richards (2001) as the accounting base. This information, as contained in the Excel version of *CAMFor*, will be transferred into *FullCAM* for future implementation and refinement.

Figure 5. The Managed Native Forests Program



The RAC area estimates can be verified by the **Land-Cover-Change** results. These areas by forest type can then be verified against forest type mapping such as the NVIS. **Forest Growth** estimates

contained in the RAC reporting can be verified against available growth models. Ancillary Data will be drawn from a variety of sources.

Land Clearing Biomass

The multi-temporal land-cover-change analyses currently being implemented by the NCAS will be able to identify the area, location and timing of clearing events between 1972 and 2000. To estimate the biomass at the time of clearing it is important to understand the rates of growth of various vegetation types in addition to the time of clearing and age since last disturbance or clearing.

The NCAS commissioned URS Consulting (with Landsberg Consulting) to identify and assess any available data on the growth in non-commercial species. Initially it was intended to consider the potential application of various stratifications and classifications into which to attribute generalised biomass increments. Surveys of experts quickly identified that site productivity, and not vegetation type, was the main determinant of rate of growth.

In a parallel project with URS (and Landsberg Consulting) and CSIRO (Drs Neil McKenzie and Nicholas Coops), the NCAS (through Dr Jenny Kesteven) undertook the development of a continental productivity surface (Landsberg and Kesteven, 2001) to test the possible derivation of spatial strata to guide the estimation or attribution of growth rates to various regions. The development of this productivity surface also allows for the application of techniques such as multi-phase sampling for the estimation of biomass at fine grid scales. This provides an alternate approach should spatial variability prove confounding to logical stratification and, therefore, to reliable stratified random or set grid sampling. The results of tests of spatial variability showed productivity to be highly variable over short distances. This spatial variability, combined with variability introduced by disturbance suggests the use of a multi-phase, continuous variable approach is required.

The potential stratifications tested for their utility were the Interim Biogeographic Regionalisation of Thackway and Cresswell (1995) and the Carnahan Vegetation Map (AUSLIG, 1990). In both instances it was found that the variation within strata was large enough that it would not be feasible to sample (for total biomass) enough sites to provide for a rigorous sample approach that was capable of removal of potential error introduced by undersampling or bias by, for example, selective sampling of the more productive components.

Following on from these findings the NCAS convened an experts workshop to consider other potential means of stratification at a finer scale and potentially more homogenous than those tested previously. A preference for a stratification based on vegetation structure, as the surrogate for total biomass, was put to the workshop.

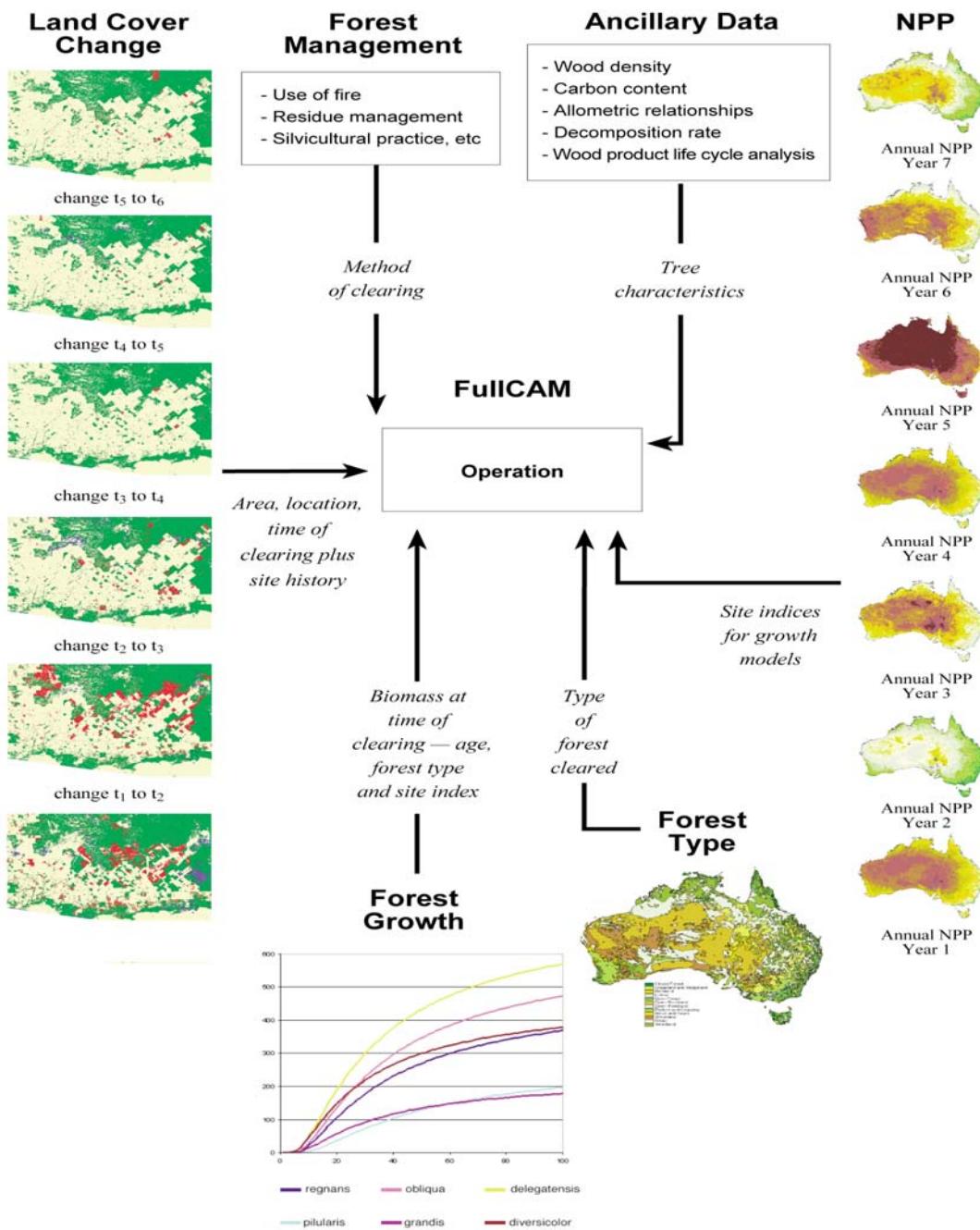
The workshop, with a mix of expertise in remote sensing and inventory design among participants recommended that, in the absence of techniques to provide a consistent and relevant continental stratification in the short to medium term that would enhance existing stratifications, the NCAS adopt a multi-phase approach to biomass estimation. Multi-phase sampling represents a major departure from the stratified random sample approaches previously envisaged for use in the NCAS. It is a move away from the large forest inventory datasets (usually limited to merchantable volume and therefore requiring variable corrections to total biomass which introduces potentially significant bias), generally compiled via random sampling, to fewer high quality total biomass measures. It also provides a significant step forward in the spatial application of *FullCAM*, as both disturbance history and biomass estimation can be extracted from high resolution spatial surfaces.

In response to the need for a grid-based continuous value productivity surface for multi-phase sampling, the NCAS has undertaken the development of a fine scale (250m) productivity grid. Unlike the 1km grid used in the initial analysis, which showed no response to slope and aspect correction for incoming solar radiation, it was presumed that slope and aspect correction is relevant on the finer 250m grid and a slope and aspect correction for solar radiation has been applied.

In multi-phase sampling, known reliable measures of total biomass can be located against known site values (of a continuous value variable) on the productivity surface. Through spatial regression techniques, it is possible to 'correct' the continuous index of productivity values across the entire surface against the known measures of biomass. Using this method, corrected indices of productivity can be developed for 'mature' forest systems. The age classes of sample locations are available from the NCAS multi-temporal land-cover-change program.

The availability of total biomass estimates across all woody vegetation systems, and the need for and potential to derive new total biomass estimates, was the subject of a further expert workshop and a program of recommended activities was derived (see Raison, 2001).

The age and intensity of disturbance can be extracted from the land-cover-change record and rates of regrowth can be derived using the productivity surface as described for regrowth forests. Appropriate growth equations, such as those of West and Mattay (1993) for regrowth forests, would need to be developed. These could be based on long-term permanent plots with known histories and calibrated against the land-cover-change record and the productivity surfaces.

Figure 6. The Land Clearing Biomass Program

The **Land-Cover-Change** results can be used to identify the area, location and time of clearing as well as the disturbance history (which will give age of forest). The **Forest Type** can be used to select the appropriate **Forest Growth** model, which can be used to make a biomass estimate given age and site index (NPP). **Ancillary Data** can be drawn from a variety of sources, while **Forest Management** information is needed on method clearing, use of fire, etc.

One of the main advantages of the use of a multi-phase sample approach is that modelling is carried out directly on total biomass and is not reliant on the potentially variable conversions from the merchantable volume or single tree measures to estimation of site (stand) based total biomass. Such conversions are much more variable than even those of total stem volume to total mass. The

approach can also be extended across all forest systems, independent of vegetation type, whereas forest inventory information is likely to only be capable of sustaining commercial forest activity. This approach to biomass estimation is also independent of commercially sensitive merchantable volume estimates, which are required if an approach based on forest inventories is used.

Confirmation of the ability to apply multi-phase sampling across differing tenures (presumed to have different management regimes applied) was required. The effect of tenure on total biomass (through total volume) was tested by Brack (2001) using the Tasmania PI typing (Stone, 1998), which uses air photographs to stratify forest condition and inventory information on total volume from inventories of private and public forests. From the results of this work, Brack (2001) found that, while merchantable volumes vary by tenure, this variation could not be established for total volume. He concluded that the crown cover and height of the dominant eucalypts explained the majority of the variation in total volume, whereas tenure made no consistent difference.

The likely explanations for this are that there is a higher proportion of 'defect' trees in the private estate and that total biomass is determined by site productivity and not by management or disturbance (which is likely to vary by tenure). While management and disturbance may cause massive changes in wood quality, they do not impact on total stand stem volume and thus the manner in which crown and height is achieved. Because total biomass is largely unaffected by land use, multi-phase sampling can be applied independent of tenure. This is particularly significant given that inventory information for verification purposes on private tenures is very limited.

Key areas of improvement to enhance the current application of this approach to biomass estimation accounting for land use change are to:

- refine the modelling of plantations and native forests in *FullCAM* through improved inputs of allometry, density, carbon content, turnover etc.;
- assemble relevant total biomass data for multi-phase sampling and implement the proposed biomass sample program; and
- refine the 250m grid resolution productivity surfaces.

Additional work underway within the NCAS will also be useful in informing these approaches. These projects include:

- the development of a standardised protocol for the destructive sampling of biomass used to develop total biomass estimates; and
- descriptions of the management practices applied to various harvest and forest types since the 1950s.

Total biomass measures will also need to consider non-tree biomass in undergrowth. As suggested in the NCAS biomass sampling program, there is a need to develop appropriate correction factors to account for undergrowth components. Different corrections will need to be applied according to situation, which is likely to be defined by vegetation structure.

Forest floor litter can also represent a significant store of carbon. Litter generation, as post-harvest slash, depends on ratios of merchantable to non-merchantable material within harvested trees. Merchantable to non-merchantable ratios at the tree level are available for a range of forest systems.

Litter inputs arising from both tree mortality and branch and leaf turnover could, with the development of physiological growth models, be estimated. However, in the short term, coarse litter estimates will need to be derived according to survey of on-site litter masses and the application of empirical decay functions derived from chronosequence studies such as that of Mackensen and Bauhus (1999). More commonly, estimates of fine litter input and decomposition rates are made and these should be available.

As reported by Turner *et. al.* (1999), fuelwood is extracted from both private and public forests, and from scattered trees on agricultural land. This is likely to be a minor amount of material, almost always taken from already dead trees, thereby effectively only increasing the rate of decomposition through combustion. The suggested approach of Turner *et. al.*, of survey of fuelwood merchants, is likely the most effective method of addressing this issue.

Grazing Lands

The accounting for carbon change in woody vegetation in grazing lands (the grazed woodlands) needs to be able to identify both the agent of change and impact of change. It is useful to consider the points in terms of Articles 3.3 and 3.4 of the Kyoto Protocol. Under Article 3.3, change crosses a threshold which defines the condition describing forest or non-forest systems. These are the deforestation (clearing or re-clearing), afforestation and reforestation (establishment of a forest) events.

Article 3.4 does not require that a change (movement over a threshold) occurs, and considers the variability in a forest that remains a forest. Article 3.3 therefore tracks the change in carbon stock associated with a movement over a threshold definition of a forest, whereas Article 3.4 tracks changes in carbon stock within a system defined as a forest.

For woodland systems, the determination of ‘causes’ of afforestation, reforestation or deforestation as an initial ‘trigger’ activity to bring an area of land into the accounting framework is readily achievable from the multi-temporal land-cover-change program. As ‘fire’ events can also be readily identified, it will be possible to segregate this ‘natural’ cause of change from land clearing events. Regrowth post-clearing can be identified and, if the land is within the accounting framework, can be attributed to a change in biomass carbon. Two methods, using canopy- or age-based models, are feasible for the allocation of growth increment related models. However, early saturation of cover, at maximum detectable limits, means that this canopy based method is only appropriate for detection in early years.

The preferred approach is to use the multi-phase biomass sample for ‘mature’ systems to cap a maximum biomass capacity, and to then ‘grow’ the forest using age based growth trajectories with site indices determined from the annual productivity layers. This would require the use of site indice based growth equations with age determined from the multi-temporal land-cover-change analyses. To deal with incremental change (aggradation and degradation) from major identifiable disturbance it would be possible to establish canopy to mass relationships (which appear to be reasonable for sparse tree systems) and to then proportionally adjust the mass estimate. This adjustment is a relatively simplistic in approach but, with a better understanding of stand dynamics (their causes and impact on carbon density), it could be upgraded to respond to changes due to mortality, recruitment and tree ‘soundness’.

Wood Products

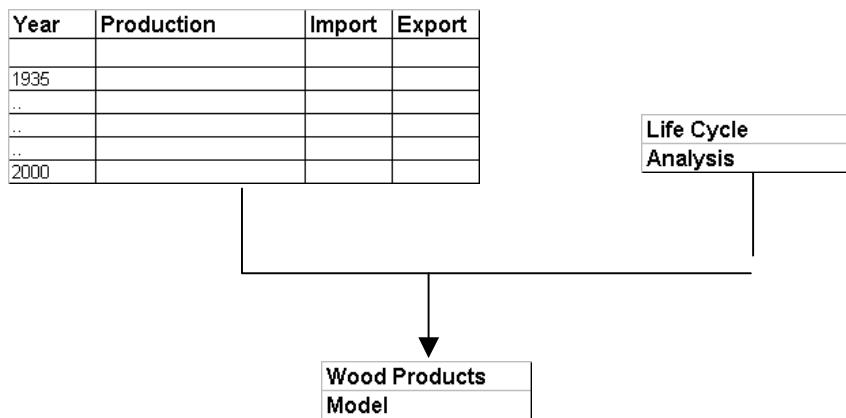
In 1999 the NCAS commissioned Jaakko Pöyry to prepare a life cycle analysis of the Australian wood products sector (Jaakko Pöyry, 1999). This initial report considered only the 1998 wood product profile and provided the basis for further development of a time series wood products model. Later work between the NCAS and Jaakko Pöyry (Jaakko Pöyry, 2000) incorporated forest production data since 1944 into the life cycle analysis. This production data has been continuously and consistently collected and is currently maintained by the Australian Bureau of Agricultural and Resource Economics (ABARE, 2000). The data includes domestic production and import and export quantities.

The NCAS Wood Products Model, jointly developed by the NCAS and Jaakko Pöyry is a part of work investigating differing accounting options in the treatment of imported and exported materials. It is now a flexible and best practice model for the carbon accounting of wood products, constructed as a transparent sheet based and formula driven (no macros) Microsoft Excel spreadsheet model.

Along with the published input data, life cycle analysis and report on model development, the model provides a robust and transparent approach to accounting for wood products at a national level.

The life cycle analysis has been adapted to the *FullCAM* model wood products accounting component to provide mechanisms for wood product accounting at a project scale.

Figure 7. Wood Products

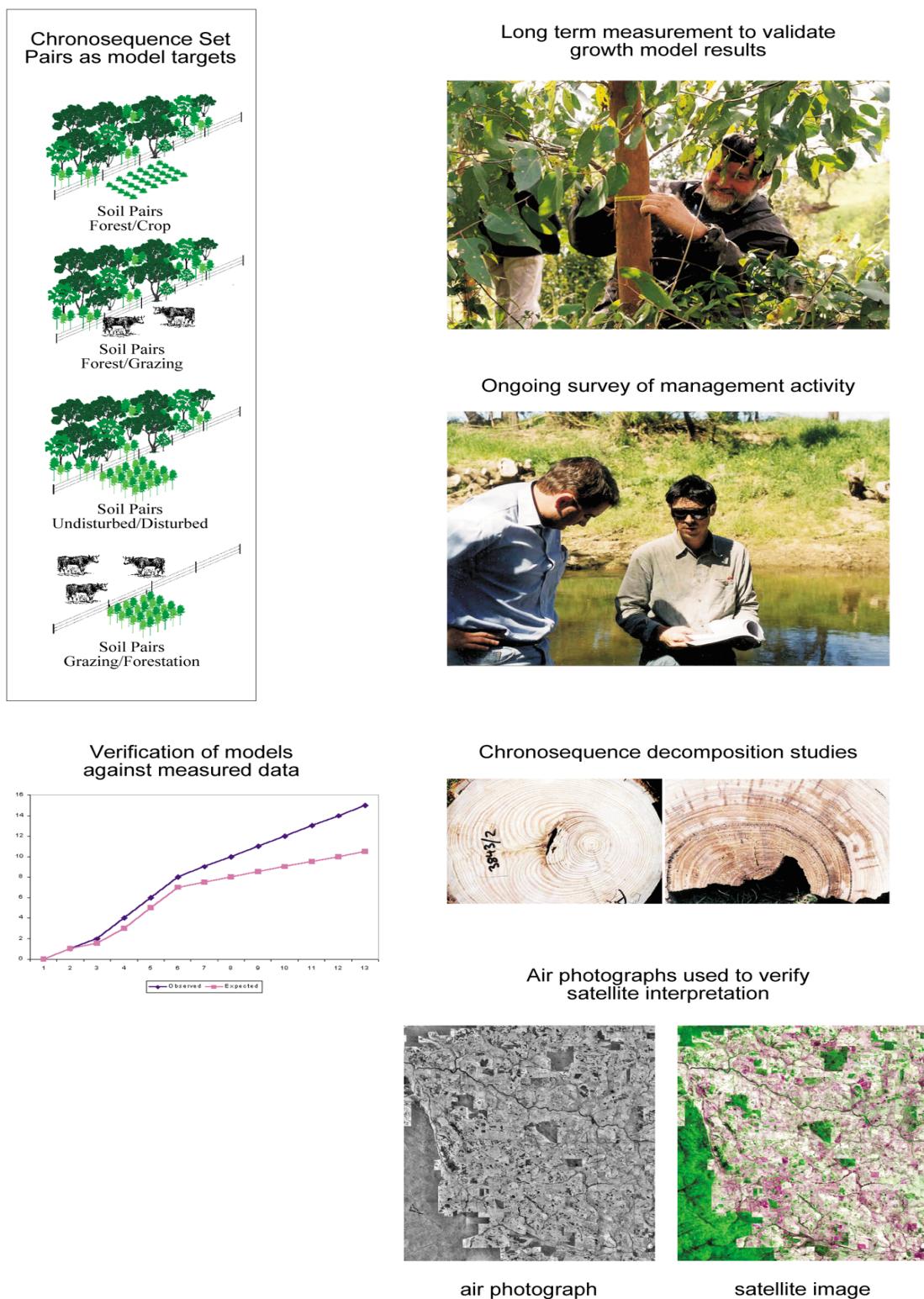


MODEL VERIFICATION

Programs undertaken for model verification are largely independent replicates of programs undertaken for model calibration. The principal difference between calibration and verification is that the ongoing verification can draw information from long-term (permanent) plots, either established or adopted as part of the program. Calibration, on the other hand, has been largely restricted to previously available, long-term and paired, chronosequence studies. Data used for model verification will be completely independent of that used for model calibration.

The various verification activities include permanent plot, long-term trials with internal measurement, landholder survey, ongoing chronosequence pairs activity, and comparison with other reliable, independent methods and models.

Any verification sites or data that may in future be used in model calibration or operation will be deleted as part of verification activities. Thus, the ongoing monitoring activities of the operational program will be able to use the verification sites and data as properly independent tests.

Figure 8. Verification Activities

CONCLUSIONS

To meet its objective of providing a comprehensive carbon accounting and projections capacity for land based activities, the National Carbon Accounting System has required the strategic development of several key datasets and modelling and accounting tools. Early reviews made it clear that approaches based on measurement were infeasible and that the calibration of relevant models would be required.

A series of programs were put in place to provide the input data and model calibration and verification to support fine resolution national scale accounting. These programs have been largely independent, although the need to integrate an overall information system was recognised (NCAS Technical Report No. 21, 2000a).

The development of the integrated *FullCAM* model has furthered this synthesis by providing an ability to operate a singular centralised model. This avoids the potential for errors of omission or double counting that could arise from multiple carbon pools and transfers being accounted for independently and subsequently summed, with little opportunity for reconciliation across or between pools.

FullCAM provides the capacity for national scale modelling at a fine spatial resolution (grids) of 1 hectare. Prior to the development of *FullCAM* it was anticipated that the NCAS would operate on a series of regional strata with a set of conditions derived by the intersects of layers of spatial data. The ensuing array of conditions and polygons defined by the intersects would then have been allocated a 'best-fit' time course of carbon change from look-up tables of pre-derived model results.

This initially envisaged approach relied on the use of averaged model inputs (conditions) over both space and time. Testing indicated that there was likely to be both a loss of resolution through averaging data and potential for 'spurious' results formed by the unrealistic arrays of conditions generated by averaging the data. This highlighted the need for an integrated model framework capable of operation at a fine grid scale, and accelerated need for the development of the *FullCAM* model.

While the approach taken in *FullCAM* relies on data of mixed resolutions, the use of such a comprehensive framework allows for strategic testing of potential improvements and development of finer resolution inputs in various data elements.

However, probably the most significant impact of *FullCAM* is that it allows for an ongoing evolution in the quality of any data inputs, be they for future accounting periods or improvements in fundamental input data or model calibration. Such ongoing improvements were not as readily made under the regional approaches envisaged formerly.

FullCAM also provides for greater responsiveness to the various reporting demands under the Kyoto Protocol. The fine spatial resolution, activity-driven and time-based modelling provides a capacity to report at both project and continental scales, in response to specific activities, and with sensitivity to the timing of an activity.

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Development of a ‘Toolbox’ for Carbon Accounting in Forests

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ABSTRACT

The National Carbon Accounting System (NCAS) of the Australian Greenhouse Office has joined with CSIRO and the Australian National University’s Department of Forestry to prepare a ‘toolbox’ for carbon accounting in forests. The toolbox will represent an evolving ‘best practice’ approach and available data and will be made available as a public domain product.

The central carbon accounting model will be the *CAMFor* (carbon accounting model for forests of Richards and Evans 2000). Much of the data needed to operate the model has been collected for the NCAS and is reported in the NCAS Technical Report Series. As a part of the development of the toolbox this information will be extracted and placed into a single compendium default data table.

Other elements of the toolbox will include descriptions of appropriate methods for the gathering and analysis of field data. These measurement guides have largely been completed as agreed protocols and have been published in the NCAS Technical Report Series. The final element of the toolbox will describe appropriate methods for risk and uncertainty analysis.

Risk and Uncertainty in a Forest Carbon Sequestration Project

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PowerPoint presentation: [www.joanneum.at/iea-bioenergy task38/workshop/canberradata/brack.ppt](http://www.joanneum.at/iea-bioenergy/task38/workshop/canberradata/brack.ppt)

ABSTRACT

The prediction of the quantity of carbon sequestered during the Kyoto Commitment Period (2008-2012) is subject to uncertainty and risk. This presentation uses CAMFor to model the sensitivity of the estimated sequestration of carbon to uncertainties in growth models, relative allocation of biomass increment, weather, decay of litter, debris and soil carbon, and harvesting of wood products. The uncertainty in wood density, equations used to predict tree growth and in the expected weather are shown to be highly influential in the uncertainty of the overall estimate of sequestration. Uncertainties in the relative allocation to leaves, twigs and bark are shown to be less important. Management decisions on the intensity and timing of harvesting and establishment regimes are subject to risk as they depend on political and unpredictable considerations. The decision to harvest or not will introduce more variance into the prediction of carbon sequestration than does the uncertainty that surrounds the estimates of weather and model estimates.

Keywords: Carbon sequestration, sensitivity, risk, carbon accounting model, Kyoto Commitment Period

INTRODUCTION

Commercial organisations are increasingly interested in potential investment in forest plantations as a means of offsetting carbon emissions. These investors need to weigh up the potential value of future carbon credits and other products against the cost of plantation establishment and maintenance. However there are uncertainties and risks associated with the estimation of the quantity of carbon sequestered in a plantation and these need to be considered before optimal investment decisions can be made.

Risks in carbon estimation are introduced by sampling errors around inputs, coefficients and model parameters - multiple estimates around the 'true' value with known (or reasonable) probability density functions. Uncertainties on the other hand, include an unknown range of outcomes for which there is no reliable probability density function. Uncertainty is introduced into investment decisions from external sources, like changes in the desired state or in the specifications of returns, new management orientation or the preference function. These changes do have probability functions associated with them.

An estimate of the quantity of carbon sequestered during the first Kyoto commitment period (2008 - 2012) incorporates a number of sources of risk and uncertainty. These sources may impact directly and indirectly on the estimates as they interact with each other. The uncertainty is extremely difficult to quantify and investors often try to minimise potential impact by diversifying to cover a range of preference functions. Simulation models, incorporating the best probability density functions and interactions available, are commonly used to investigate the impact of risk on investment decisions. This presentation summarises the derivation of appropriate probability density functions, sources of risk, and a sensitivity analysis model for estimating carbon sequestration in the first Kyoto commitment period.

METHOD

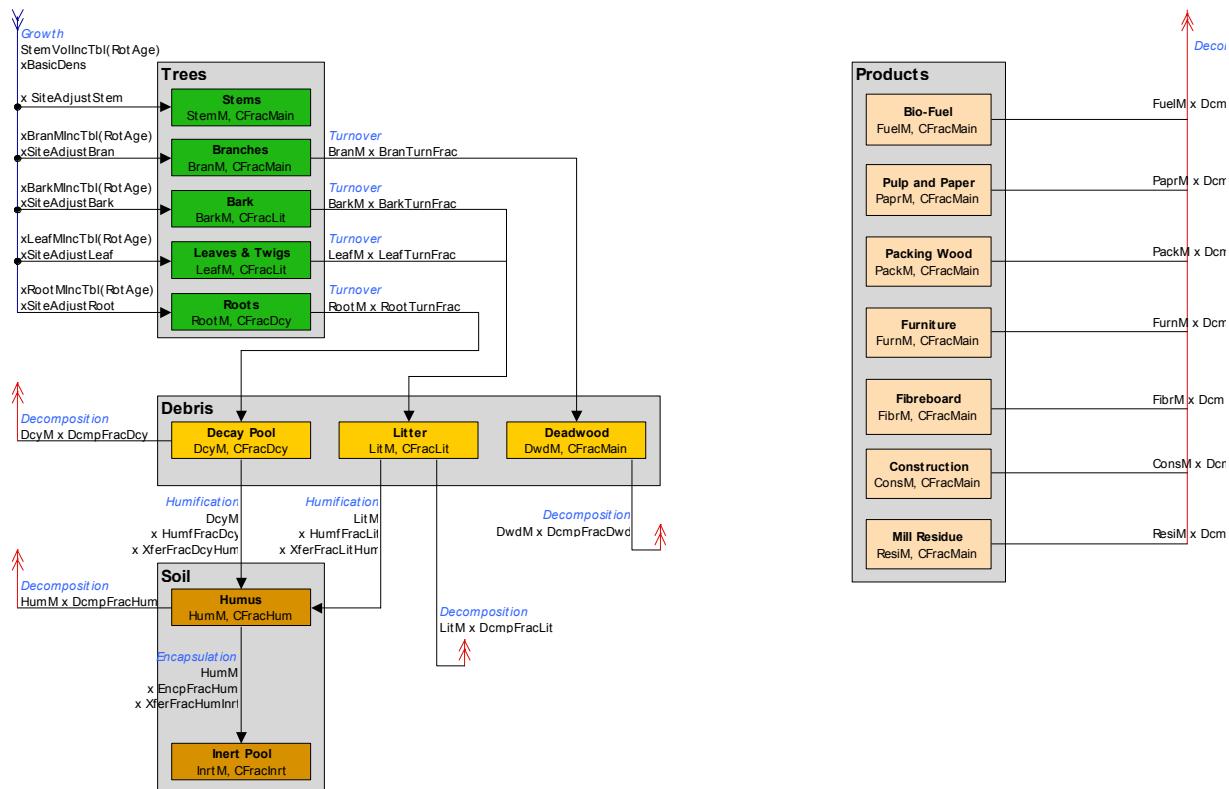
CAMFor - Carbon Account Modelling for Forests - developed by Richards and Evans (2000) was used to provide the sensitivity model framework. CAMFor tracks carbon equivalents in and through various pools on an annual basis:

- Biomass (stem wood, branches, bark, fine and coarse roots, leaves and twigs)
- Soil (active humus and inert charcoal)
- Debris pool (coarse and fine litter, below ground dead material)
- Products (dead wood, sawn timber, paper, biofuel, reconstituted wood products)

The user provides an estimate of the current annual increment (CAI) and the relative distribution of this increment to the stem wood, branches, etc. This is most commonly achieved by a predictive model of the annual stem-wood growth in volume and a series of coefficients and ratios to convert volume into carbon mass and relative growth of the other biomass pool components. Transfer or turnover of the carbon between the various biomass pools and the soil, debris, product pools and atmosphere is modelled by user nominated ratios that reflect death, decay, fire and product harvest (Figure 1). The pools and transfers can be tracked through thinnings, multiple rotations and fires.

Best estimates of the CAI, conversion and turnover coefficients for a medium site quality plantation of *Eucalyptus grandis* (flooded gum) were drawn from the literature. Realistic probability density functions and correlations were also drawn from the literature and the author's experience as the basis for the sensitivity analysis. These probability density functions were embedded into the CAMFor spreadsheet using @Risk probability density variables (Palasade Corporation, 1997).

Figure 1: Schematic of CAMFor



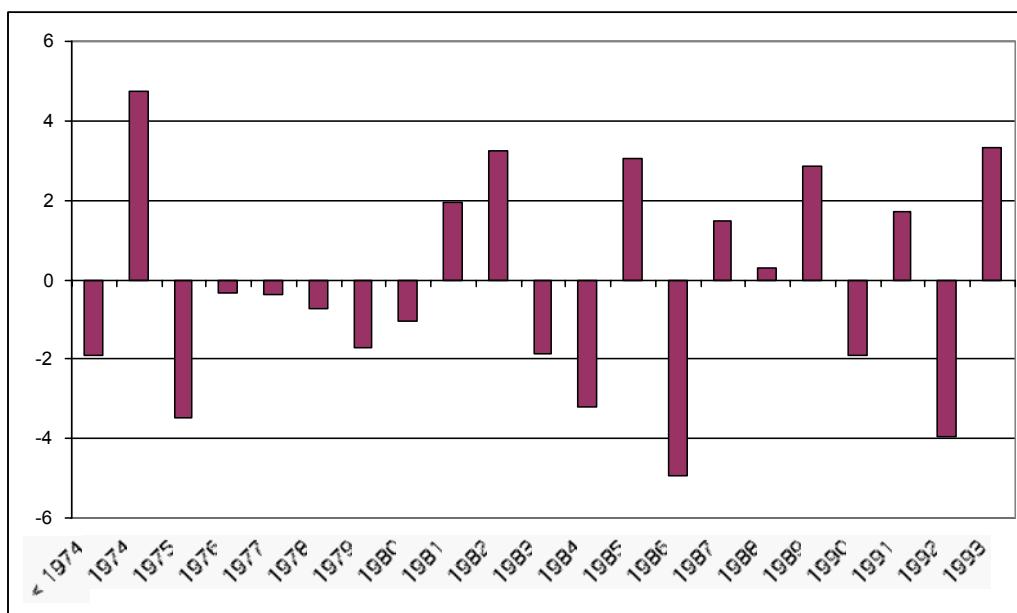
STEM-WOOD INCREMENT

The CAI (m³/ha/yr) for the stem-wood increment of initial or base model was based on the growth model developed by West (1999). It was assumed that this model was an unbiased estimator of the stem volume growth for a medium site quality over a full rotation of 30 years.

Sensitivity to the correct determination of site quality and growth model parameter estimation was modelled through the introduction of six @Risk probability density variables - model-1991, -1996, -2001, -2006, -2011 and -2016. The model1991 correction was applied to the 5 years of growth between 1991 and 1995, model1996 the next 5-years, etc. These variables were defined as a triangular probability density function with minima and maxima estimated as the ratio of average growth between a medium site quality plantation and a plantation of the same age but one site quality class lower or higher.

Temporal variations, for example caused by patterns in the weather, could cause a model to have localised bias and imprecision even though the overall rotation estimates were unbiased and relatively precise. An examination of the differences between the modelled growth and inventory-based estimates of change for Pinus plantations in NSW between 1974 and 1993 demonstrated these localised problems (Figure 2). For any 5-year period, the coefficient of variation for the difference between the modelled and the inventory-estimate of growth was about 18%. However there was a consistent pattern in the localised bias for these 5-year intervals - if one 5-year period grew below the average modelled increment, then the next 5-year period was likely to grow at above the average. To model this variation, six @Risk probability density variables - weather-1991, -1996, -2001, -2006, -2011 and -2016 - were developed. These variables were used as multipliers to the base model for consecutive 5-year periods. They were defined as being normally distributed around 1.0 with a CV of 18%. Every second variable was also weakly and negatively correlated with the preceding variable, thus an overestimate in the first period would be 'balanced' by an underestimate in the next period.

Figure 2 Differences between model-based prediction of growth and change in sampled inventory demonstrating localised bias and imprecision.

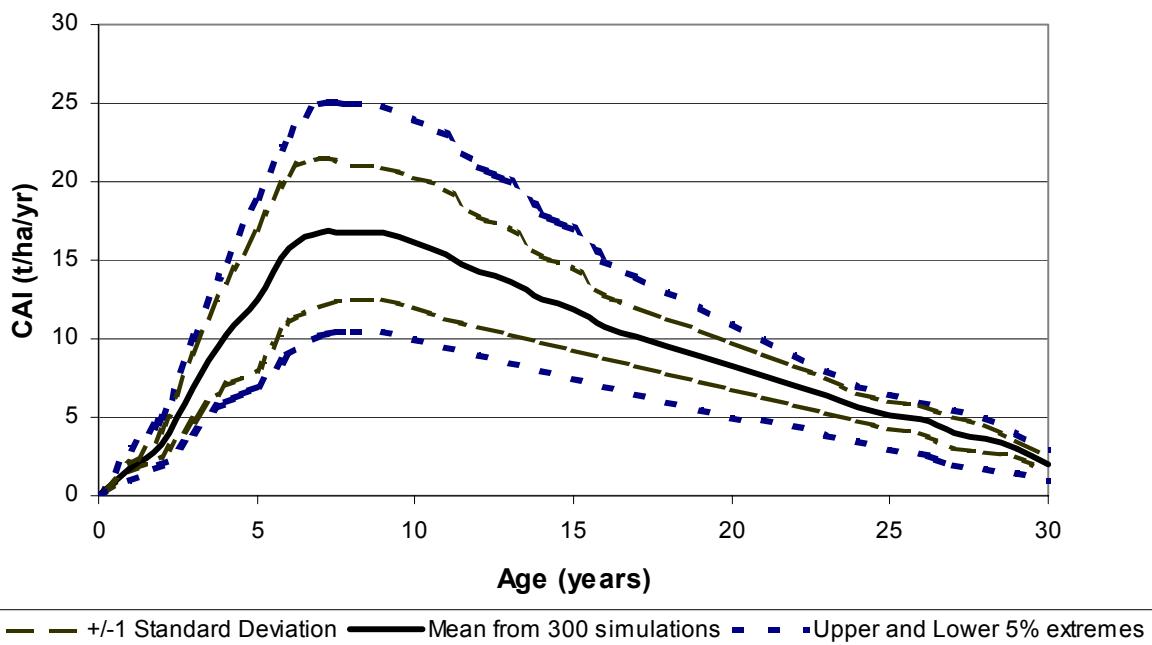


Density and Carbon Content

Base-case density data for plantation grown *E. grandis*, provided by State Forests of NSW, is 500 kg / m³. Greenhill and Dadswell (1940) indicate that the CV% in density across stands is in the order of 11%. Therefore density sensitivity is modelled by an @Risk variable - Density - with a normal distribution, mean of 500.0 and a standard deviation of 56. This analysis assumes variation in carbon content within the biomass is incorporated in the density variation.

Figure 3 summarises the mean and sensitivity range for the annual increment of stem-wood mass of the representative *E. grandis* plantation.

Figure 3: Annual increment in stem-wood mass (and sensitivity range) modelled *E. grandis* plantation.



Allocation of biomass between pools

Allocation of growth to branches, bark, twigs, leaves and roots (fraction increase relative to stem increase) was based on data derived from coefficients used in CO2Fix (Mohren et al 1990). These fractions were ratio adjusted so that the derived expansion factor (total above ground mass divided by stem mass) and root:shoot ratios agreed with the mean values reported by Snowdon et al (2000). The @Risk variables for modelling were modelled iteratively using variables - Expansion1991 - Expansion2016 and Root1991 - Roots2016 - that adjusted the allocation in 5-year periods for the above- and below- ground components respectively. The @Risk variables were defined as a triangular distribution with mean of 1.0 and minimum and maximum iteratively selected to mimic the range of expansion and root:shoot values reported by Snowdon et al (2000) (Figures 4 and 5). The distributions are weakly correlated with the corresponding weather variable when the weather distribution indicates above average stem growth, there is also likely to be above average growth of leaves, twigs and bark, but a below average growth of roots.

Figure 4: Expansion factors (and sensitivity range) modelled from CAMFor allocation and @Risk variables

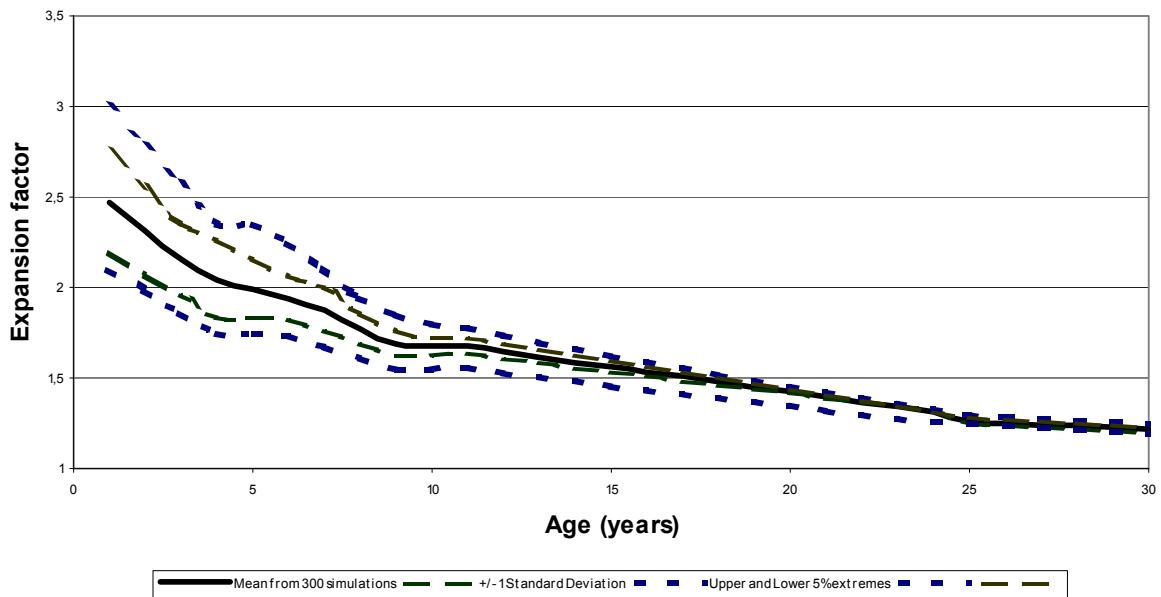
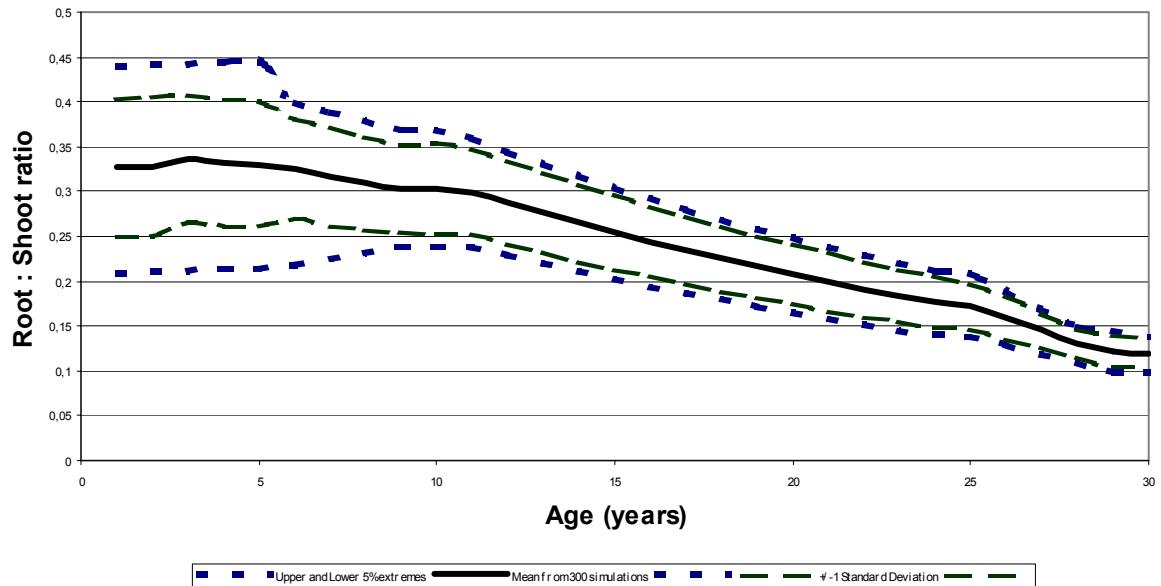


Figure 5: Root:Shoot ratios (and sensitivity range) modelled from CAMFor allocation and @Risk variables.



Soil carbon pool

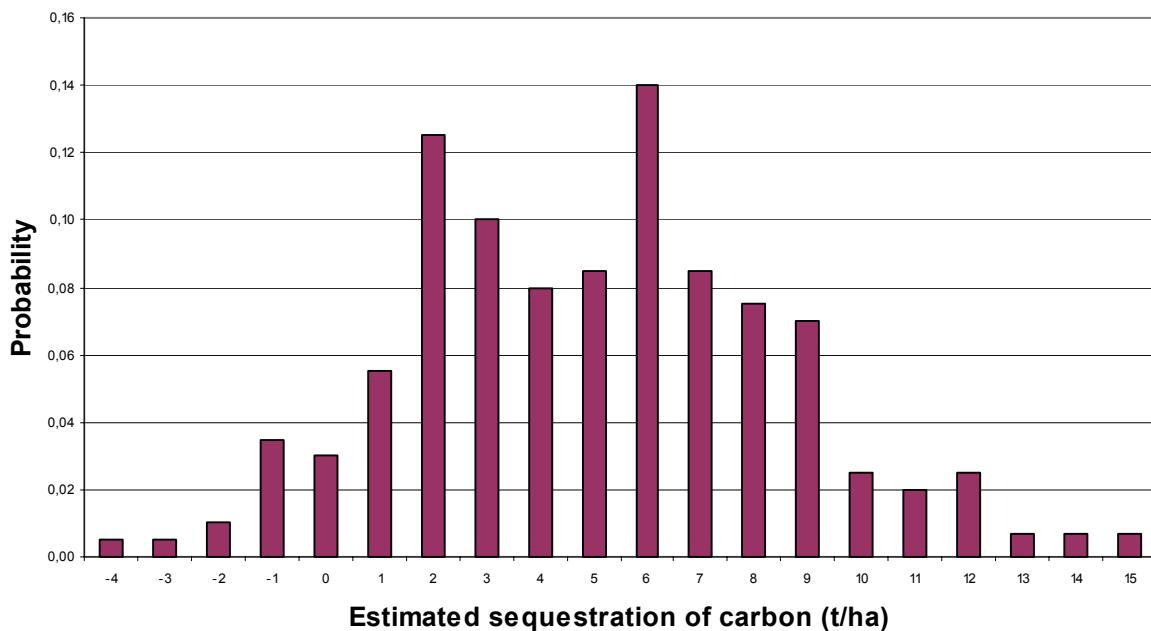
There was little data available on the soil carbon pool for Eucalyptus plantations in northern NSW. Suggested values estimated by State Forests of NSW were that the soil carbon at the start of a

rotation would be about 200 t/ha (varying between 100–300 t/ha), reducing by about 10% over the 5 years after conversion, after which it would reach a steady state. This was modelled using two @Risk variables with triangular distributions: Soil modelled the initial soil carbon pool size and had mean value of 200 with a minimum and maximum of 100 and 300 respectively. Soil-Chg modelled the annual fraction of soil carbon that remained in the soil for the first 5 years with a mean, minimum and maximum values of 0.97, 0.94 and 1.0 respectively.

RESULTS AND DISCUSSION

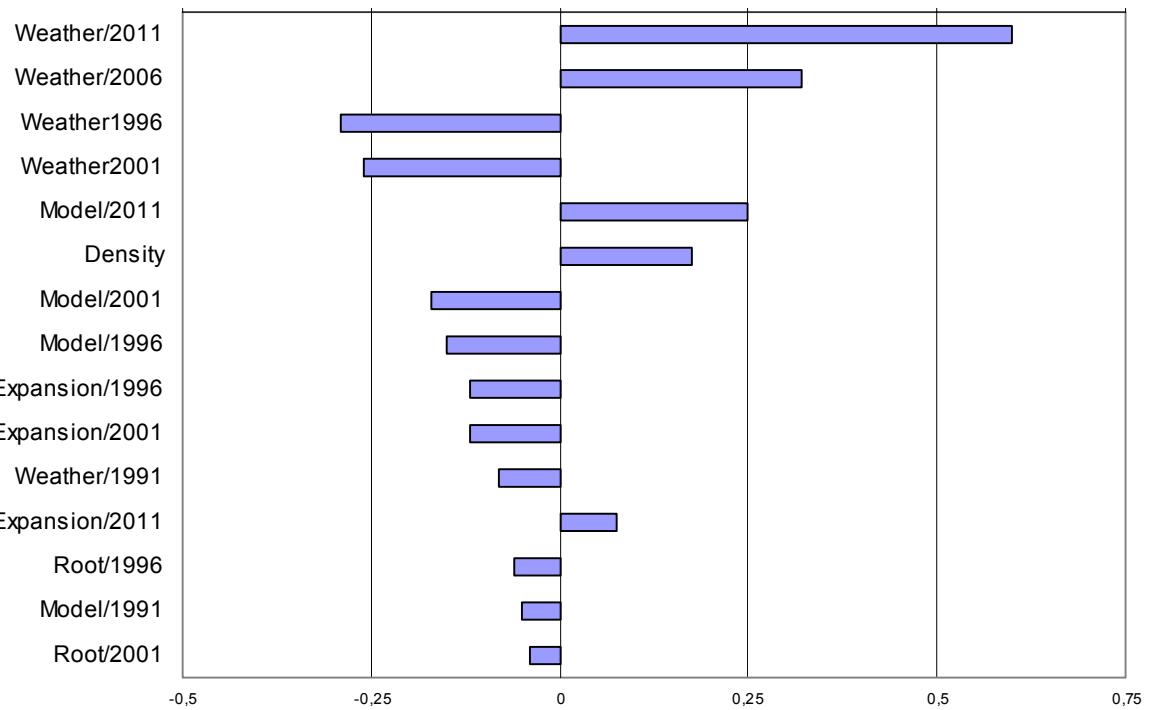
An initial sensitivity analysis consisted of 300 simulations using the @Risk probability variables and a 1 ha plantation established in 1990. This plantation was assumed to be on 'bare earth', ie the initial biomass, litter and product pools were empty. The output of interest was the mass of carbon sequestered by this plantation during the Kyoto commitment period, 2008-2012 (Figure 6). The frequency distribution is distinctly bimodal which may reflect the weather pattern introduced by the assumptions of negative correlation between consecutive 5-year periods. A small fraction of simulations predicted an emission of carbon as more mass decayed than was sequestered during the Commitment Period.

Figure 6: Frequency of estimates for the net carbon sequestered (t) during the Kyoto Commitment Period by 300 sensitivity simulations of a 1 ha Eucalyptus plantation.



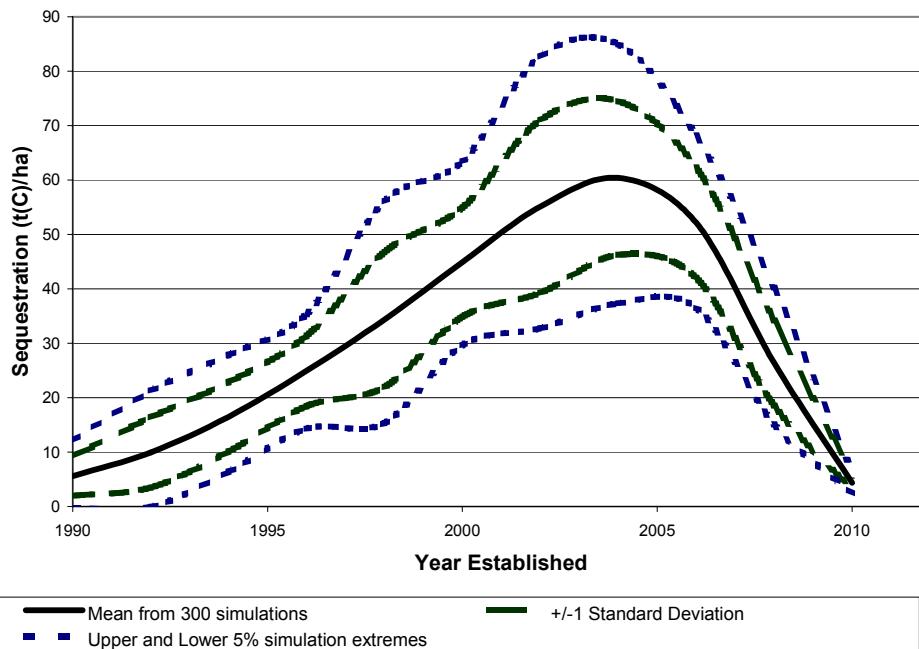
A tornado diagram (Figure 7) which ranks the strength of the correlation between the @Risk input variables and the carbon sequestered supports this idea. The most influential @Risk variables were weather2006 and weather2011 - if the weather promotes above (below) average growth during the Kyoto Period, the amount of carbon will increase (decrease) from the mean estimate. The weather variables prior to the Commitment period were negatively correlated - above average growth caused by "good" weather in 1996 - 2005 is correlated with smaller amounts of carbon being sequestered. This negative correlation may be due to the increased mass of leaves and twigs being produced prior to 2008, which subsequently decay and emit carbon during the Commitment period. Density and growth model estimates were the next most influential variables. The influence of risk in the allocation of growth to the leaves, twig, branches and roots was relatively unimportant with a correlation coefficient of less than 0.2.

Figure 7: Tornado diagram of correlation between input variables and carbon sequestered during the Kyoto Commitment Period.



A series of sensitivity analyses for plantations established between 1990 and 2010 indicates that the carbon sequestered in the biomass tends to increase to a maximum when established between 2002 - 2006 (Figure 8). This corresponds to plantations that will be about 5 to 10 years of age during the Commitment Period, which is the age range where CAI is at a maximum (Figure 3). Note also that the distribution of estimates is not equal around the mean - the upper 95% range is further from the mean than the lower 95% range.

Figure 8: Summary of carbon sequestered during the Kyoto Commitment Period in the biomass of plantations established between 1990 and 2010.



Routine management would allow a partial harvest or thinning for this type of plantation at age 12 years. Upon thinning, about 50% of the aboveground biomass pool would be turned over to debris or product pools. The impact of this thinning on the carbon sequestered depends on how close it is to the Commitment Period (Figure 9). A plantation established in 1996 and thinned in 2008, for example, would emit a large amount of carbon during the Commitment Period as the thinning debris and products harvested have their maximum rates of decay immediately after the operation. However this emission is balanced by the net growth of the plantation during this period. Plantations established earlier and therefore thinned before 2008 do not emit as much carbon from the remaining debris and product decay during the Commitment Period, but nor do the trees grow as fast.

A final simulation examined the carbon sequestration of a 5,500 ha estate of *E. grandis* where 500 ha were planted every two years from 1990 onwards (Figure 10). The emission of carbon from the soil is only significant for plantations established within 5 years of the Commitment Period. Age classes established in about 2002 to 2004 appear to maximise the sequestering of carbon. These plantations are growing relatively quickly, do not emit any carbon due to losses incurred due to thinning and may only loose a minor amount of carbon from the soil. Age classes thinned within the Commitment Period may be net emitters of carbon due to their relatively slow growth and high quantities of slash and wood product. However there is a chance that even these plantations could request significant quantities of carbon if the weather conditions during the Commitment Period are favourable. Age classes established at the end of the Commitment Period are likely to be net emitter of carbon as the soil carbon is released.

Figure 9: Impact of thinning on carbon sequestered during the Kyoto Commitment Period by biomass, debris and wood products

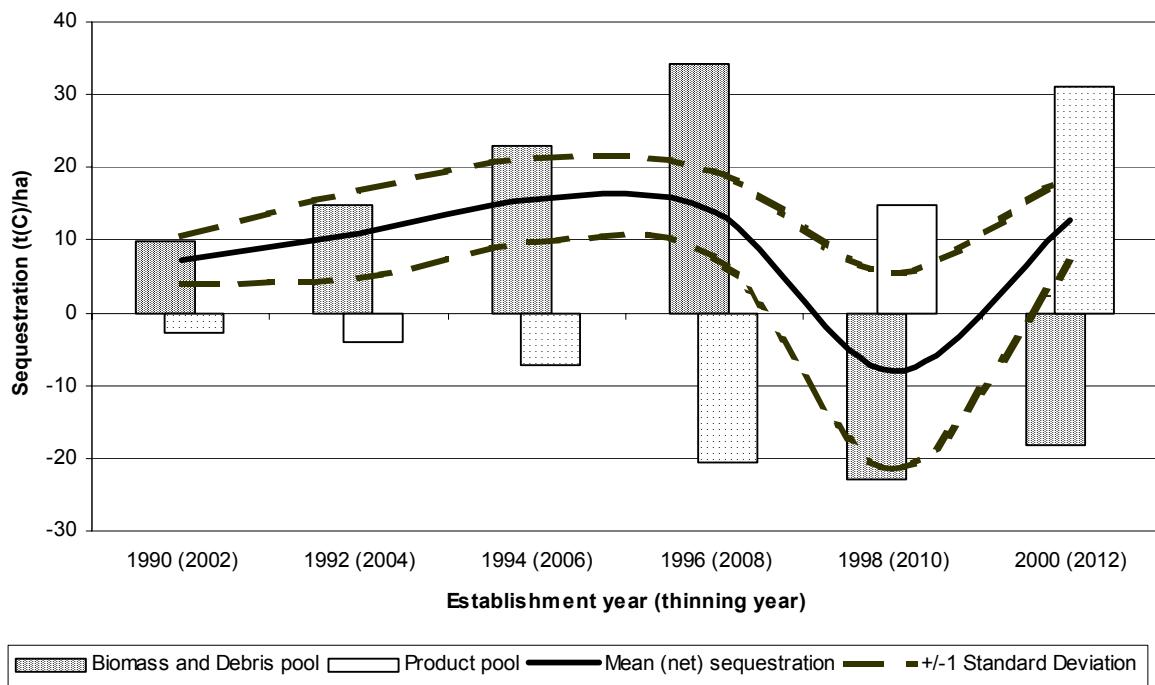
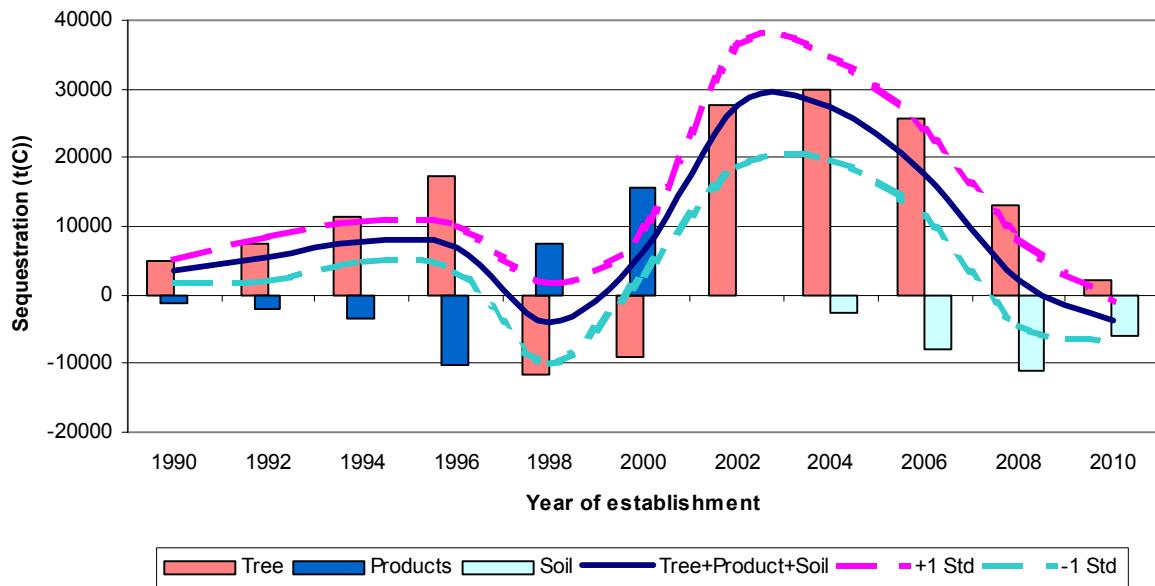


Figure 10: Summary of carbon sequestered by each age class during the Kyoto Commitment Period of a 5,500 ha plantation estate established between 1990 and 2010.



CONCLUSIONS

The influential sources of uncertainty in modelling for carbon sequestration vary with plantation age and proximity to the Kyoto Commitment Period. When the age is within the period of maximum CAI, errors in the model parameters and predictions of the weather will result in a high degree of uncertainty. When the CAI in the Commitment Period is low, eg very young or old stands, then uncertainty in estimating soil carbon emission and product decay becomes more important.

Management decisions, eg thinning or establishment, within the Kyoto Commitment period will have a much greater impact on the estimates of carbon sequestration than decisions prior to that Period. Therefore the ability to predict the management decision is very important. However, management decisions are also risky. Options to harvest prior or during the Kyoto Commitment Period may be influenced by unpredictable changes in management goals or objectives. Thus the uncertainty in the sequestration estimates introduced by weather and model variations may be completely dominated by political and management decisions of a 'risky' nature.

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Modelling Carbon Sequestration following Afforestation or Reforestation: Preliminary Simulations using GRC3

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ABSTRACT

The Australian Greenhouse Office (AGO), as part of its National Carbon Accounting System, is developing a capability to predict the change in carbon in Australian forests. To meet this objective a new model, GRC3, has been developed for forests combining four existing models: 3PG (growth of trees, allocation of carbon, and turnover of residues), GENDEC (litter decomposition), RothC (soil carbon turnover), and CAMFor (integrative tracking of carbon in managed plantations). Although each of these has been separately calibrated and validated under some systems, the integrated model has not been tested. In particular the GENDEC and RothC models need testing for plantations in Australia. The model, when calibrated and verified, would also form the basis of a 'carbon accounting toolkit' being developed by the AGO and others.

Keywords: Afforestation, Australia, carbon, GRC3, modelling

INTRODUCTION

In Australia, the area of plantation is expected to increase by about 2 million ha by 2020 compared to that existing in 1996. Most of these new plantations will be on agricultural land, and may provide an effective and practical contribution towards meeting Australia's international commitments to address climate change.

At a broad scale the effect of forest establishment on carbon stocks is best predicted through a verified modelling approach. A new model, GRC3, has been designed to track carbon transfer and turnover in forest establishment systems. This model combines four existing models: 3PG (growth of trees, allocation of carbon, and turnover of residues), GENDEC (litter decomposition), RothC (soil carbon turnover), and CAMFor (integrative tracking of carbon in managed plantations).

GRC3 has been developed in Microsoft Excel, and is expected to be superceded by FullCAM, prepared in C++ code. The two models are essentially the same, although FullCAM has additional features including an agricultural equivalent and ability to operate in a spatial mode. It is envisaged that FullCAM will provide the basis of an Australian carbon accounting system.

Although the submodel components of GRC3 have been separately calibrated and validated under some systems, the integrated model is currently untested. Prior to the collection and collation of data for broad application, testing is required to ensure that GRC3 is suitable for tracking of carbon through plantations via accurate simulation of dynamics of plantation growth, litter layer, and soil.

CSIRO is testing GRC3 for its ability to predict change in carbon under afforestation under Article 3.3 of the Kyoto Protocol, and specifically developing its ability to predict change in soil carbon. Here we:

- calibrate the model to various components of growth for seven select case studies of plantation establishment and management - land-use history, plantation productivity, soil type, climate and harvesting, and
- predict the cumulative change in carbon within tree biomass, debris, soil and total ecosystem pools for each study.

The objective is to quantify potential change in ecosystem carbon for seven case studies of plantations, and to identify important controlling processes that may need special attention for subsequent verification of the model.

MODEL DESCRIPTION AND METHODS

The integrated suite of models that comprise GRC3 are:

- 3PG, physiological growth model for forests (Landsberg and Waring 1997);
- CAMFor, Australian Greenhouse Office carbon accounting model for forests (Richards and Evans 2000);
- GENDEC, litter decomposition model (Moorhead and Reynolds 1991; Moorhead et al. 1999), and;
- RothC, soil carbon decomposition model (Jenkinson et al. 1991).

Each of these models have been independently developed and are suited to run on a monthly time-step. The model is represented diagrammatically in Figure 1.

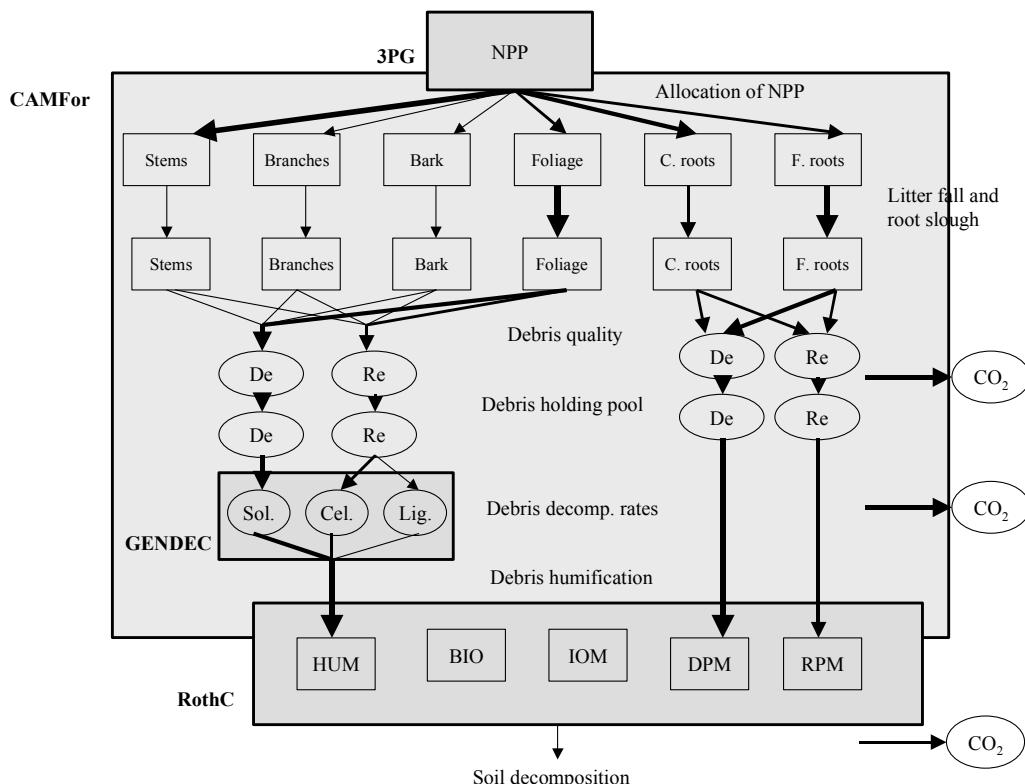


Figure 1: Basic structure and flows of carbon in FULLCAM. Boxes distinguish submodels. Arrows represent the main flows of carbon between submodels.

Seven regions and plantation management systems were chosen to provide the first test of GRC3, being selected on the basis that:

- they were one of the main forest establishment regions in Australia;
- at least one detailed growth study had been conducted in the region, and
- information on soil carbon content under pastures was available.

These regions and some of their characteristics are listed in Table 1.

Table 1: The seven sites, plantation species, and climatic data for case studies analysis.

Case study regions	Species	Abbreviation	Annual rainfall (mm)	Average temp. (°C)
Low rainfall, south-west WA	<i>E. globulus</i>	LRWA	632	15.7
High rainfall, south-west WA	<i>E. globulus</i>	HRWA	1,022	14.9
Green Triangle, SA/Vic.	<i>P. radiata</i>	SA	704	13.4
South-east Q'land/North-east NSW	<i>E. grandis</i>	QLD	1138	20.4
South-east highlands, NSW/Vic.	<i>P. radiata</i>	NSW	791	13.5
South-east Vic.	<i>E. globulus</i>	VIC	1039	13.3
Florentine Valley, Tas.	<i>E. nitens</i>	TAS	1215	10.2

For each of the case studies listed in Table 1, there were between 4 and 27 sites where measurements of one or more of the following were made:

- mean annual increment
- stem volume
- leaf area index
- root mass
- litter fall
- litter layer mass.

It was assumed that all of these plantations were established on improved pastoral land and thus were relatively fertile.

As far as possible, GRC3 was calibrated to the observed above- and below-ground components of growth (i.e. mean annual increment, stem volume, leaf area index), and to litterfall and accumulation of the litter layer. This was done by ‘tuning’ the allocation of NPP to the various tree components such that the predicted growth and litter layer accumulation matched that observed. The model outputs presented in this report form part of a sequential strategy to develop capability in predicting soil carbon change following afforestation. However, it is important to note that results for changes in soil carbon remains unverified.

E. globulus plantation, LRWA region scenario

The National Plantation Inventory (Bureau of Rural Resources, March 2000) indicated that Western Australia (WA) had 33% of all the new plantations established in Australia in 1999. It was projected that this would increase to 39% by 2000. In 1999, 88% of all the new plantations in WA were hardwoods, mostly *Eucalyptus globulus* planted in the south-west of the state. This region is represented by the LRWA case study. General inputs are shown in Table 2. Table 3 details studies of plantation in the LRWA region from which growth, biomass, litter fall, and litter layer accumulation data was collated for preliminary model calibration.

Table 2: General inputs used for simulation of the LRWA region.

	Value	Reference
Latitude (°)	33.69	
Soil type	Sandy loam	Hingston et al. (1998)
Initial soil C content (0-30 cm, t C ha ⁻¹)	31.7	Grove et al. (2000); Mendham pers. com. (2000)
Available soil water capacity (mm)	232	Hingston et al. (1998)
Clay content (%, 0-30 cm)	7	Hingston et al. (1995)
Average rotation length (yrs)	10	O'Connell (2000) pers. com.
Initial stocking (stems ha ⁻¹)	787	Hingston et al. (1998)
Thinning operations	None	O'Connell (2000) pers. com.

Table 3: Plantation experiments in the LRWA region and age (years) at which data was collected for MAI (mean annual increment), SV (stem volume), AGB (above ground biomass), BGB (below ground biomass, LAI (leaf area index), LF (litter fall), and LLM (litter layer mass)).

Site	MAI	SV	AGB	BGB	LAI	LF	LLM	Reference
Mumbulup	5	5-8	2-5	~	6-8	6, 7	~	Hingston et al. (1995; 1998)
Darkan	6, 9	6-12	3-9	~	7-12	7-11	~	Hingston et al. (1995; 1998)
Gibbs	10	0-4	~	~	~	~	~	Grove et al. (2000)
Cox	~	~	~	~	3	~	H*	O'Connell (2000) pers. com.

*represents stand at harvest

E. globulus plantation, HRWA region scenario

Most of the 27,500 ha of new *E. globulus* plantations established in WA in 1999 were planted within the high rainfall region in the south-west. The HRWA case study represents the high annual rainfall (900-1,500 mm) zone in south-western WA. It is the area of WA where *Eucalyptus globulus* plantations are most productive, and provides a useful comparison with the LRWA case study described above. General inputs used are shown in Table 4. Table 5 details studies of plantation in the LRWA region from which growth, biomass, litter fall, and litter layer accumulation data was collated for preliminary model calibration.

Table 4: General inputs used for simulation of the HRWA region.

	Value	Reference
Latitude (°)	33.69	
Soil type	Sandy loam	Hingston et al. (1998)
Initial soil C content (0-30 cm, t C ha ⁻¹)	49.8	Aggangan et al. (1998, 1999); Grove et al. (2000); Mendham pers. com. (2000)
Available soil water capacity (mm)	232	Hingston et al. (1998)
Clay content (%, 0-30 cm)	7	Hingston et al. (1995)
Average rotation length (yrs)	10	O'Connell (2000) pers. com.
Initial stocking (stems ha ⁻¹)	787	Hingston et al. (1998)
Thinning operations	None	O'Connell (2000) pers. com.

Table 5: Plantation experiments in the HRWA region and age (years) at which data was collected for MAI (mean annual increment), SV (stem volume), AGB (above ground biomass), BGB (below ground biomass, LAI (leaf area index), LF (litter fall), and LLM (litter layer mass)).

Site	MAI	SV	AGB	BGB	LAI	LF	LLM	Reference
Northcliffe	7	7-10	4-7	~	10-12	8, 9	~	Hingston et al. (1995; 1998)
Manjimup	9	9-12	6-9	~	6-8	10,11	~	Hingston et al. (1995; 1998)
Moltoni	11	0-4	~	~	~	~	~	Grove et al. (2000)
Windfield	~	~	~	~	~	~	H-1	Shamma (1999)
Carpenters	1-5	~	~	~	1-5	~	H	O'Connell pers. com. (2000)

Where H represents stand at harvest

Pinus radiata plantation, SA region scenario

The National Plantation Inventory (Bureau of Rural Resources, March 2000) indicated that in the years 1999 and 2000, the Green Triangle region of South Australia and Victoria contained 9-12% and 20-28% of all the new plantations established in Australia, respectively. In temperate regions, *Pinus radiata* is the most common softwood species. General inputs are shown in Table 6. Table 7 details studies of plantation in the SA region from which growth, biomass, litter fall, and litter layer accumulation data was collated for preliminary model calibration.

Table 6: General inputs used for simulation of the SA region.

	Value	Reference
Latitude (°)	37.75	
Soil type	Sand	Carlyle (2000) pers com.
Initial soil C content (0-30 cm, t C ha ⁻¹)	43.9	Lewis et al. (1981, 1987); Carlyle (2000) pers com.
Available soil water capacity (mm)	250	Carlyle (2000) pers com.
Clay content (%, 0-30 cm)	2.2	Carlyle (2000) pers com.
Average rotation length (yrs)	35	Carlyle (2000) pers com.
Initial stocking (stems ha ⁻¹)	1,352-1,600	Carlyle (1995, 1998)
<i>Thinning operations</i>		
1 st thinning, age 10-15 years	50%	Carlyle (2000) pers com.
2 nd thinning, age 20-25 years	25%	Carlyle (2000) pers com.
3 rd thinning, age 25-30 years	10%	Carlyle (2000) pers com.

Table 7: Plantation experiments in the SA region and age (years) at which data was collected for MAI (mean annual increment), SV (stem volume), AGB (above ground biomass), BGB (below ground biomass, LAI (leaf area index), LF (litter fall), and LLM (litter layer mass).

Site	MAI	SV	AGB	BGB	LAI	LF	LLM	Reference
Mt. Gambiar ¹	~	~	~	1-3	~	~	~	Nambiar (1983)
Mt. Gambiar ¹	~	1-7	~	~	~	~	~	Nambiar et al. (1990)
Mt. Gambiar ¹	~	~	2-6	2, 6	6	~	~	Nambiar (1990)
Sphers-EM88	~	~	0-3	~	~	~	~	Smethurst and Nambiar (1995)
Caroline EM89	~	~	11	~	~	11,37	11,35 ²	Carlyle (1993); Smethurst and Nambiar (1990)
Caroline 366	~	~	~	~	24-28	~	~	Carlyle (1999) pers. com.
Sphers-6 EM99	~	10,11	~	~	12	~	10-11	Carlyle (1995)
Sphers-6	24-58	~	~	~	11-12	11-13	24-58	Carlyle (1998)
Mt. Gambiar ¹	24-58	~	~	~	~	~	~	Carlyle et al. (1998)
Tarpeena	~	~	3	~	~	~	~	Woods et al. (1992)
Mt. Gambiar ¹	30	16-29	~	~	16-29	16-19	16-29	May pers com. (2000)

¹Numerous sites within the Mount Gambiar region

²1-3 years after clear felling

E. grandis plantation, QLD region scenario

In the years 1999 and 2000, Queensland and New South Wales contained 3-5% and 7-8% of all the new plantations established in Australia, respectively. A substantial proportion of new hardwood plantations are likely to be established in coastal regions of southeastern Queensland and northeastern New South Wales (QLD region). *E. grandis* is commonly planted in north-eastern NSW and there are detailed growth studies of this species within the QLD region. General inputs are shown in Table 8. Table 9 details studies of plantation in the QLD region from which growth, biomass, litter fall, and litter layer accumulation data was collated for preliminary model calibration.

Table 8: General inputs used for simulation of the QLD region

	Value	Reference
Latitude ($^{\circ}$)	26.18	
Soil type	Sandy loam	Ross and Thompson (1991)
Initial soil C content (0-30 cm, t C ha $^{-1}$)	67.7	Ross and Thompson (1991); Bell et al. (1999); Noble et al. (1997); Turner and Lambert (2000)
Available soil water capacity (mm)	89	Thackway and Cresswell (1995)
Clay content (%), 0-30 cm)	11-17	Ross and Thompson (1991)
Average rotation length (yrs)	12-14	Cromer et al. (1991)
Initial stocking (stems ha $^{-1}$)	756-1,110	Turner and Lambert (1983; 2000)
Thinning operations	None	Cromer pers. com. (2000)

Table 9: Plantation experiments in the QLD region and age (years) at which data was collected for MAI (mean annual increment), SV (stem volume), AGB (above ground biomass), BGB (below ground biomass, LAI (leaf area index), LF (litter fall), and LLM (litter layer mass).

Site	MAI	SV	AGB	BGB	LAI	LF	LLM	Reference
Conglomerate	~	~	27	~	~	27	27	Turner and Lambert (1983)
Coffs Harbor ¹	2-31	~	5-27	~	~	8-28	5-31	Turner (1986)
Coffs Harbor ¹	~	~	9-12	~	~	~	9, 12	Birk and Turner (1992)
Atherton	3	1-6	0-3	~	1-3	~	~	Cromer et al. (1990; 1991, 1995)
Coffs Harbor	3	1-6	0-6	~	1-6	7	~	Cromer et al. (1990; 1991, 1995)
Buladelah	~	3-6		~	~	~	~	Cromer et al. (1995)
Pomona	~	3-6		~	~	~	~	Cromer et al. (1995)
Coffs Harbor ¹	~	~	2-31	~	~	~	~	Byrne (1989)
Gympie	~	~	~	~	0-1	~	~	Leuning et al. (1991)
Toolara	~	~	~	1-2	~	1-3, 6	6	Stewart et al. (1990); Cromer et al. (1993); Raison et al. (1995)

¹Sites near the Coffs Harbor region

P. radiata plantation, NSW region scenario

New South Wales contains 7-8% of all new plantations established in Australia in 1999 and 2000 (The National Plantation Inventory, Bureau of Rural Resources, March 2000). *Pinus radiata* is widely planted being established within the south-west slopes and southern highland regions. General inputs are shown in Table 10. Table 11 details studies of plantation in the NSW region from which growth, biomass, litter fall, and litter layer accumulation data was collated for preliminary model calibration.

Table 10: General inputs used for simulation of the NSW region

	Value	Reference
Latitude ($^{\circ}$)	35.21	
Soil type	Loamy sand	Benson et al. (1992)
Initial soil C content (0-30 cm, t C ha $^{-1}$)	46.8	Williams and Donald (1956); Gifford and Barrett (1999); Gifford (2000)
Available soil water capacity (mm)	250	Kirschbaum (1999)
Clay content (%), 0-30 cm)	5	Mike Connell (2000) pers. com.
Average rotation length (yrs)	37	Snowdon (2000) pers. comm.
Initial stocking (stems ha $^{-1}$)	997-1,680	Benson et al. (1992); Woollons et al. (1995)
<i>Thinning operations</i>		
1 st thinning, age 10 years	50%	Snowdon (2000) pers. comm.
2 nd thinning, age 24 years	25%	
3 rd thinning, age 27 years	10%	

Table 11: Plantation experiments in the NSW region and age (years) at which data was collected for MAI (mean annual increment), SV (stem volume), AGB (above ground biomass), BGB (below ground biomass, LAI (leaf area index), LF (litter fall), and LLM (litter layer mass).

Site	MAI	SV	AGB	BGB	LAI	LF	LLM	Reference
Pierces Crk	11-15	10-14	10-14	14	10-14	10-14	10-20	Snowdon and Benson (1992); Raison and Myers (1992); Khanna pers. com. (2000)
Buccleuch	~	14-28	~	~	~	~	~	Snowdon et al. (1995); Woollons et al. (1995)
Blue Range	~	~	5	~	~	~	~	Snowdon and Waring (1985)

E. globulus plantation, VIC region scenario

The National Plantation Inventory (Bureau of Rural Resources, March 2000) showed that in 1999 and 2000, Victoria contained 20-28% of all new plantations established in Australia in 1999. A substantial proportion of the 25,326 ha of new harwood plantations in Victoria are *Eucalyptus globulus* in the south-east Gippsland region. General inputs are shown in Table 12. Table 13 details studies of plantation in the VIC region from which growth, biomass, litter fall, and litter layer accumulation data was collated for preliminary model calibration.

Table 12: General inputs used for simulation of the VIC region

	Value	Reference
Latitude (°)	38.10	
Soil type	Clay loam	Judd et al. (1996); Sargeant et al. (1997); Hooda (1998)
Initial soil C content (0-30 cm, t C ha ⁻¹)	103.1	Sargeant et al. (1997)
Available soil water capacity (mm)	340	Mike Battaglia (2000) pers. com.
Clay content (%, 0-30 cm)	23	Bennett et al. (1996)
Average rotation length (yrs)	15-20	Cromer (2000) pers. com.
Initial stocking (stems ha ⁻¹)	900-1,015	Hooda (1998)
Thinning operations	None	Cromer (2000) pers. com. (2000)

Table 13: Plantation experiments in the VIC region and age (years) at which data was collected for MAI (mean annual increment), SV (stem volume), AGB (above ground biomass), BGB (below ground biomass, LAI (leaf area index), LF (litter fall), and LLM (litter layer mass).

Site	MAI	SV	AGB	BGB	LAI	LF	LLM	Reference
Boola	2-9	2-6	2-10	~	6	2-6	6	Cromer and Williams (1982); Judd et al. (1996); Bennett et al. (1996; 1997); Hooda (1998)
Glrncoe	2-9	2-6	4-7	~	6	2-6	6	Cromer and Williams (1982); Judd et al. (1996); Bennett et al. (1996; 1997); Hooda (1998)
Maryvale	2-9	2-6	2,-7	~	6	2-6	6	Cromer et al. (1975); Cromer and Williams (1982); Judd et al. (1996); Bennett et al. (1996; 1997); Hooda (1998)

E. *nitens* plantation, TAS region scenario

In 1999-2000, 15-20% of new plantations in Australia were established in Tasmania (The National Plantation Inventory, Bureau of Rural Resources, March 2000). In 1999, 87% of all new plantations in Tasmanian were hardwood plantations. A substantial proportion of the 16,467 ha of new harwood plantations in Tasmania are *Eucalyptus nitens* planted in the frost prone, high rainfall regions. General inputs are shown in Table 14. Table 15 details studies of plantation in the TAS region from which growth, biomass, litter fall, and litter layer accumulation data was collated for preliminary model calibration.

Table 14: General inputs used for simulation of the TAS region

	Value	Reference
Latitude ($^{\circ}$)	38.10	
Soil type	Clay loam	Wang et al. (1996); Bell et al. (1999); Sparrow et al. (1999)
Initial soil C content (0-30 cm, t C ha^{-1})	99.6	Sargeant et al. (1997)
Available soil water capacity (mm)	340	Mike Battagila (2000) pers. com.
Clay content (%), 0-30 cm)	23	Bennett et al. (1996)
Average rotation length (yrs)	15-20	Cromer pers com. (2000)
Initial stocking (stems ha^{-1})	900-1,015	Hooda (1998)
Thinning operations	None	Mike Battagila (2000) pers. com.

Table 15: Plantation experiments in the TAS region and age (years) at which data was collected for MAI (mean annual increment), SV (stem volume), AGB (above ground biomass), BGB (below ground biomass, LAI (leaf area index), LF (litter fall), and LLM (litter layer mass).

Site	MAI	SV	AGB	BGB	LAI	LF	LLM	Reference
Westfield	~	6-8	1-3, 8	1-3, 8	6-7	8	~	Misra et al. (1998); Baillie pers. comm. (2000)
Tasmania ¹	13	~	~	~	3, 7	~	~	Battaglia et al. (1998)

¹Other Regions in Tasmania

RESULTS AND DISCUSSION

Figures 2 to 6 are examples of how allocation of NPP to various tree components was calibrated such that predicted growth, litter fall and litter layer accumulation matched that observed. The examples of calibrated model output given in Figures 2 to 5 are for the NSW case study.

Figure 2: Stem volume of *P. radiata* plantations at NSW. Solid circles represent observed data taken from Snowdon and Benson (1992), Woollons et al. (1995), and Snowdon et al. (1995).

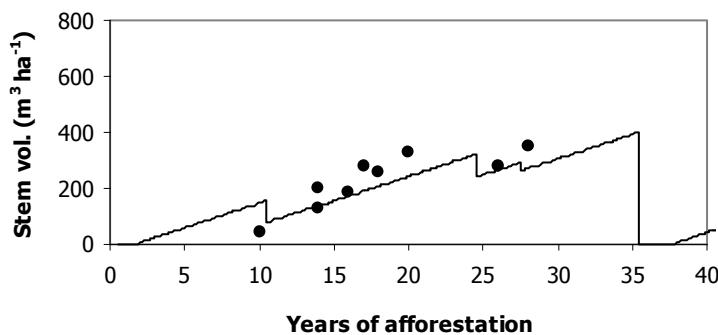


Figure 3: Above ground biomass of *P. radiata* plantations at NSW. Solid circles represent observed data taken from Snowdon and Waring (1985) and Snowdon and Benson (1992).

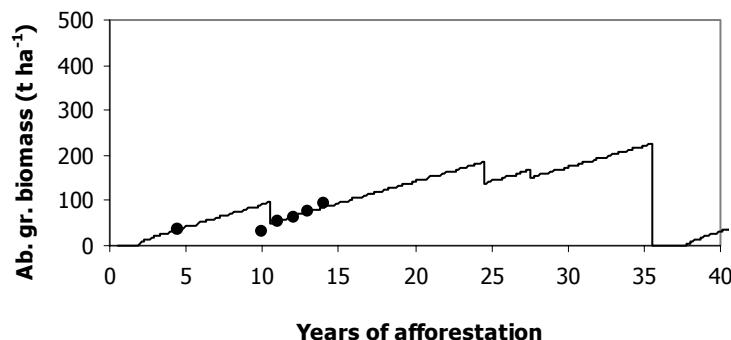


Figure 4: Leaf area index of *P. radiata* plantations at NSW. Solid circles represent observed data taken from Raison et al. (1992).

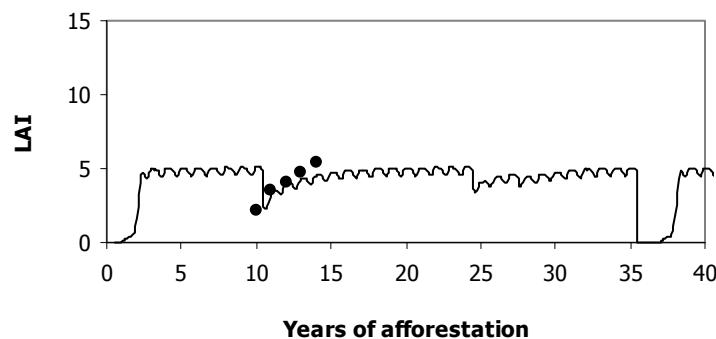


Figure 5: Total litter fall (minus C removed in products) under *P. radiata* plantations at NSW. Solid circles represent observed data taken from Raison et al. (1992).

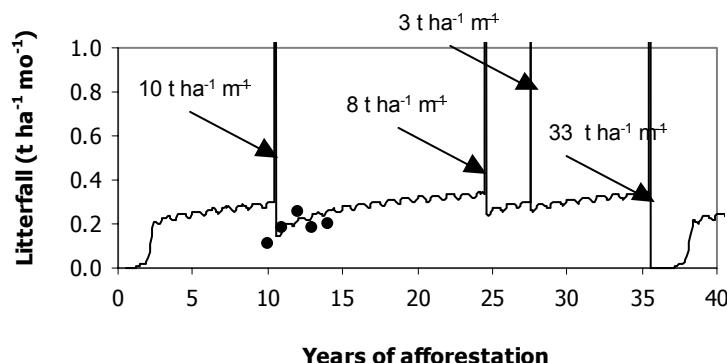
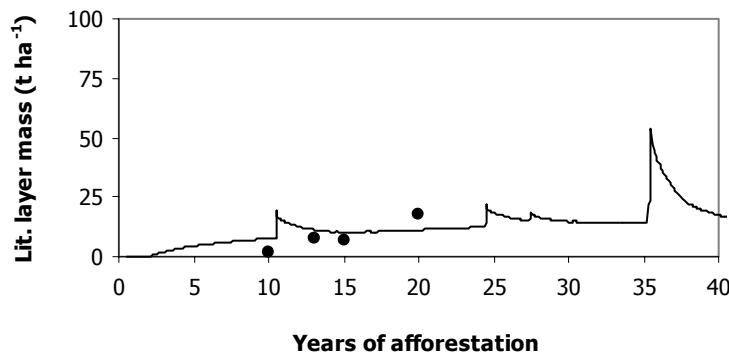


Figure 6: Litter layer mass under *P. radiata* plantations at NSW. Solid circles represent observed data taken from Khanna (2001) pers. com.



Changes in carbon within trees (both above- and below-ground), debris and soil for each case study are shown in Figures 7-13. After 40 years of afforestation it was predicted that between 373 and 810 t C ha^{-1} had been sequestered. It was predicted that 34-56% and 24-25% of this carbon entered the debris and soil, respectively. However due to the loss of carbon during debris and soil decomposition, up to only 5% of the net carbon sequestered accumulated in soil and debris, whereas 44-66% was in harvested products or in trees.

GRC3 has been calibrated to plantation growth, litter fall and accumulation of litter. However, simulations of the change in soil carbon remain unverified. Although the model was calibrated to litter accumulation by adjusting the allocation of NPP to the various tree components, the rate of carbon during litter decomposition and the rate of debris humification remains untested. The GENDEC and RothC models of decomposition need to be verified.

Figure 7: Net accumulation of carbon within tree biomass, debris, soil and total ecosystem over a 40 year period of forest establishment in the LRWA region.

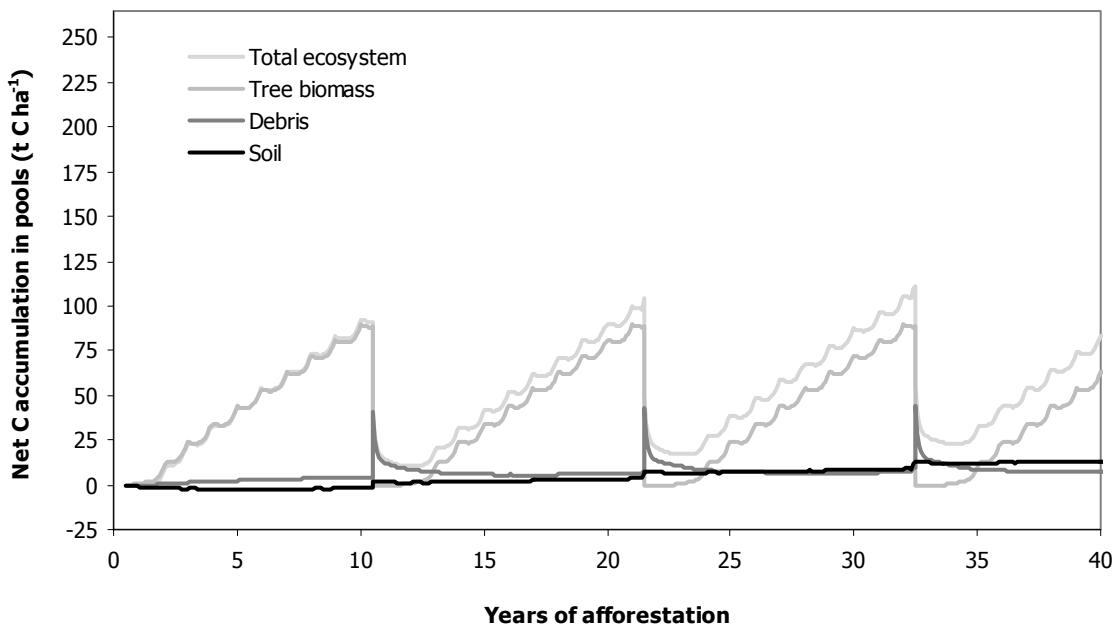


Figure 8: Net accumulation of carbon within tree biomass, debris, soil and total ecosystem over a 40 year period of forest establishment in the HRWA region.

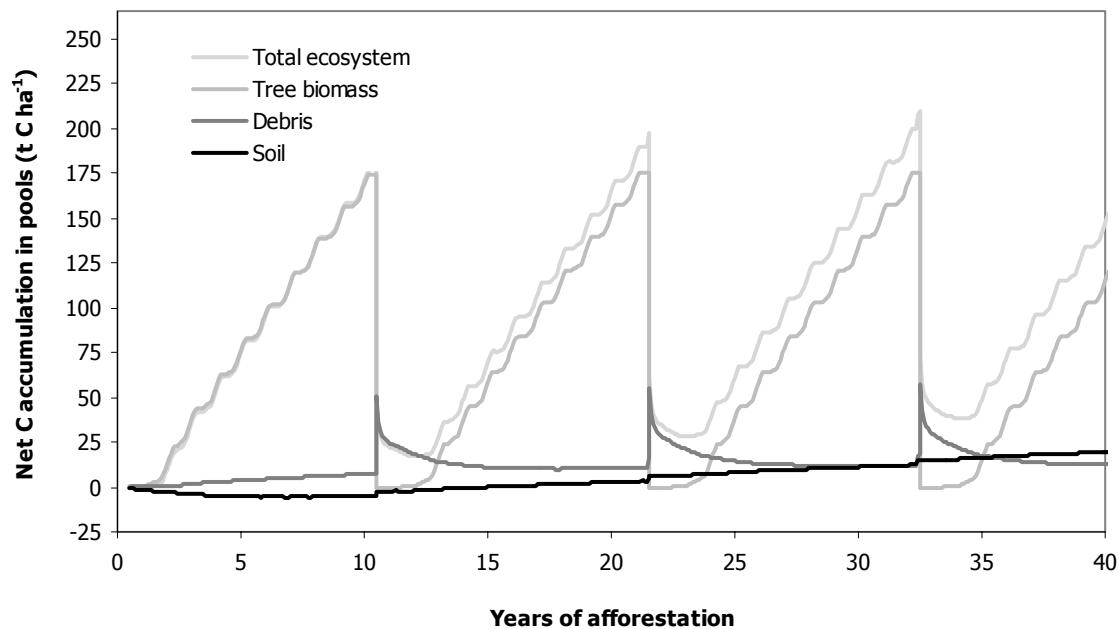


Figure 9: Net accumulation of carbon within tree biomass, debris, soil and total ecosystem over a 40 year period of forest establishment in the SA region.

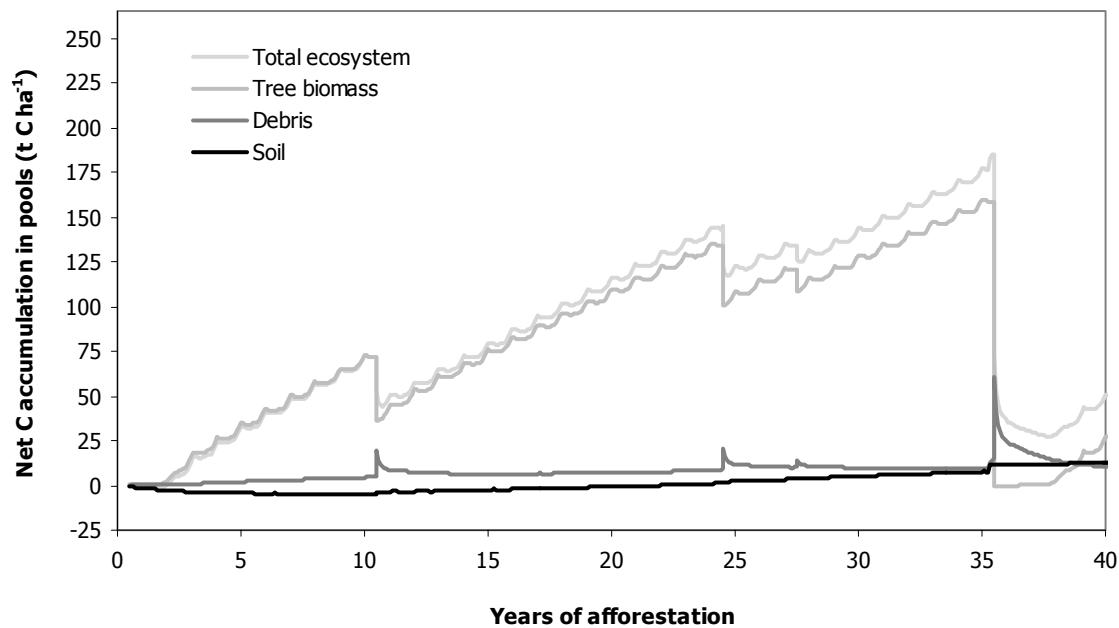


Figure 10: Net accumulation of carbon within tree biomass, debris, soil and total ecosystem over a 40 year period of forest establishment in the QLD region.

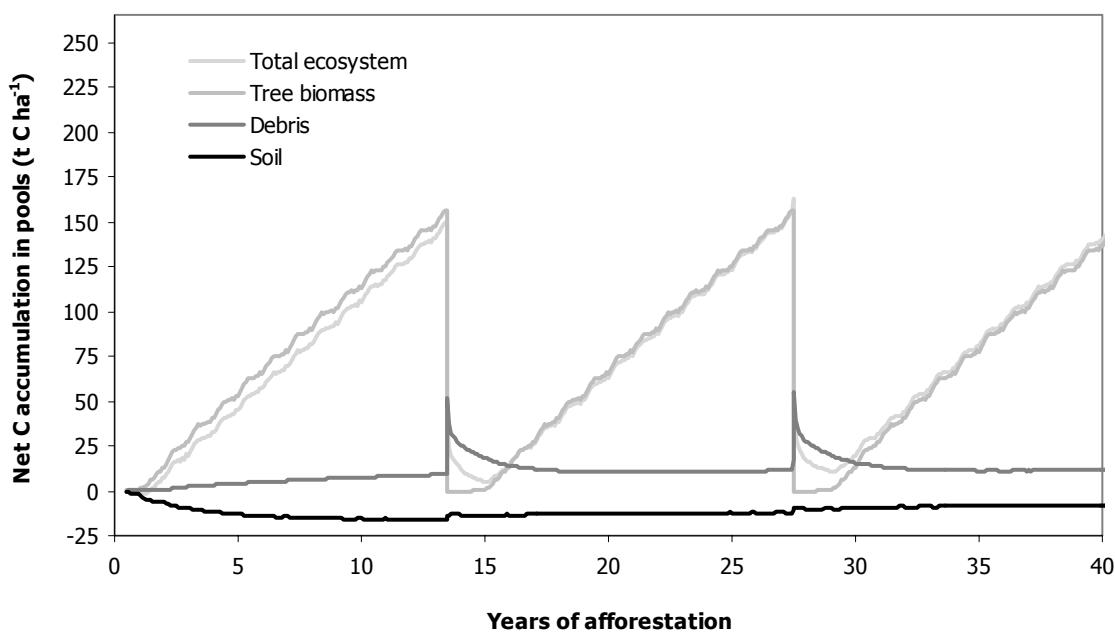


Figure 11: Net accumulation of carbon within tree biomass, debris, soil and total ecosystem over a 40 year period of forest establishment in the NSW region.

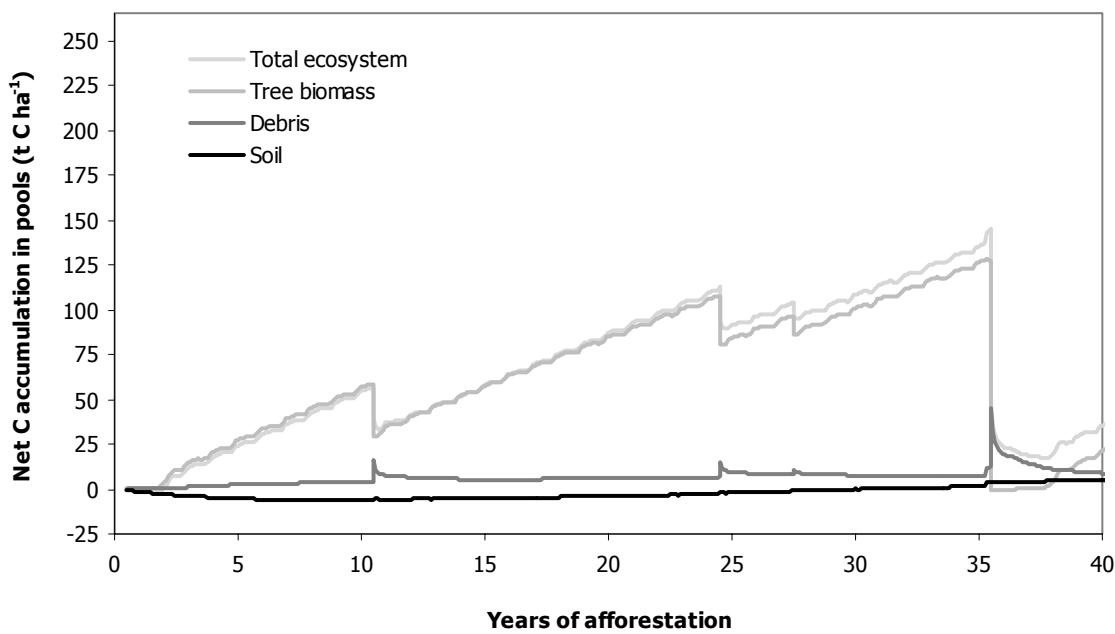


Figure 12: Net accumulation of carbon within tree biomass, debris, soil and total ecosystem over a 40 year period of forest establishment in the VIC region.

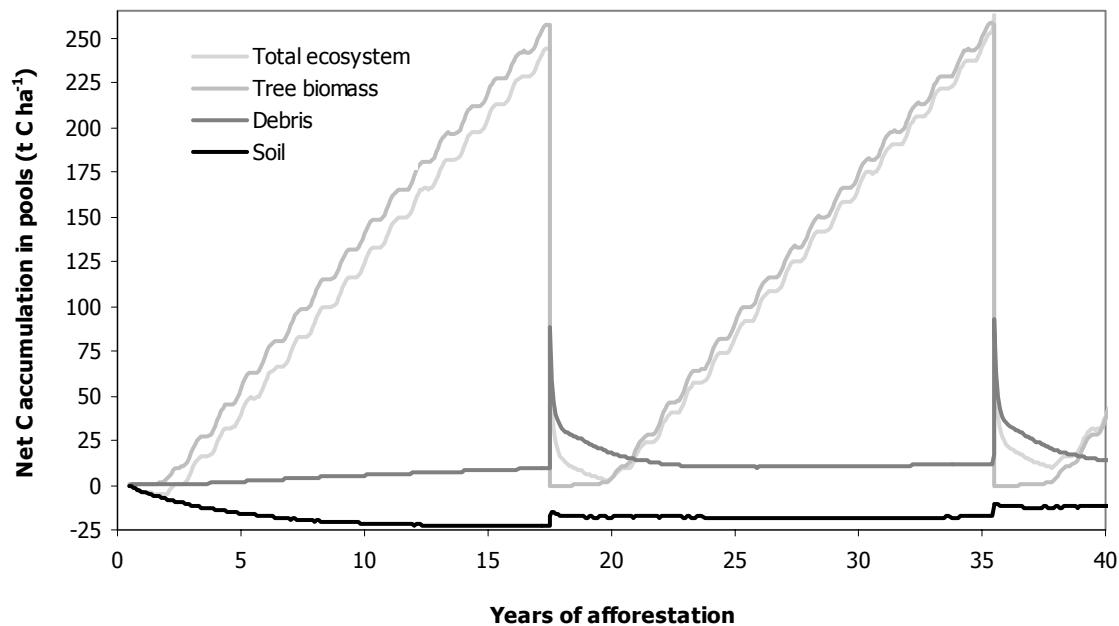
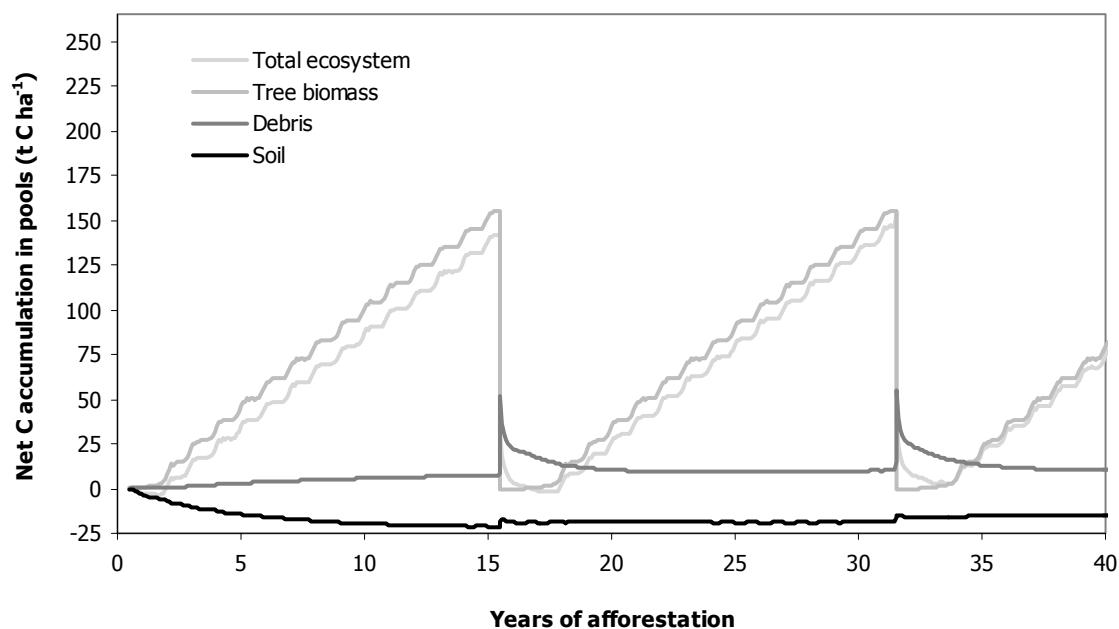


Figure 13: Net accumulation of carbon within tree biomass, debris, soil and total ecosystem over a 40 year period of forest establishment in the TAS region.



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The Development of a National Wood Products Model

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ABSTRACT

The Australian Greenhouse Office commissioned Jaakko Pöyry Consulting to develop a model of the carbon sequestered in wood products. Quantitative data were obtained on the fate of carbon within a wide range of wood manufacturing processes. Quantitative data were also obtained in an attempt to estimate the amount of carbon stored in wood products already in Service.

The proposed methods of accounting for carbon in wood products suggested at Dakar, Senegal in 1998 were examined and applied to the model in an attempt to quantify the impact on Australia of adopting the various approaches to stored carbon in wood products.

The methodology developed has been used within CAMFor to allow the amount of carbon in wood products to be calculated.

Keywords: wood product accounting

INTRODUCTION

Greenhouse Inventories describe the current internationally accepted methodology for accounting for greenhouse gas emissions. For emissions associated with carbon in wood products, the Guidelines specify that, for wood traded internationally, emissions must be accounted for in the country where the timber is grown. This is different to the treatment of fossil fuels such as coal or oil, where the importing country, not the exporter, accounts for the emissions associated with the burning of these fuels. Under the default methodology, carbon emissions are accounted for at the time of harvest. The Guidelines do, however, allow for delays in emissions associated with various decay rates of wood products if a country has adequate data on which to base such an assessment.

There has been some international interest in reviewing the methodology used for wood products accounting and, in 1998, the IPCC held a workshop (Brown et al 1998) to consider different accounting approaches. Adopting different approaches to the accounting may have significant implications for countries such as Australia and New Zealand that trade extensively in wood products.

The National Carbon Accounting System of the Australian Greenhouse Office (AGO) engaged Jaakko Pöyry Consulting to undertake a study of the methodologies and their potential impact.

BACKGROUND

Jaakko Pöyry Consulting prepared a report for the AGO (Jaakko Pöyry Consulting 1999) titled 'Usage and Life Cycle of Wood Products'. This report examined the fate of carbon in wood products in Australia. The study considered all forest products and included both exports and imports. In addition, the study initiated an analysis of the carbon accounting methodologies described above by developing and using a Jaakko Pöyry Consulting-developed model: the 'National Carbon Accounting Model for Wood Products in Australia', or as used in this report, the Carbon Model.

A key limitation of the Carbon Model involved the assumptions surrounding the size and components of the pool of Carbon in wood products in service at the beginning of the Model's simulation period. To help overcome this limitation, historical data from ABARE's Forest Products Statistics series were used to populate the model and provide a more realistic estimate of the initial wood products carbon pool. Outputs from the model using the revised data series are presented.

ACCOUNTING APPROACHES

The four accounting approaches for carbon emissions from timber harvesting and wood products presented at the 1988 IPCC Dakar meeting (Brown et al, *loc. cit.*) are described below.

The IPCC Default Approach

The IPCC default approach accounts for all wood products as an emission at harvest and no decay rates apply. Hence, countries that export wood and wood products will ultimately be responsible for the emitted carbon. Under this methodology, there is no wood products carbon pool. This is the most simple of the approaches to apply. The IPCC Default Approach is illustrated in Figure 1

Production Approach

The Production Approach accounts for all wood products derived from wood grown in Australia, regardless of the country in which the product finally decays. This requires an understanding of the destination of exported raw material and wood products, as well as the final products that they are converted into. Additionally, this approach requires division of all wood products within Australia into two categories: wood grown in Australia; and wood grown outside Australia.

Difficulties arise where similar products exported from Australia are used for different end uses and affected by different environments at their final destination. Decay rates for each country must be obtained to determine the rate at which carbon is released into the atmosphere under local conditions. An additional complication is the need to track wood products re-imported to Australia (e.g. Australian woodchips exported to Japan, converted to paper and subsequently imported by Australia).

The Production Approach places the responsibility on Australia for monitoring changes in the wood products pool of all countries that Australian wood is exported to. This can only be achieved through the cooperation and provision of data by each trading partner. For some countries (e.g. Non Annex I countries) this may be difficult.

The flow of carbon from the forest through the wood products pools counted in the Production Approach is shown in Figure 2.

It is our opinion that the Production Approach would be extremely difficult for Australia to adequately implement.

Stock-change Approach

The Stock-Change Approach accounts for emissions from all wood products within Australia, regardless of their origin. Exported wood products do not need to be accounted for by Australia. The origin of imported wood products does not need to be tracked. However, the flow of imported wood products into various pools within Australia must be monitored.

The Stock-Change Approach places the responsibility exclusively on Australia for monitoring the wood products pool.

The Stock-Change Approach is a feasible concept that fairly recognises the impacts of exports and imports and fairly accounts for decay rates of wood products in service. The flow of carbon from the forest through the wood products pools counted in the Stock-Change Approach is shown in Figure 3.

Atmospheric Flow Approach

The atmospheric flow approach is very similar to the stock-change approach in that decay rates for wood products are recognised and exports are regarded as having been removed from consideration as an emission. The sequestration of carbon from the atmosphere into forests can be readily tracked in the same way as growth is handled as a change in stocks in the other methods. Determining the actual decay of wood products rather than applying some assumed decay function is very difficult. For practical purposes, it is not considered possible to calculate atmospheric flow.

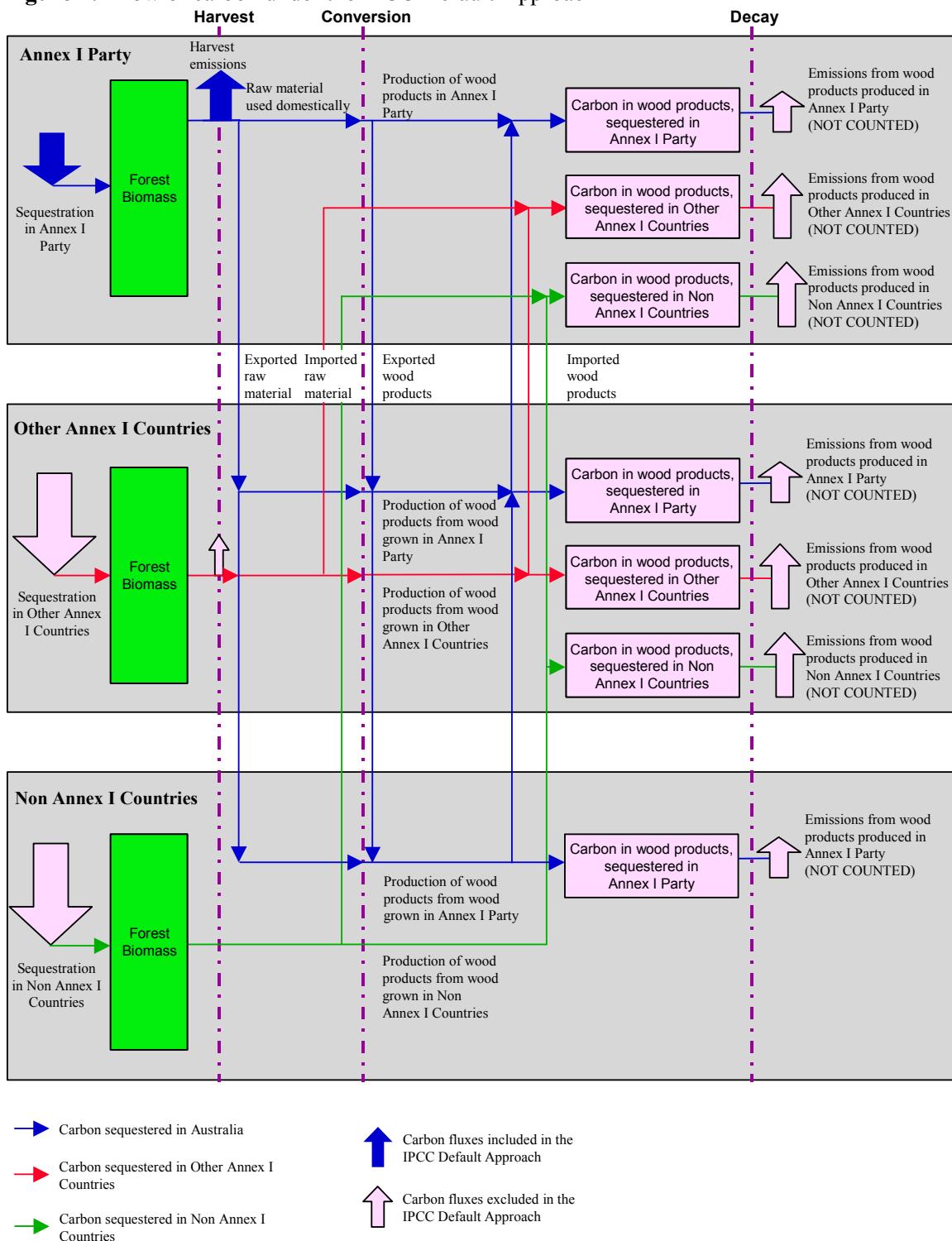
Figure 1: Flow of carbon under the IPCC Default Approach

Figure 2: Flow of carbon through wood products pools under the Production Approach

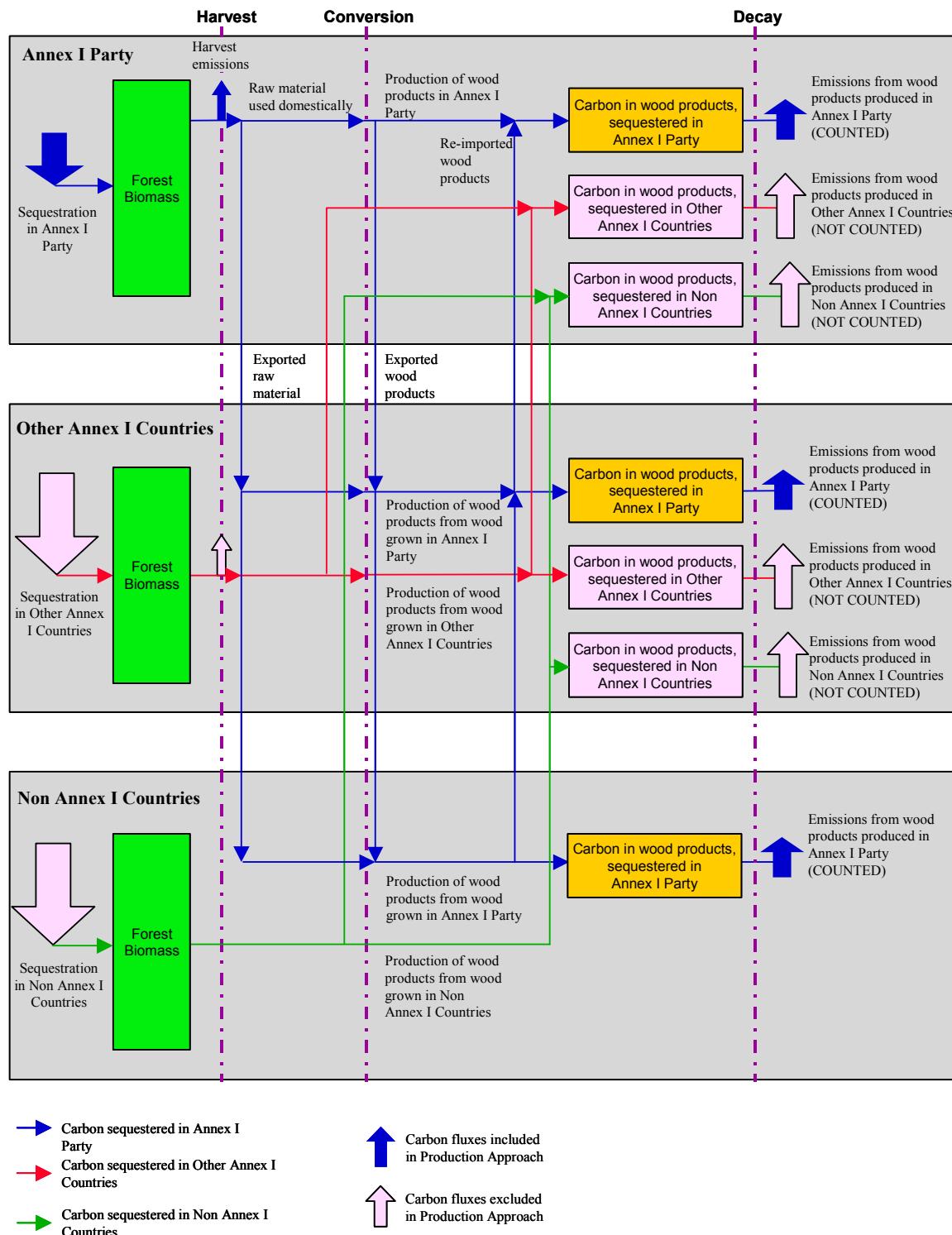
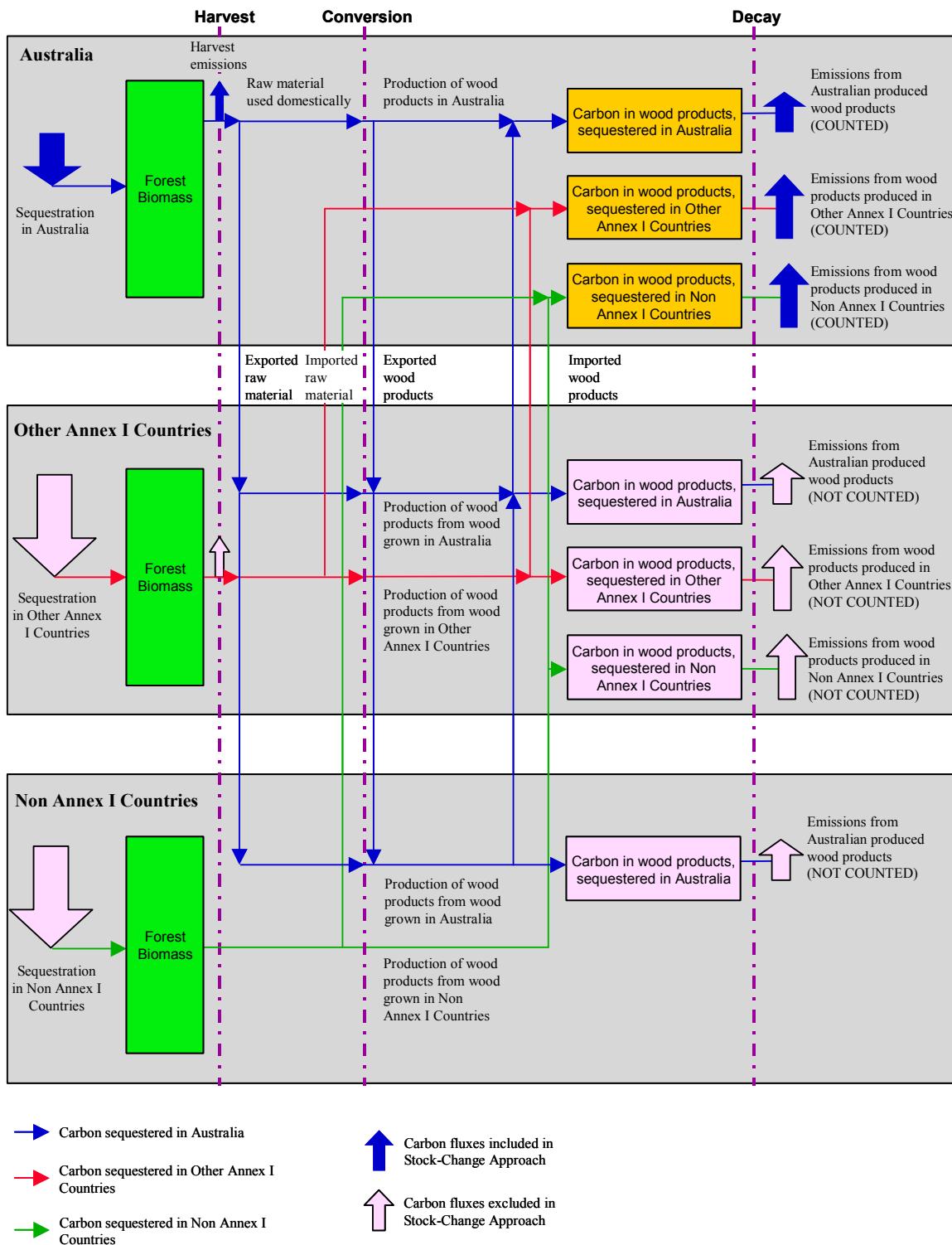


Figure 3: Flow of carbon through wood products pools under the Stock-Change Approach

LOG FLOW AND WOOD FLOW FROM PROCESSING

Annual log removals were estimated from data supplied from sources such as ABARE and State forest agencies. Log removals were estimated for softwood, hardwood and cypress pine and further divided by crown and private tenure, State and log product. Table 1 shows log removals by log type. Bark was not included in the Carbon Model; bark is regarded as harvesting residue.

Table 1: Log removals in Australia for 1997/98 in thousands of m³

	Sawlogs & other	Pulplogs
Softwood	7260	3915
Hardwood	3505	5981
TOTAL	10765	9896
GRAND TOTAL		20661

CARBON POOL CATEGORIES

For the purpose of identifying carbon pools, the various wood products produced in Australia were divided into the following six species/industry categories and their respective subcategories.

Sawmilling

- Softwood sawmilling is plantation grown softwood – either exotic pine (the great majority) or native hoop pine. The industry is generally geared to high volumes and high recovery of product.
- Hardwood sawmilling largely refers to native forest sawlogs. While some plantation grown logs are sawn, the impact of different technology is ignored – this may need to change in future as the plantation hardwood industry develops.
- Cypress pine sawmilling is treated separately, however, apart from the basic density of the raw material, it has very similar characteristics to hardwood sawmilling.

Preservative Treatment

- Softwood preservation is based on plantation grown softwood.
- Hardwood poles, sleepers and miscellaneous products are based on native forests.

Plywood

All plywood products are included under one category and the roundwood equivalents are calculated back from plywood production statistics.

Particleboard and Medium Density Fibreboard (MDF)

Includes particleboard, MDF and Hardboard.

Pulp and Paper Products

This product is not split into sub categories.

Export Logs

Woodchips and log exports are considered as one sub-category.

WOOD FLOW AND THE CARBON MODEL

The Carbon Model allows for separate wood flows for each processing sector. Wood flows are integrated across sectors as wood waste and by-products are often used as fibre sources for other wood products industry sectors.

In conjunction with the carbon pool and life cycle of timber products, this model enables the total and future carbon pools to be estimated.

The components of the models developed for each sector are similar and use estimates of:

- raw materials inputs;
- the products of processing;
- an estimate of the proportion of products by product life span;
- a final figure for total Australian consumption by end-use categories converted to wood fibre content and to tonnes of carbon. (For the Carbon Model, a figure of 50% carbon by weight of oven dry wood has been used as a default but may be readily changed as required); and
- import and export data.

Wood flow diagrams for each industry sector in the Carbon Model are presented in Appendix 1. Specific calculations have been made for various sub-categories and the percentages shown in the diagrams relate to the major sub-category.

LIFE SPAN OF WOOD PRODUCTS

The life span of wood products must be taken into account when ascertaining the quantity of carbon stored in timber products. In this study, considerable attention has been given to subdividing the various timber products pools into different classes based on product and decay rates. The product life spans differ from those in the Land Use Change and Forestry Workbook 4.2 – 1998 Supplement. It was assumed that the decay rate over the lifespan of the product was constant. However, this assumption may not be valid and it requires further investigation.

For shorter-term products, the impact of the size of previous stocks is fairly slight as the additions to the pools quickly have the major impact. For long-term products, an estimate of the size of the pool is essential, but difficult. Jaakko Pöyry Consulting has estimated the size of the housing pool using housing starts data. Other pools are also only estimates.

The proportion of the pool that has been derived from Australian-grown wood is required in order to implement the Production Approach. However, this component is difficult to estimate and as such, it is emphasised any estimates should be treated with considerable caution.

LIFE SPAN POOLS ASSUMED FOR THE CARBON MODEL

Very short-term products – Pool 1

3 years has been nominated for:

- Softwood – pallets and cases.
- Plywood – formboard.
- Paper and paper products.

Short-term products – Pool 2

10 years has been nominated for:

- Hardwood – pallets and palings.
- Particleboard and MDF – shop fitting, DIY, miscellaneous.
- Hardboard – packaging.

Medium-term products – Pool 3

30 years has been nominated for:

- Plywood – other (noise barriers).
- Particleboard and MDF – kitchen and bathroom cabinets, furniture.
- Preservative treated pine – decking and palings.
- Hardwood – sleepers and other miscellaneous hardwood products.

Long-term products - Pool 4

A 50 year life span has been nominated for:

- Preservative treated pine – poles and roundwood.
- Softwood – furniture.
- Hardwood – poles, piles and girders.

Very long-term products – Pool 5

The following products are used predominantly in house construction and are therefore regarded as having a life cycle of 90 years:

- Softwood – framing, dressed products (flooring, lining, mouldings).
- Cypress – green framing, dressed products (flooring, lining).
- Hardwood – green framing, dried framing, flooring and boards, furniture timber.
- Plywood – structural, LVL, flooring, bracing, lining.
- Particleboard and MDF – flooring and lining.
- Hardboard – weathertex, lining, bracing, underlay.
- Preservative treated pine – sawn structural timber.

POOL OF WOOD PRODUCTS IN SERVICE

The approach adopted for use in the Carbon Model presented in the ‘Usage and Life Cycle of Wood Products’ report for estimating the carbon pool in housing and the rate at which that carbon is released was to:

- use housing starts figures as a base;
- assume an average wood content per house;
- convert the total wood content to a carbon equivalent; and
- assume a constant decay rate over 90 years.

Historical production data from ABARE’s Forest Products Statistics series from 1944 to 1998 enabled an estimation of existing carbon pools to be made. The start points for the Carbon Model are shown in Table 2.

Table 2: Estimates of size of carbon pools in 1998 based on historical production data used for calculation of Production and Stock-Change approaches to carbon accounting

Pool Class (no. yrs to decay)	Production Approach (Mt carbon)	Stock-Change Approach (Mt carbon)
1 - Very short-term (3)	8.2	5.2
2 – Short-term (10)	1.0	1.0
3 – Medium-term (30)	4.1	4.5
4 – Long-term (50)	2.5	2.8
5 – Very long-term (90)	43.9	55.7
Total (all Pools)	59.7	69.2

These results would be sensitive to changes in the base assumption that a constant annual decay rate over 90 years is appropriate.

OUTPUT FROM THE CARBON MODEL

In conjunction with the carbon pool and life cycle of wood products, the model enables the total and future carbon pools to be estimated.

In broad terms, the components of the models developed for each sector are similar, using:

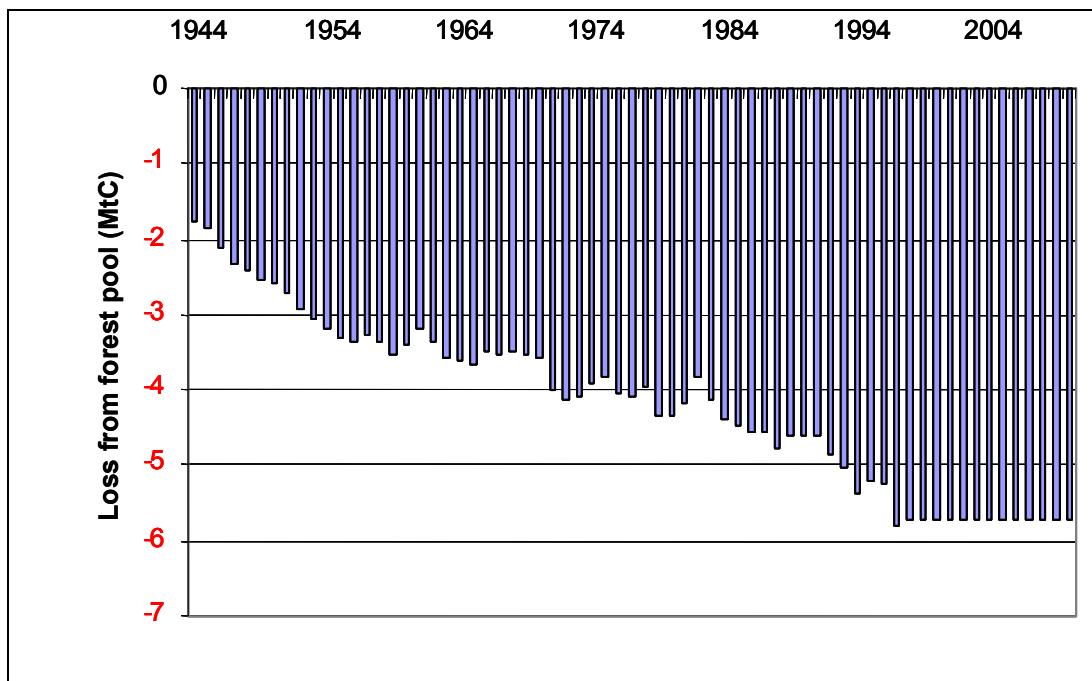
- An estimate of raw materials input, whether of sawlogs, woodchips ex-sawmill, or pulp logs.
- An estimate of the products of processing, e.g. "x%" sawdust, shavings or sander dust for on site energy generation or compost, "y%" woodchips for other manufacturing processes, "z%" of sawn timber products, panel products, paper, etc.
- An estimate of the proportion of products by product categories, depending on whether their expected end-use is long-term or short-term.
- A final figure for total Australian consumption by end use categories, converted to wood fibre content (oven-dry weight) and to tonnes of carbon.
- Import and export data were obtained from the ABARE reports by end use categories.

The carbon model developed by Jaakko Pöyry Consulting calculates the quantity of carbon in each of the pools described above. The current levels of production, export and import are assumed to continue at current levels. To allow the carbon accounting methodologies to be applied, imports and exports are kept separate.

IPCC Default Methodology

The IPCC default methodology assumes all wood is an emission at harvest. Figure 4 shows the impact of applying the IPCC default methodology: all of Australia's wood production is treated as an emission.

Figure 4 Indicative emissions from forest harvesting - IPCC default approach



Stock-Change Approach

Figure 5 shows the impact of applying the stock-change methodology.

Figure 5 Indicative carbon stocks in Australia using the stock-change approach

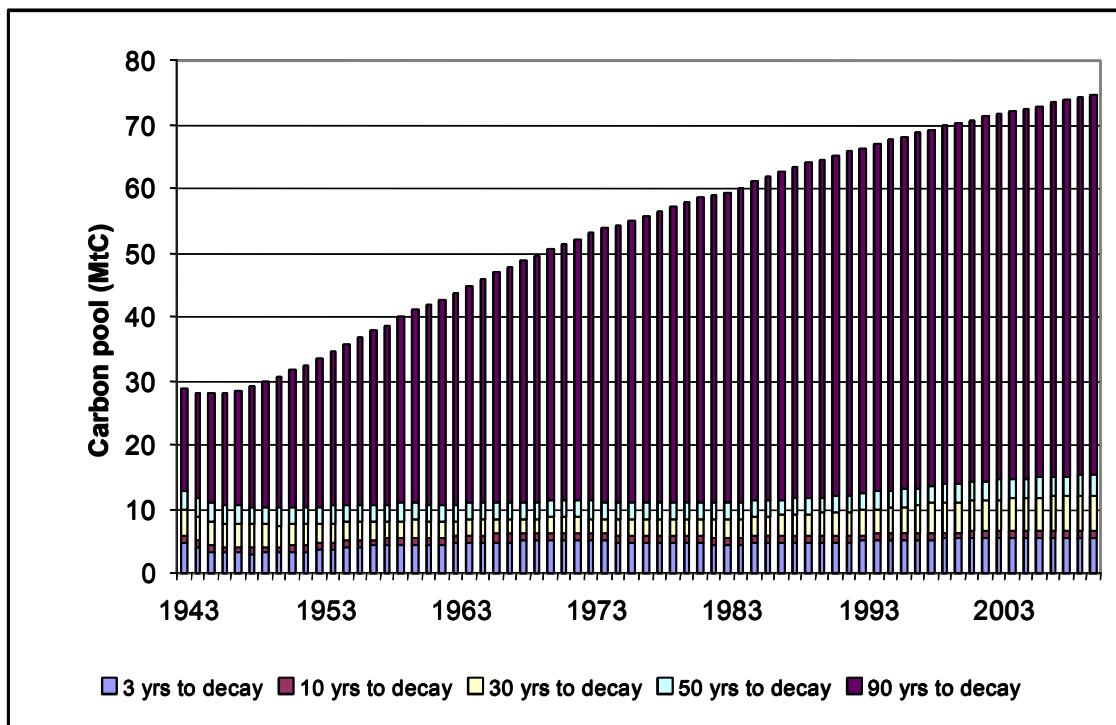
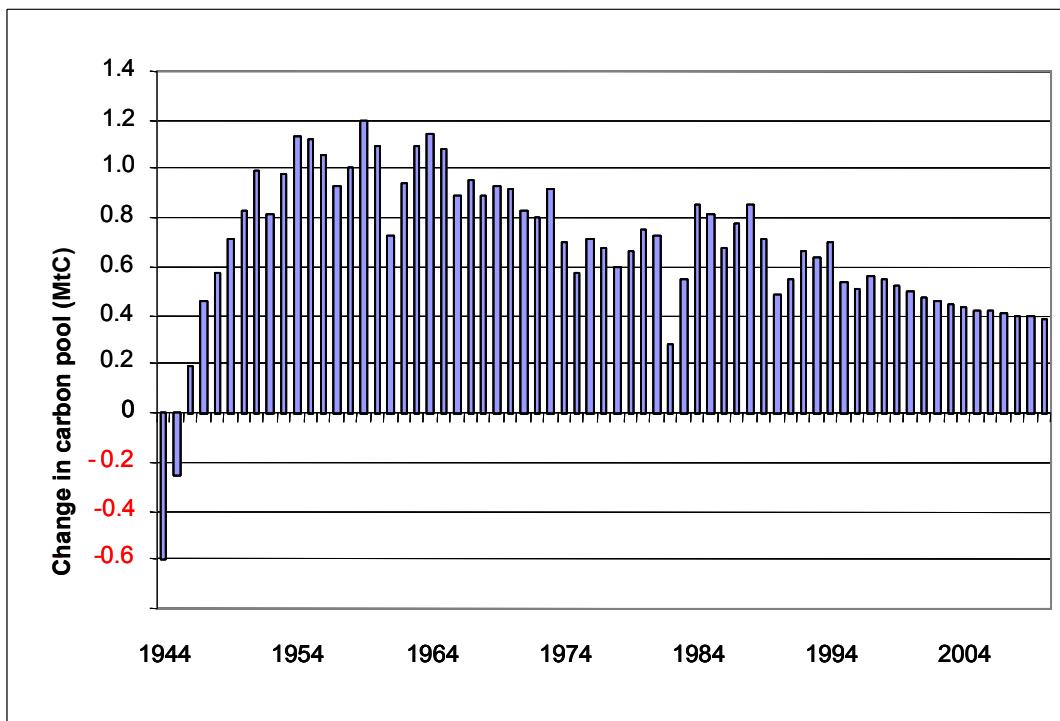


Figure 6 show the change in carbon stocks under the stock-change approach. It is important to recognise that the current version of the Carbon Model assumes production remains constant from 1998. Therefore, annual additions to the pool are also constant. Given that the amount of carbon lost annually through decay within each pool is a function of the size of the pool, the amount of carbon lost through decay each year increases until the amount of carbon lost through decay equals the addition to the pool from production.

Figure 6 Change in carbon stocks under the stock-change approach



Production Approach

Figure 7 shows the impact of applying the production approach.

Figure 7: Indicative carbon stocks in Australia using the production approach

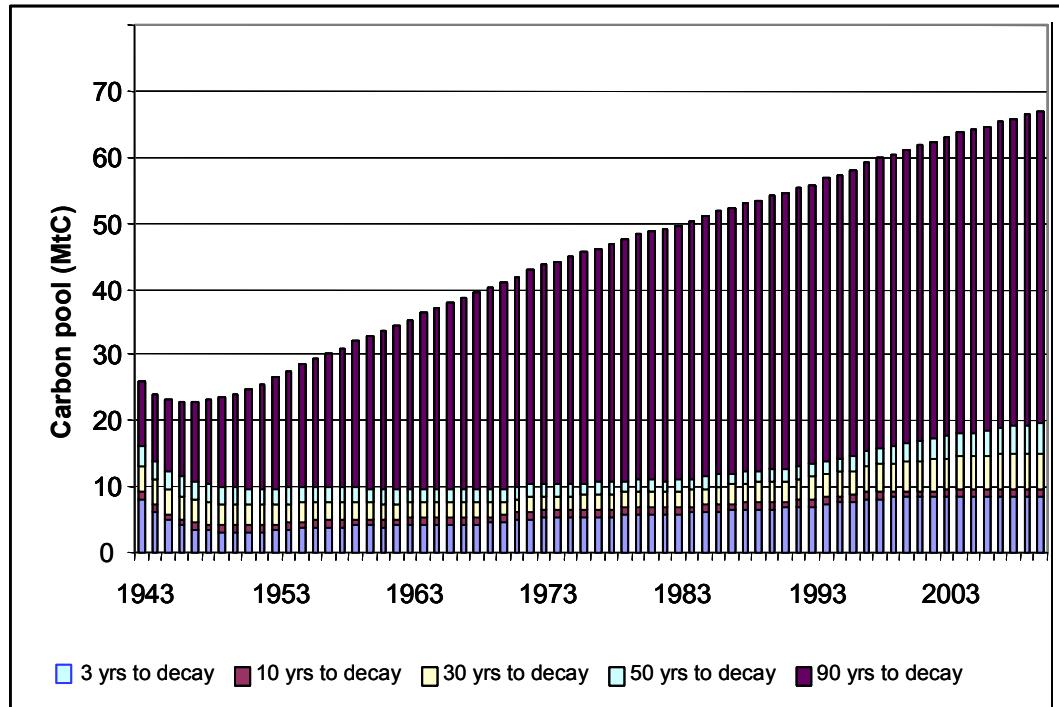
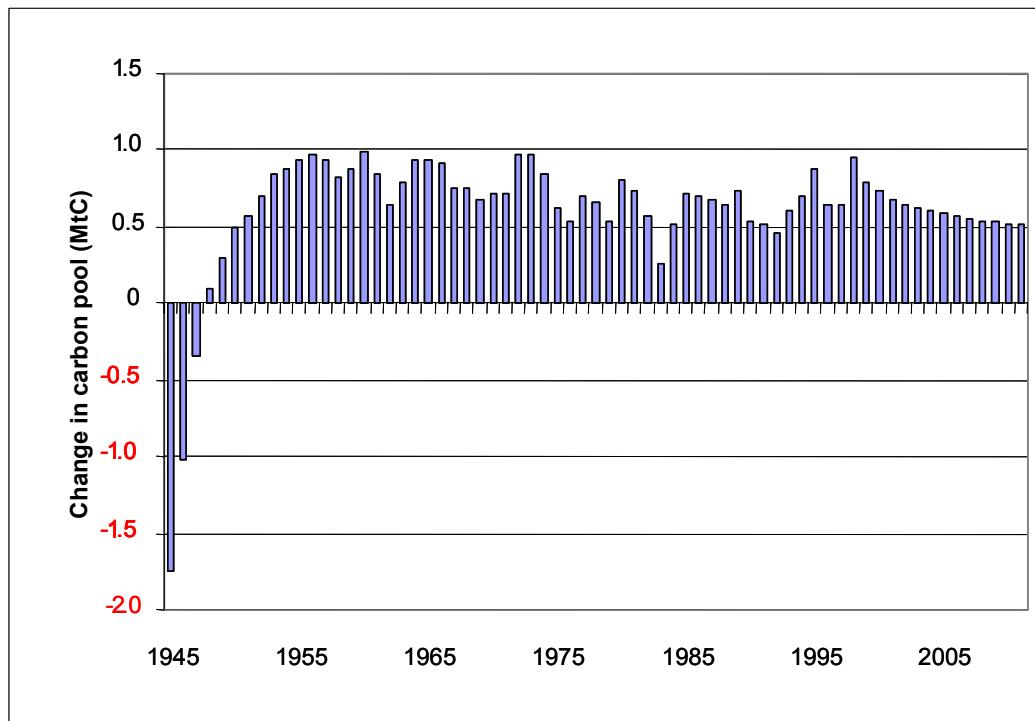


Figure 8 shows the change in carbon stocks under the production approach. The decline shown in the rate of increase in the carbon pool indicates that the amount of carbon lost through decay exceeds the increase in the carbon pool arising from production.

Figure 8 Change in carbon stocks under the production approach



OVERALL COMPARISON OF ACCOUNTING METHODOLOGIES

It is emphasised that the Model's outputs are indicative.

Importantly, however, the Model provides a mechanism by which Australia's carbon stocks can be determined using different accounting approaches. In Figure the outcome of the three accounting methods are compared incorporating historical forest production data. Figures plotted refer to the year 1998. As shown in

Figure 1 and Figure 3 carbon sequestration is constant across all three accounting methodologies. Figure below presents emissions only, to enable comparison between the methodologies.

Figure 9: Comparison of emissions from wood products using the three accounting methodologies

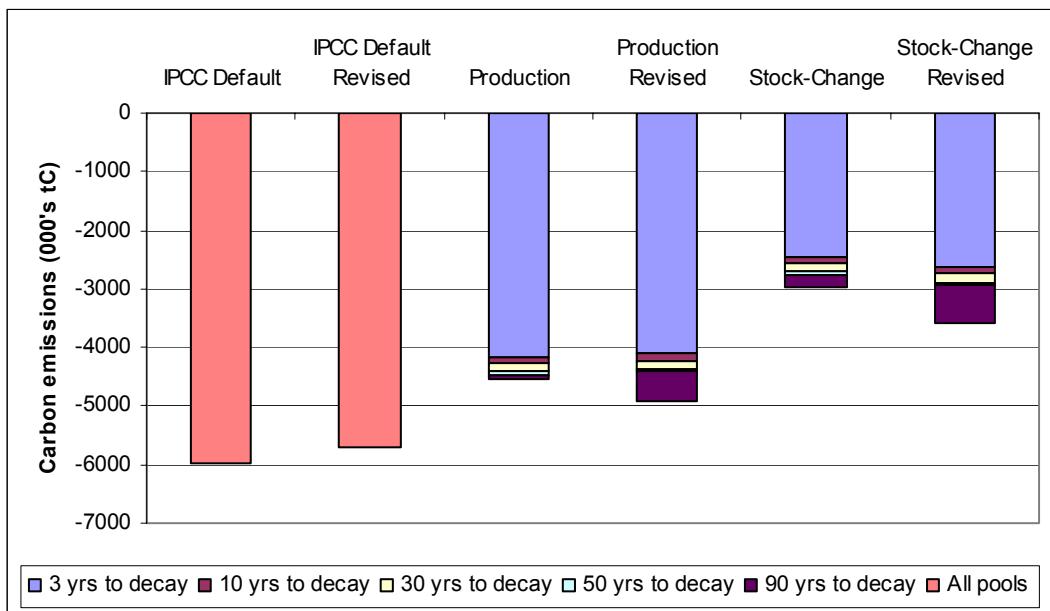


Table 3 summarises emissions.

Table 3: Changes in the wood products pool and emissions for the revised model in 1998

Changes in wood products pool	IPCC Default (Mt carbon)	Production (Mt carbon)	Stock-change (Mt carbon)
Pool carried over from previous year		58.9	68.7
Increase in product pool		5.7	4.1
Decrease in pool due to decay		-4.9	-3.6
Total pools at end of year		59.7	69.2
Emissions under different accounting approaches			
Emission from harvest (IPCC Default)	-5.7		
Emission due to losses in carbon pools (Production and Stock-change)		-4.9	-3.6

It is important to note that we made no attempt to quantify the atmospheric flow approach.

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APPENDIX

Figure 10: National Carbon Accounting Model for Wood Products - Sawmilling Wood Flows *

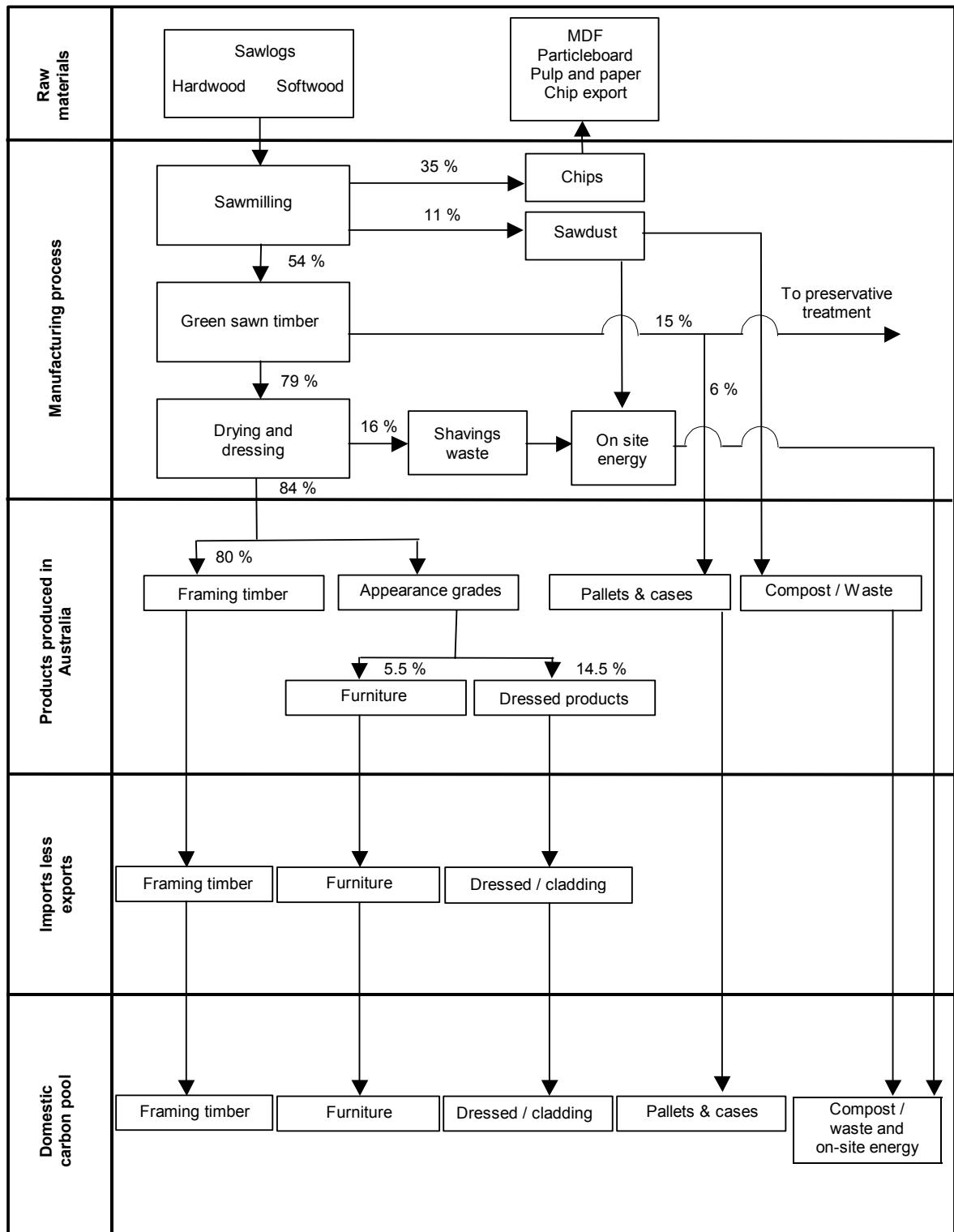


Figure 11: National Carbon Accounting Model for Wood Products - Wood Flows in Preservative Treated Products

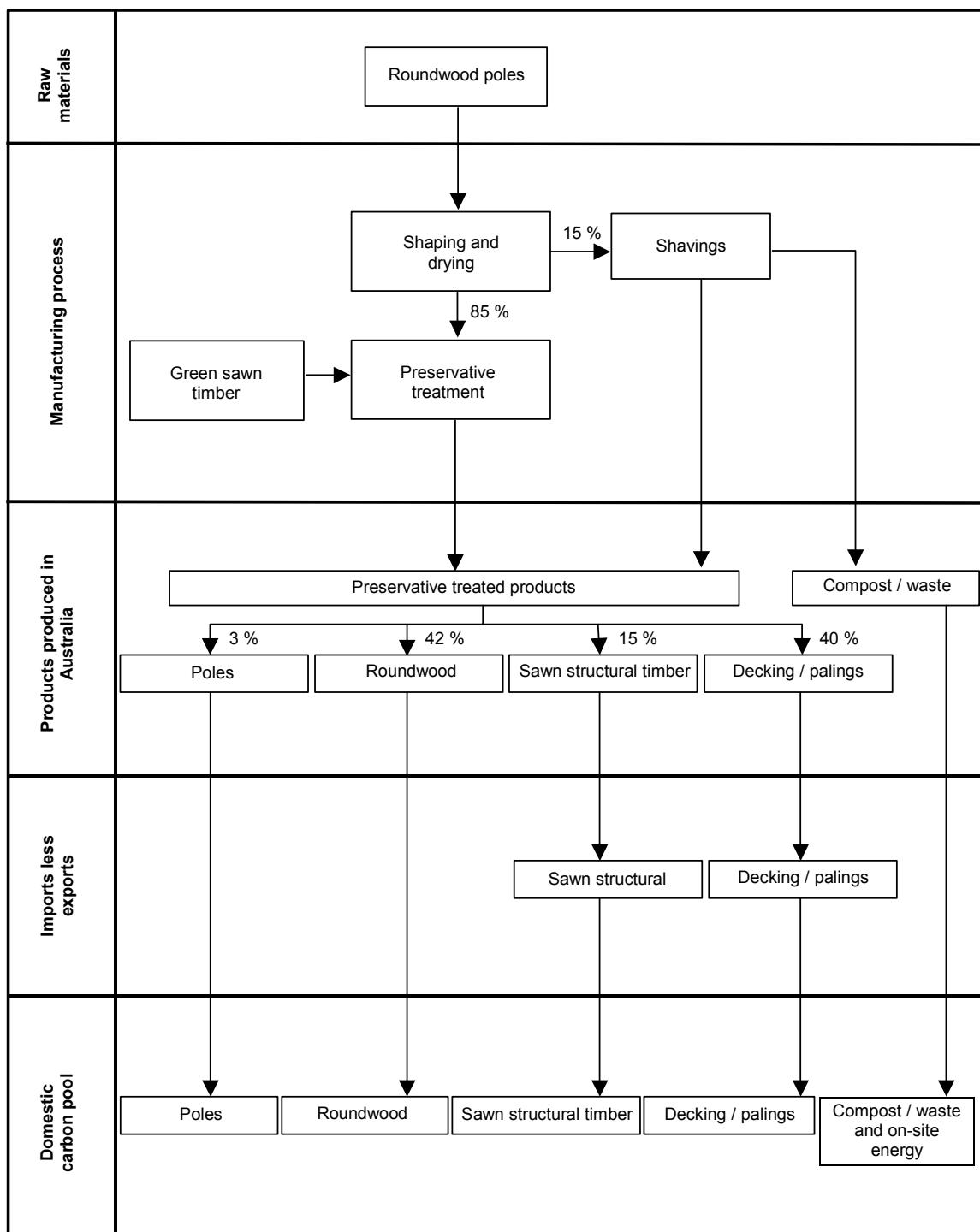


Figure 12: National Carbon Accounting Model for Wood Products - Wood Flows in Plywood Production

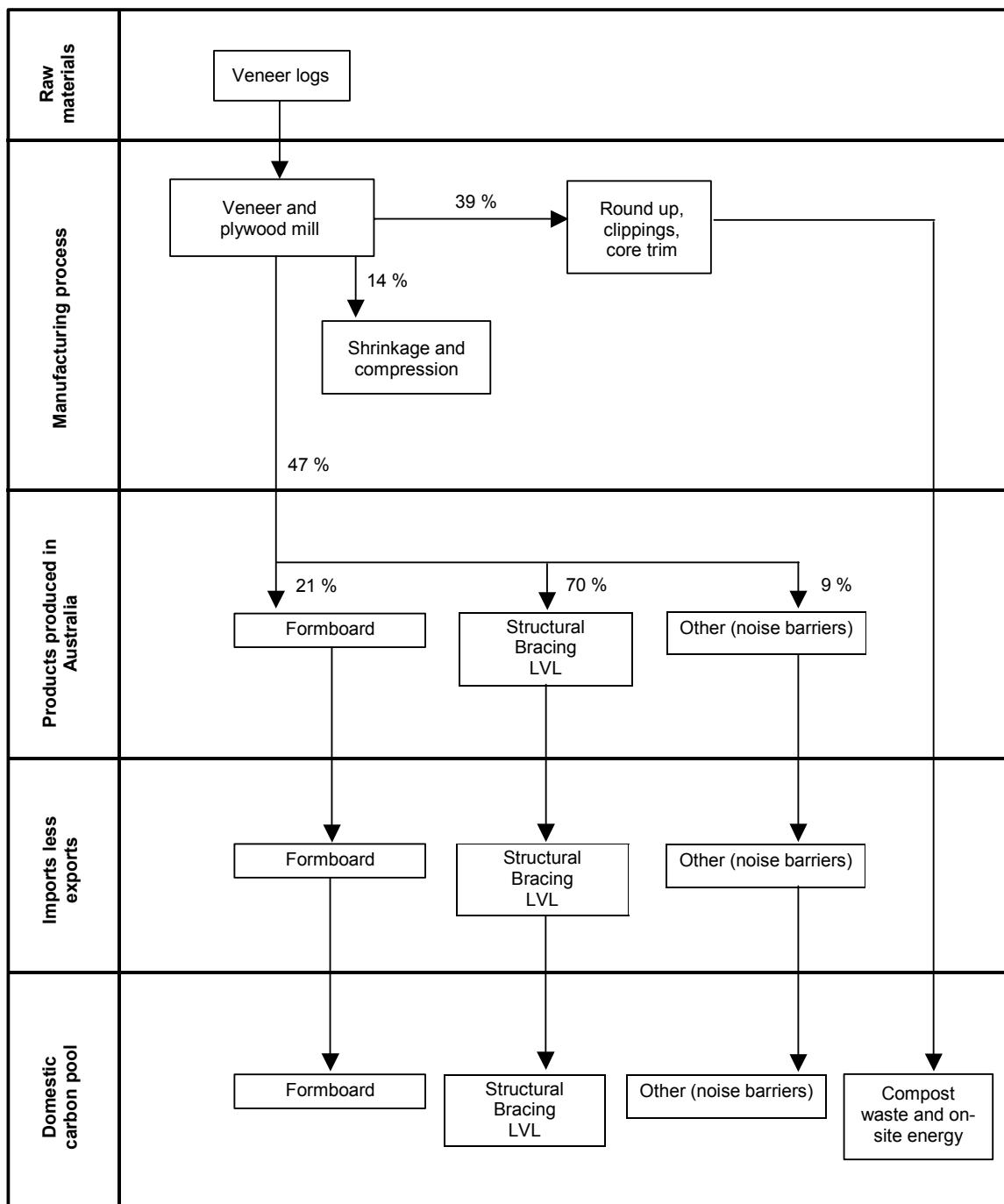
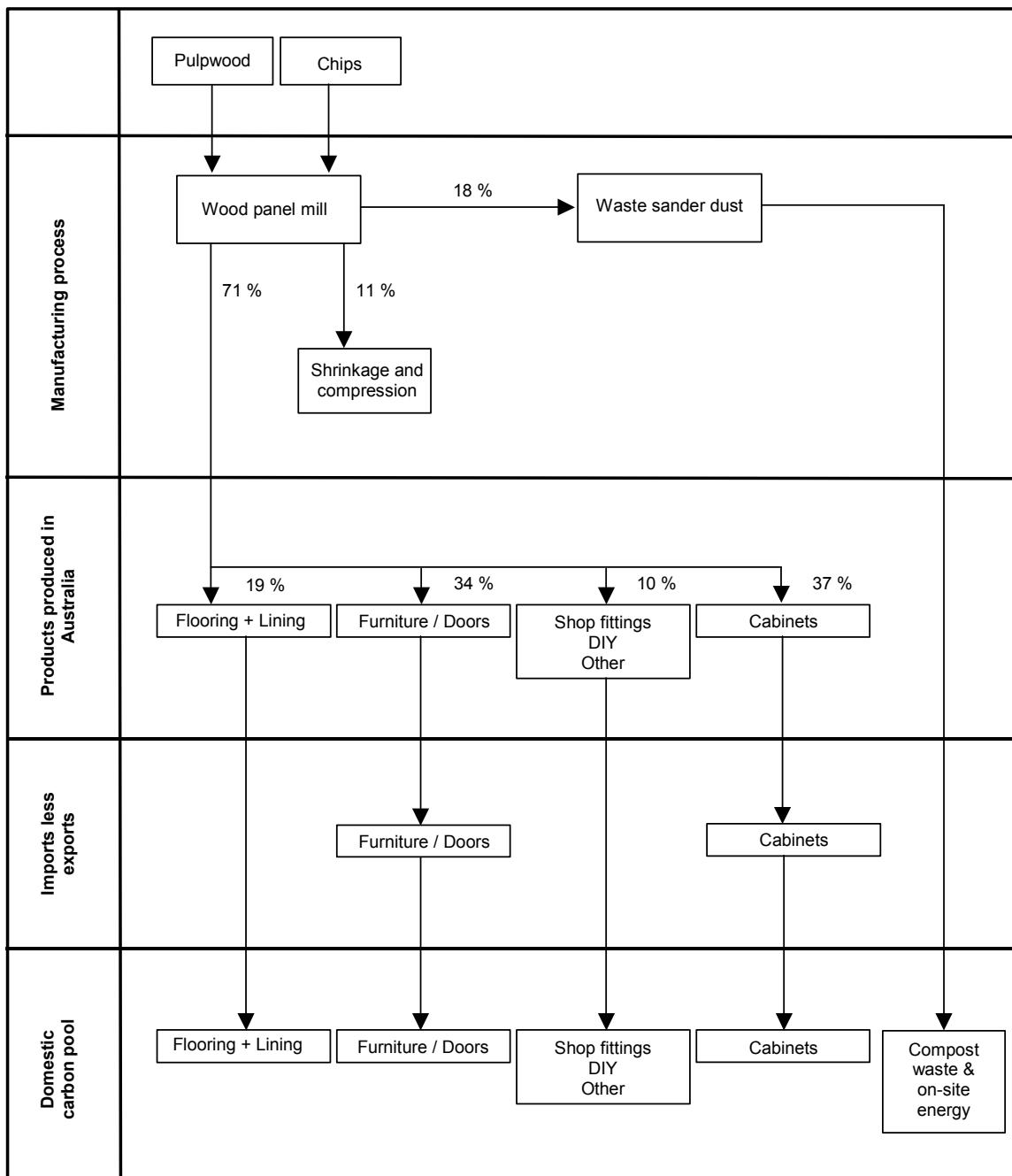


Figure 13: National Carbon Accounting Model for Wood Products - Wood flows in MDF and particleboard manufacture *



* Percentages shown for particleboard manufacture – see model for details on MDF

Figure 14: National Carbon Accounting Model for Wood Products - Wood Flows in pulp and paper manufacture.

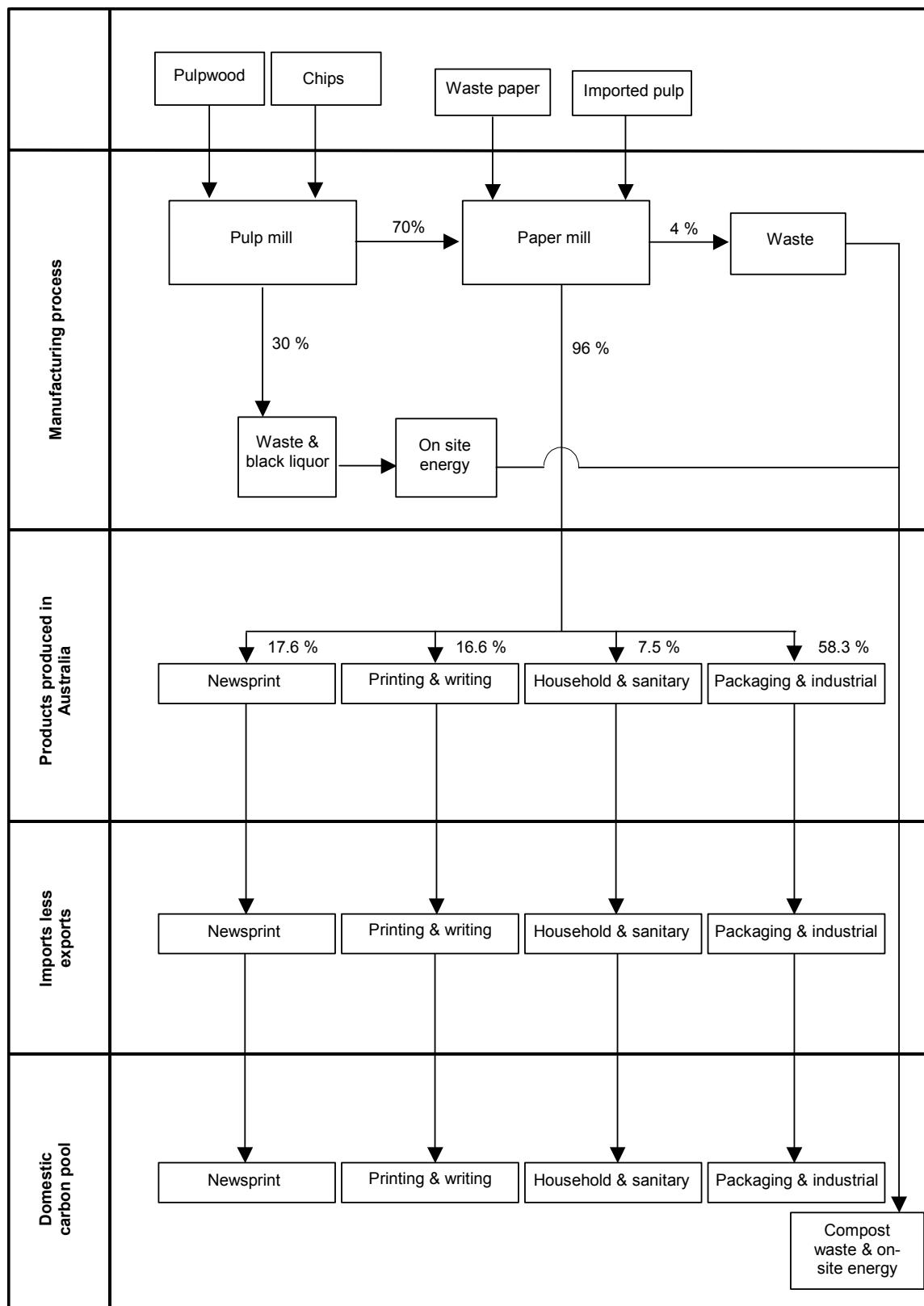
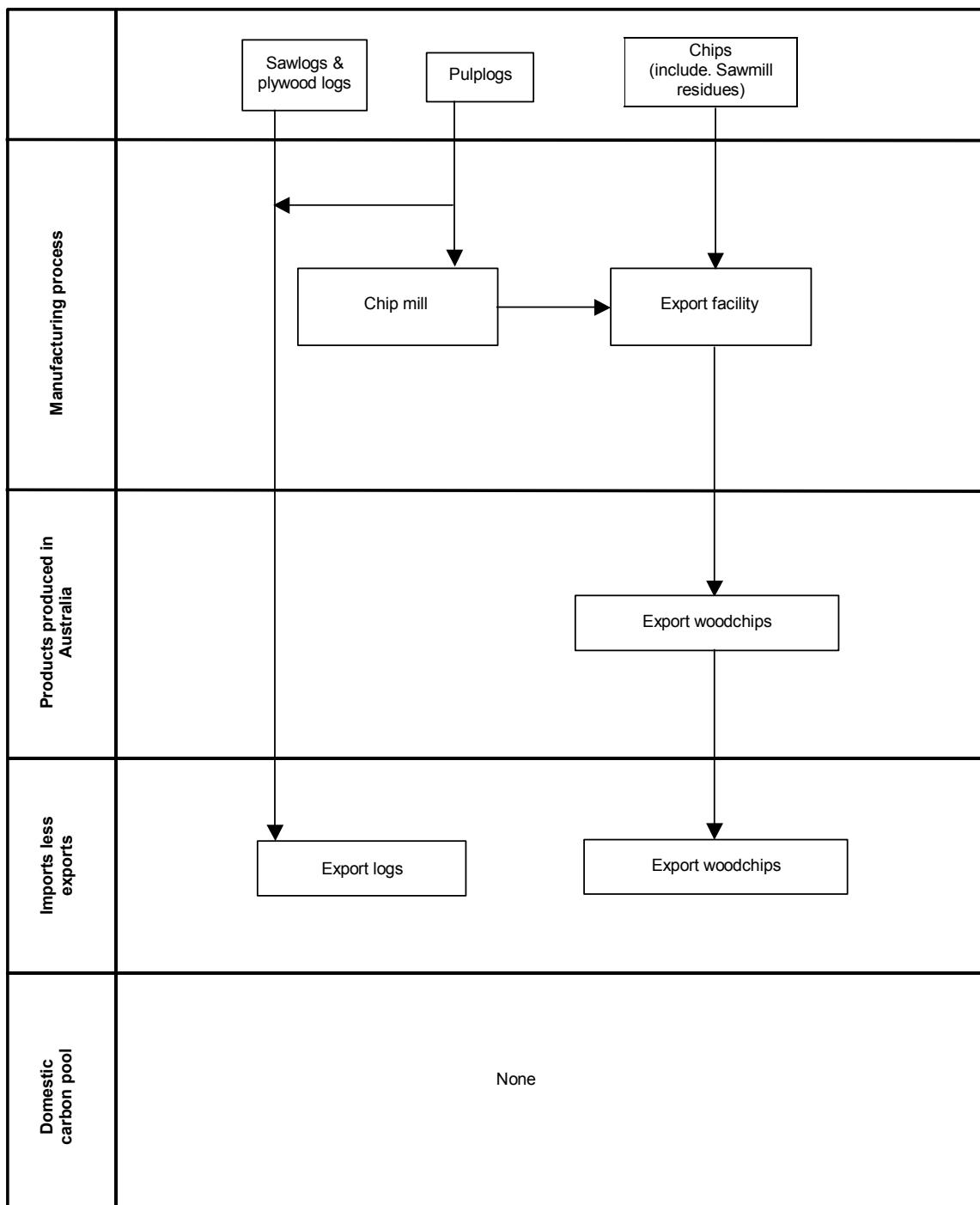


Figure 15: National Carbon Accounting Model for Wood Products - Wood flows in export woodchips and logs.



Chairman's Summary: Harvested Wood Products Workshop Rotorua, New Zealand, 12-16 February 2001

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ABSTRACT

This meeting sought to further develop and refine concepts proposed by the IPCC/OECD/IEA meeting on Evaluating Approaches for Estimating Net Emissions of Carbon Dioxide from Forest Harvesting and Wood Products held in Dakar, Senegal, in May 1998. It was intended that the outcomes of this workshop contribute to the consideration of HWP issues at the 2001 SBSTA meeting and to assist with the preparation of country submissions due on 15 March 2001. A hierarchy of methods, ranging from the simple to the complex, was considered to be the most appropriate means of meeting the reporting requirements of various countries. There are several priority topics that require further information such as: lifetimes of products and product pools; carbon content of products and product pools; disposal after use (landfill, burning, decay, recycling); rate and extent of decay in landfills; rate and proportion of carbon emitted from landfills as methane and carbon dioxide and the co-ordination of assumptions and landfill decay methods with those used in the waste management sector to avoid double counting of emissions

Keywords: Harvested Wood Products, accounting, measurement, data,

INTRODUCTION

The Government of New Zealand sponsored an informal international workshop on the topic of Harvested Wood Products (HWP) to support activities related to the Framework Convention on Climate Change (FCCC) and the Kyoto Protocol. Twelve papers and a series of workshop sessions formed the basis of discussions held in Rotorua, New Zealand from 12–16 February 2001. These papers are available on the Forest Research website at <http://www.forestresearch.co.nz/site.cfm/hwpworkshop>.

The meeting was attended by 52 participants from 17 countries from governmental agencies, the private sector, international and research organisations. The participants expressed their appreciation and thanks to the New Zealand Government and **Forest Research** for organising and hosting the workshop. NZ Forest Industries Council and the American Forest and Paper Association were thanked for sponsoring the field tour that preceded the workshop.

Please note that any points of view presented in the Chairman's summary do not necessarily represent views of particular Parties to the FCCC and should not be viewed as preliminary positions in preparation for the 14th session of the Subsidiary Body for Scientific and Technical Advice (SBSTA).

BACKGROUND

Under the United Nations Framework Convention on Climate Change (UNFCCC), Parties are committed to prepare national greenhouse gas (GHG) inventories of anthropogenic emissions by sources and removals by sinks. The standard reporting framework for preparing GHG inventories is

the *Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories* (Guidelines). The revised 1996 Guidelines were later adopted in Kyoto by the Conference of the Parties as the basis for Annex B Parties to report under the Protocol.

Approaches for accounting for HWP have been the subject of debate within the IPCC process. The last official consideration was the IPCC/OECD/IEA meeting on Evaluating Approaches for Estimating Net Emissions of Carbon Dioxide from Forest Harvesting and Wood Products held in Dakar, Senegal, in May 1998. That meeting sought to identify alternative methodologies to the default approach contained within the Revised 1996 IPCC Guidelines. The IPCC default approach assumes there is no change in the stocks of carbon in wood products and therefore assumes that “all carbon in biomass harvested is oxidised in the removal year”. However, the IPCC Guidelines permit the inclusion of harvested products in national inventories “to account for increases in the pool of forest products. This information would, of course, require careful documentation including accounting for imports and exports of forest products during the inventory period” (Revised 1996 IPCC Guidelines). The accounting approach or methods to be used for such a reporting process are not yet specified. The Dakar meeting defined these terms as follows:

Approach is a conceptual framework for estimating emissions and removals of greenhouse gases in inventories. Within each approach, there may be more than one method.

Method is the calculation framework within an *approach* for estimating emissions and removals of greenhouse gases in inventories.

The accounting approaches discussed at the Dakar Workshop include:

- **Stock Change** approach
This accounting approach uses estimates of net changes in carbon stocks in the forest and wood products pool. Changes in carbon stock in forests are accounted for in the country in which the wood is grown, referred to as the producing country. Changes in the products pool are accounted for in the country where products are used, referred to as the consuming country. These stock changes are counted within national boundaries, *where* and *when* they occur.
- **Production** approach.
This accounting approach also uses estimates of the net changes in carbon stocks in the forests and the wood products pool, but attributes both to the producing country. This approach uses inventories of domestically produced stocks only and does not provide a complete inventory of national stocks. Stock changes are counted *when*, but not *where* they occur if wood products are traded.
- **Atmospheric Flow** approach
This accounting approach uses net emissions or removals of carbon to/from the atmosphere within national boundaries, *where* and *when* the emissions and removals occur. Removals of carbon from the atmosphere due to forest growth are accounted for in the producing country, while emissions of carbon to the atmosphere from oxidation of HWP are accounted for in the consuming country.

The system boundaries of the three accounting approaches differ. All three approaches offer tiered methods, ranging from the default method based on currently available data, to a second or third tier relying on national statistics of varying levels of detail.

This informal workshop on harvested wood products sought to further develop and refine concepts proposed by the meeting in Dakar. It is intended that the outcomes of the workshop will assist Parties with preparation of submissions due on 15 March 2001 and contribute to the consideration of HWP issues by the SBSTA.

POLICY ISSUES

Among other benefits increasing the stocks of carbon in harvested wood products and increasing the use of biofuels were generally considered to be beneficial to atmospheric greenhouse gas concentrations. Providing there were no disincentives for emission reductions, appropriate incentives and other mechanisms, for increasing the stocks of carbon in wood products and the use of biofuels were generally considered to be policy relevant outcomes.

More information on the magnitude and source of the global and national HWP stocks and movement, and an improved understanding of the responses of these stocks to policy direction would benefit decision-makers. Greater knowledge of the economic, environmental and social factors that drive demand for wood products, and that influence carbon stocks of these products would assist in achieving these objectives.

A hierarchy of scientifically credible methods may be needed. Such a hierarchy of methods, comparable with other greenhouse gas inventories, is presented in the technical section below.

The meeting noted the clear **distinction between reporting** requirements for HWP under the UNFCCC and **the accounting** requirements under the Kyoto Protocol

The current uncertainty surrounding the Kyoto Protocol, specifically with regard to Articles 3.3 and 3.4, is one aspect limiting the development of policy options relating to HWP.

The challenges in developing policies for dealing with HWP were noted. Important issues raised by some participants included:

- The need for globally relevant policies over the longer term, and their possible conflict with the limited country involvement and forest coverage.
- The Land Use, Land Use Change and Forestry (LULUCF) accounting rules proposed for the Kyoto Protocol.
- The potential impacts of HWP accounting approaches and methods on developing countries.

The meeting agreed that application of the IPCC default accounting approach may not capture the atmospheric impact of HWP and may not provide a direct incentive for the long-term storage of carbon in wood products. However, the meeting also noted that current method provide some incentives for using woody biomass for fuel.

The Dakar Report assessed some policy issues related to the four proposed approaches, e.g., the incentives for sustainable forest management, deforestation, and the use of biofuels. There is a need to further examine the existing and proposed approaches in this policy context. A detailed assessment of the likely impacts of the approaches on trade flows was considered to be necessary by some participants. This assessment may require involvement of a number of competent national and international bodies. Some participants noted that an agreement on approach may facilitate the elaboration of appropriate inventory methods.

Priority topics requiring further information

These items were identified for further investigation:

- Magnitude/scale and source of harvested wood products and their changes over time.
- Assessment of HWP stock changes at a global level as a means of determining the validity of the IPCC default.
- Trade flow implications of the various approaches.

TECHNICAL ISSUES

A hierarchy of methods, ranging from the simple to the complex, was considered to be the most appropriate means of meeting the reporting requirements of various countries. Production data,

including roundwood production, and the imports and exports of wood products, were generally considered to be robust whereas data on stocks and dynamics of products in use and after disposal, such as product lifecycle information, decay rates, and landfill information were more uncertain.

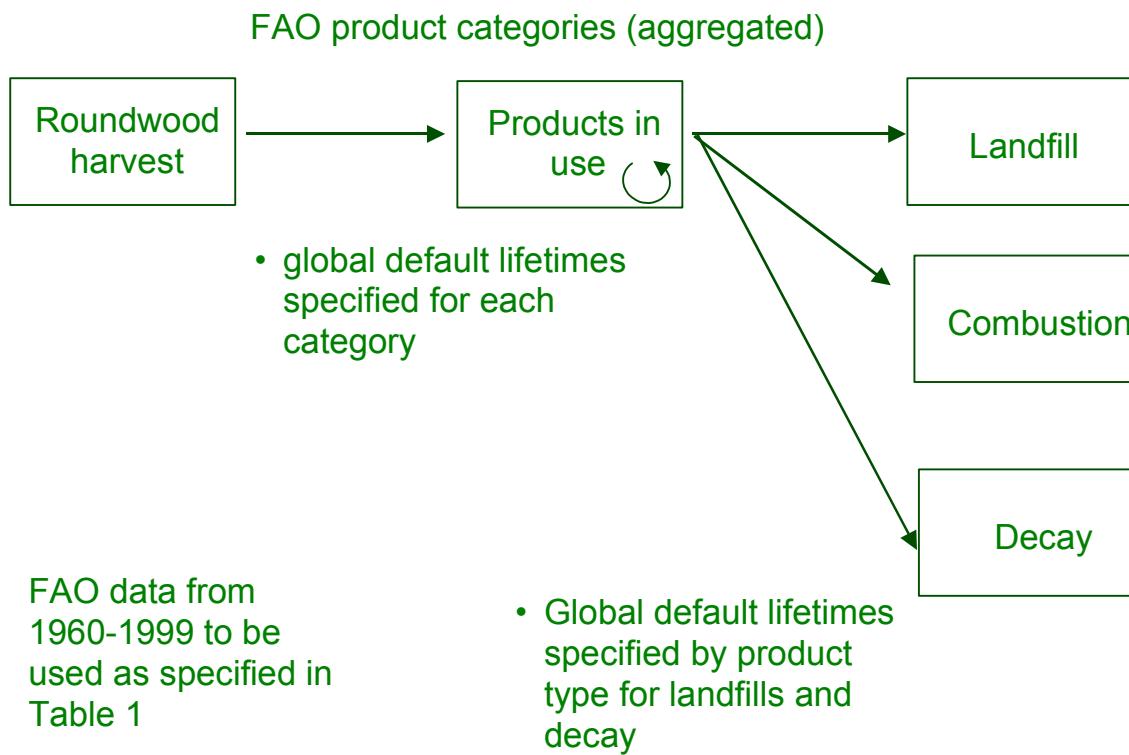
It was suggested it would be difficult to trace the origin of wood products, e.g., from different countries or forests. One solution proposed is to include the management of harvest wood products carbon stock as an additional activity under Article 3.4.

There may be a need for a clear distinction between wood products in use and those disposed of in landfills, and to ensure there is no double counting between sectors. In the future, both LULUCF and waste sector inventory guidelines may require further work.

Tier 1 methods: estimating carbon stock additions, removals and emissions from HWP

A tier 1a method, which is the simplest method, was initiated as shown in Figure 1. The FAO forest products database, which covers the period from 1961-1999, was proposed as a starting point for making estimates. The adequacy of the data and the proposed method need further evaluation. The FAO database, together with estimates of decay and emissions from products could be sufficient to make estimates needed for all the Dakar accounting approaches. An argument was presented that the FAO fuelwood data, which may be less robust, would not be required for estimating stock changes

Figure 1: Tier 1a HWP method



over an extended period (i.e., a time interval at least as long as the product lifetime), these data may be used to estimate the stocks of carbon in the different product pools. It was noted that an incorrect starting stock assumption may generate misleading results because emissions from wood products generated prior to the start date are ignored. The methodology for calculating the carbon stock data is summarised in Table 1 and a suggestion of aggregated product categories based upon the FAO Classification and definitions of forest products, is presented in Table 2. Data on lifetimes for each product category and in landfills is required to complete the calculation. Examples of product lifetime ranges for these pools are presented in Table 2. The participants suggested that the waste management sector decay guidelines could be used in order to remain consistent with existing IPCC

Guidelines. It is acknowledged that estimates of product lifetimes and decay rates will vary regionally and nationally and are based on limited data. Improving the accuracy of these estimates is considered to be a priority topic.

Table 1: Example of Tier 1 calculation methodology

Roundwood harvest (including bark)	= Products with long lifetime (A) + Products with medium lifetime (B) + Products with short lifetime (C) + Fuelwood from roundwood + Residue not used for above products
Quantities A, B, and C are intended to be estimates of a country's harvested wood fibre in a year that ends up in products. Countries may export some of the products. Amounts of carbon exported would be noted. Emissions from the products remaining in country would be estimated over time. Emissions from a country's imported wood products would also be estimated over time. For products with HWP inputs from other countries (such as paper and paperboard products which may use imported market pulp) or recycled inputs the method would need to allow for this refinement.	

Table 2: Examples of aggregated forest product categories and possible life times

Product category	Product type	Possible life time (years)
Long life time	Softwood sawnwood Hardwood sawnwood Veneer sheets Plywood	40-60
Medium lifetime	Particleboard (including OSB) Fibreboard Fibreboard compressed Medium density fibreboard Hardboard Insulating board	15-30
Short lifetime	Wood pulp Recovered paper Newsprint Printing and writing Household and sanitary Wrapping and packaging Other paper and paperboard	1-3

It is recognised that product lifetimes will vary due to a number of technical and socioeconomic factors. These vary both between region and over time. Where national information is available on product lifetimes, these data may be substituted for the global default values. This method has been termed Tier 1b and is represented in Figure 2.

Tier 2 method: direct inventory

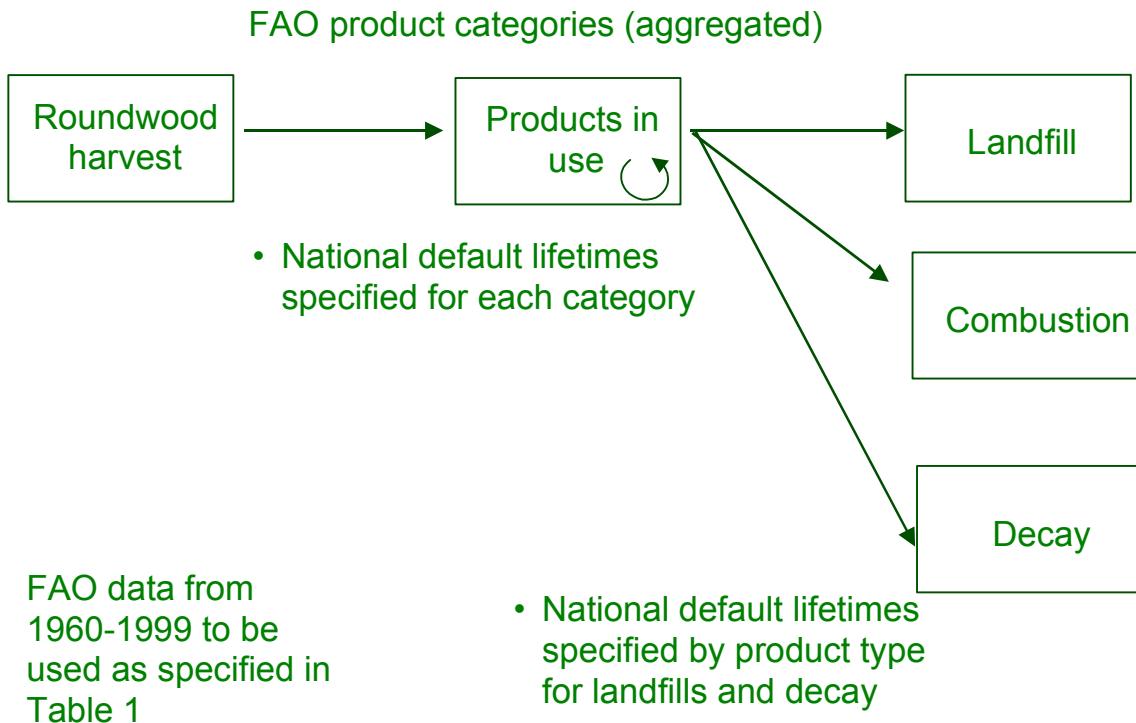
Countries may use their own data to improve inflows and outflows, e.g., roundwood removals, product manufacture, and landfill decay rates. Where suitable data are available, a direct inventory method, which is based on an empirical estimate of the product pool, is preferred. Such a method may result in a more accurate assessment than the Tier 1 methods. At present, some countries are able to undertake a direct inventory of some products. Countries are encouraged to use a hybrid of Tier 1 and 2 methodologies as data availability permits and to move towards a complete Tier 2 method over time. Inventory surveys could be used to initialise Tier 1 methods.

Priority topics requiring further information

The following list summarises the major areas of data uncertainty. These items are priority topics for further investigation:

- lifetimes of products and product pools
- carbon content of products and product pools
- disposition after use (landfill, burning, decay, recycling)
- rate and extent of decay in landfills
- rate and proportion of carbon emitted from landfills as methane and carbon dioxide
- alignment of assumptions and landfill decay methods with those used in the waste management sector to avoid double counting of emissions.

Figure 2: Tier 1b HWP method



INTERNATIONAL COLLABORATIVE STUDY

It was agreed that development of a Tier 1 method and a series of case studies testing the Tier 1 and improved methods would be the best means of advancing capability in reporting on HWP, determining the areas of greatest uncertainty and providing input to a variety of accounting approaches. Undertaking the case studies may also guide countries' understandings of the policy implications that need to be addressed in the HWP deliberations.

An informal international study to develop such case studies was tentatively agreed to by the following countries:

- Australia
- Canada
- Finland
- France
- Japan
- New Zealand
- Norway
- Sweden
- United Kingdom
- United States

Other participants indicated that their countries may be able to participate in this study and would confirm their involvement after the meeting. The meeting encouraged the participation of Annex 1 and Non-Annex 1 countries in this work.

New Zealand undertook to coordinate the collaboration. An outline of the proposed collaboration will be circulated by 31 March 2001 and confirmation of participation will be sought by 30 April 2001. The output from this informal collaboration may be used to contribute to formal processes within the framework of the IPCC and UNFCCC.

ACKNOWLEDGEMENTS

The assistance of Justin Ford-Robertson, Angela Duignan and Dianne LeBas in writing this summary (with support from the New Zealand Foundation for Research Science and Technology under CO4X0009) is greatly appreciated. The comments from New Zealand government and industry participants, as well as other participants from overseas, have greatly improved the final version of this report.

Fossil Carbon Emissions Associated with Carbon Flows of Harvested Wood Products

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ABSTRACT

Specific fossil-carbon (C) emissions and primary energy use associated with manufacture of harvested wood (HWP) products in Finland are estimated and expressed as emissions or energy use per amount of C in wood raw material and per amount of C in end product. Supplied fuels as well as electricity bought from the markets are allocated to different product groups, and represent average numbers of the Finnish forest industries. C emissions of electricity (kgC/MWh) bought from the national-grid are calculated on the basis of its energy sources. The reference year in the calculations is 1995. The main product groups considered in the analysis are in mechanical wood processing sawn wood, plywood, particle board, and wood fibre board; and in pulp and paper industries: production lines based on chemical pulping, mechanical pulping, and recycled fibre, including also paper milling.

The results of the study show, for example, that the primary energy use per wood based C in end product is of the order of 2 MWh/tC for sawn wood but for virgin paper grades it is 17-19 MWh/tC. In papers based on chemical pulping the energy rucksack is highest, but around 60% of energy is in this case produced from by-product wood wastes (black liquor, bark etc.). The corresponding specific emissions of fossil C per wood based C in end products are of the order 0.07 for sawn wood and 0.3-0.6 for paper. The above energy and emission rucksacks may be illustrative indicators when evaluating the greenhouse impact of integrated forestry for wood products and bioenergy. Especially they should be remembered when considering wood products as a thinkable C sequestration option.

Keywords: Specific fossil C emissions, primary energy use, C flows of wood products, C emission and primary energy rucksacks, C sequestration in wood products.

INTRODUCTION

Harvested wood products (HWP) form a stock of carbon (C), which is sequestered from the atmosphere due to the process of photosynthesis. Basically, by increasing this C stock HWP act as C sink by which the atmospheric amount of C can be lowered. In addition, HWP can substitute for other, more energy-intensive and fossil-fuel-intensive products, which means that in some cases by using HWP we can reduce indirectly fossil C emissions. Wood residues building up during harvesting and manufacturing of HWP can also be utilised as bioenergy as well as HWP themselves at the end of their life cycle, by which fossil fuel use can be reduced additionally.

For the present the changes of C stocks in HWP are basically not reported (on the reporting guidelines, see IPCC, 1996) under the United Nations Framework Convention for Climate Change (UNFCCC, 1992). However, at the moment there is going on an intensive discussion how HWP could be included to the national greenhouse gas (GHG) balances reported and what would be the benefits and disadvantages of the various reporting approaches proposed (HWP workshop, 2001; Brown et al. 1998). It has also been proposed that HWP should be taken into account in the national GHG balances when the attainment of national GHG commitments are assessed under the Kyoto Protocol (UNFCCC, 1998). The Article 3.4 of the Protocol could allow a formal framework for that.

The use of HWP has side effects on the atmosphere in the form of fossil C emissions from harvesting, transportation and manufacturing of HWP, which are not becoming aware if only changes of C stocks in HWP are counted. In fact, the total life cycle of HWP, including waste management, should be considered when assessing their true impact on global warming (GW). HWP are a relatively inhomogeneous group. They have varying life times, from very short-lived paper grades to long-lived timber structures. Manufacture of HWP demands very different amounts of energy depending on product types, and in addition, energy demand in the manufacture can be supplied in various ways. Also waste management and recycling differ a lot between various HWP. Demand for HWP is determined in the markets, but when assessing GHG mitigation strategies associated with HWP, individual companies and even countries should pay attention to the total C balance including the side effects or emission rucksacks discussed above.

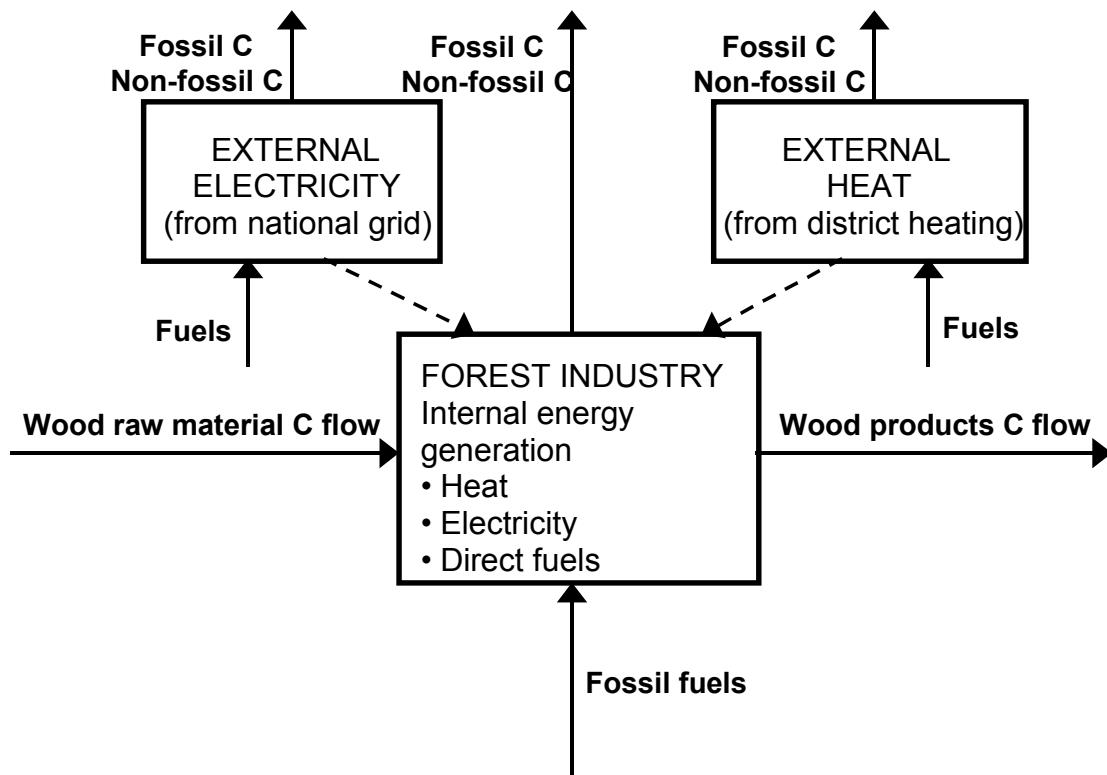
The aim of the study is to estimate the specific fossil C emissions and primary energy use associated with manufacturing of various types of HWP in Finland. These specific numbers are expressed as fossil C emissions or energy use per amount of C in wood raw material and per amount of C in end product. The fossil C emission in proportion to C in end product also illustrates how effective tool different HWP can be in C sequestration. In addition, results from a separate case study on fossil C emissions of harvesting and transportation of HWP are compared with the emissions of manufacture HWP, to open up a view of the GHG impacts of using wood products.

METHODS

For the study a model was developed, which allocates the fossil C emissions and primary energy consumption of manufacture HWP to the main production lines of the forest industries. The parameters collected and used in the model represent average numbers in the Finnish forest industries in 1995. The C flows and energy production, associated with forest industries, are illustrated in Figure 1. Within forest industries heat and electricity are produced from by-product fuels of wood processing and additional fossil fuels are bought from the markets. Great bulk of electricity and a small amount of heat used by Finnish forest industries are supplied from external sources. Thus also fossil C emissions and primary energy consumption related to these sources had to be included into the model.

The forest industries can be divided into two major parts: mechanical wood processing and pulp and paper industry, which, however, are closely interconnected with each other. The main wood material flows of the forest industries are illustrated in Figure 2. For instance, a significant portion of wood raw material used in pulp and paper manufacture is wood residues coming from mechanical wood processing. For simplicity and the sake of clarity, HWP manufactured in these two parts were grouped to main production lines, also shown in Figure 2, which in their energy use essentially differ from each other.

Demand for heat, electricity and direct fuels of the different production processes was the starting point of the calculations. On the basis of the estimated efficiency rates of boilers, fuel mix and proportion of self-generated electricity, the amount of purchased fuels, electricity and heat was estimated and allocated to each production line. The numbers represent an average value in each branch of production in the Finnish forest industries. The C emissions were calculated on the basis of fuel consumption by applying conventional emission factors for each fuel (see e.g. IPCC, 1996; Ministry of the Environment, 1999; Lehtilä and Tuhkanen, 1999, Statistics Finland 1996).

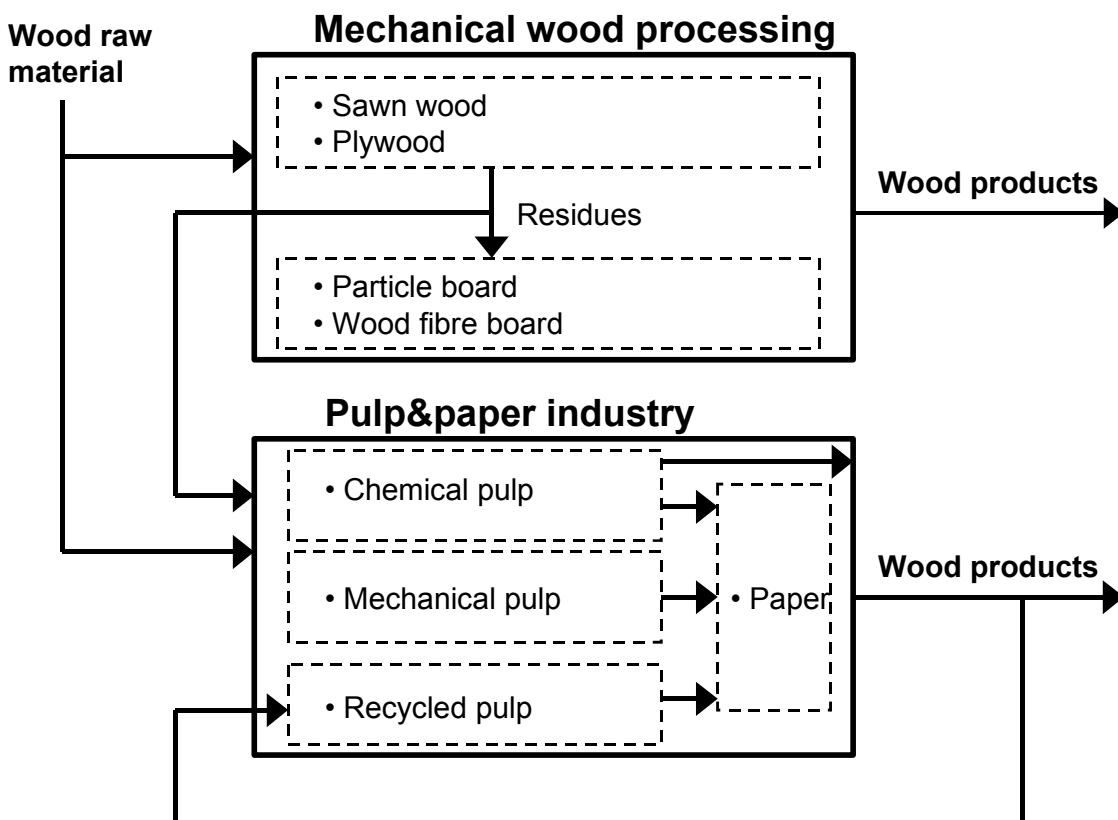
Figure 1. C flows and emissions associated with manufacture of HWP.

Mechanical wood processing

In mechanical wood processing the main branches of production considered were manufacturing of sawn wood, plywood, particle board, and wood fibre board. The specific demand for heat, electricity and wood raw material for the branches is given in Table 1. The energy demand was supplied by internal generation with a fuel mix given in Table 2, and in addition a part of electricity and heat was bought from external sources also indicated in Table 2. The energy content of wood residues of saw and plywood milling, used by other processes as raw material (see Fig. 2), were not accounted for these primary processes although the residues could in theory be used for their energy supply.

Table 1. Total production in 1995 and estimated specific demand for heat, electricity and raw material in the main production branches of mechanical wood processing in Finland (Finnish Forest Research Institute, 1996; Lehtilä, 1995; Myréen and Anhava, 1992).

	Production 1000 m ³ /a	Heat MWh/m ³	Electricity MWh/m ³	C in raw material / C in end product
Sawn wood	9 400	0.22	0.078	2.22
Plywood, block board	778	1.10	0.30	2.59
Particle board	485	0.49	0.18	1.22
Wood fibre board (1000 t/a, MWh/t)	79	2.11	0.64	1.22

Figure 2. Main wood material flows within forest industries.**Table 2.** Estimated average energy supply in the main production branches of Finnish mechanical wood processing in 1995 (A. Lehtilä, personal communication).

	Sawn wood	Plywood	Particle board	Wood fibre board
Internal energy generation				
Assumed efficiency of heat production = 80 %				
<u>Fuels:</u>				
Coal	6 %	0 %	0 %	1 %
Oil	14 %	16 %	40 %	5 %
Peat	1 %	1 %	0 %	7 %
Gas	29 %	1 %	0 %	80 %
Biomass	50 %	82 %	60 %	6 %
Self-generated electricity				
% of internal energy generation	13 %	3 %	0 %	7 %
External energy				
(share of total supply)				
Heat (district h. + pulp&paper i.)	20 %	20 %	20 %	20 %
Electricity (national grid)	60 %	90 %	100 %	77 %

Pulp and paper industry

In pulp and paper industries we grouped the production lines according to main pulp types and not end products, which are various paper grades, as the differences in energy demands between the main pulp types appear to be so essential. The production lines considered were those of chemical pulping, mechanical pulping, and recycled fibre, also including paper milling in each line. The energy consumption of paper milling varies dependent on the paper grade. Therefore, the energy use of each paper grade is allocated to each of the three production lines on the basis of the paper recipes, i.e. of the proportion of each pulp type in each paper grade, which can be found in Table 3. We can also see from Table 3 that some paper grades contain significant amounts of non-wood based material, due to mainly stone-based fillers and various coating materials.

The specific demand for direct fuels, heat, and electricity are given for pulping in Table 4 and papermaking in Table 5. In Table 4 is also given the estimated demand for wood raw material in proportion to wood material in pulp. It should be remarked that the demand for energy within each major pulp type (mechanical, chemical, recycled) is dependent on the relative production share of different pulp grades within each of the above main pulp types.

Table 3. Average papermaking recipes in Finland in 1995 (A. Lehtilä, personal communication).

Main paper grades	t paper / t pulp	MECHANICAL PULP					CHEMICAL PULP			RECYCLED PULP	
		GWP, NB	GWP, B	TMP, NB	TMP, B	SCP . .	HSUP, B	SSUP, NB	SSUP, B	REC, NB	REC, B
Chemical pulp board	1.02	0	0	0	0	0	0.527	0	0.473	0	0
Mech. woodpulp containing board	1.01	0.347	0	0.183	0	0	0.216	0	0.165	0.089	0
Fluting	0.96	0	0	0	0	1.000	0	0	0	0	0
Liner	0.99	0	0	0	0	0	0.107	0.731	0.106	0.056	0
Other papers (tissue etc)	0.98	0.113	0	0	0	0	0.148	0.105	0.215	0.127	0.293
Other papers (kraft etc)	0.97	0	0	0	0	0	0.107	0.731	0.106	0.056	0
Newsprint paper	0.99	0.292	0.024	0.530	0.032	0	0	0	0.059	0	0.062
Fine grade paper, coated	1.59	0	0	0	0	0	0.680	0	0.292	0	0.028
Fine grade paper, uncoated	1.22	0	0	0	0	0	0.680	0	0.292	0	0.028
Mech. woodpulp paper, coated	1.49	0	0.354	0	0.242	0	0	0	0.395	0	0.010
Mech. woodpulp paper, uncoated	1.24	0	0.354	0	0.242	0	0	0	0.395	0	0.010

Abbreviations used:

GWP = groundwood pulp, TMP = thermomechanical pulp, SCP = semi-chemical pulp,

HSUP = hardwood sulphate pulp, SSUP = softwood sulphate pulp,

REC = recycled pulp, B = bleached, NB = unbleached

Table 4. Total production in 1995 and estimated specific demand for direct fuels, heat, electricity, and raw material of the main pulp grades in Finnish pulp industry (Finnish Forest Research Institute, 1996; Lehtilä, 1995; Carlson and Heikkinen, 1998; Malinen et al. 1993; Myréen and Anhava, 1992).

	Main pulp grades	Production 1000 t/a	Direct fuels MWh/t	Heat MWh/t	Electricity MWh/t	C in raw material / C in end product
MECHANICAL PULP	GWP, NB	801		0	1.55	1.20
	GWP, B	1 167		0	2.10	1.20
	TMP, NB	943		-0.75	2.40	1.20
	TMP, B	818		-1.17	3.37	1.20
	SCP	509		1.06	0.40	1.45
CHEMICAL PULP*	HSUP, B	2 174	0.39	3.07	0.69	2.46
	SSUP, NB	680	0.52	2.77	0.57	2.71
	SSUP, B	2 928	0.52	3.33	0.75	2.71
RECYCLED PULP	REC, NB	180		0	0.10	1.05
	REC, B	272	0.25	0.17	0.40	1.10
	Total pulp production	10 472				

*Pulp drying applied to 51% of production included in the numbers

Abbreviations used:

GWP = groundwood pulp, TMP = thermomechanical pulp, SCP = semi-chemical

pulp, HSUP = hardwood sulphate pulp, SSUP = softwood sulphate pulp,

REC = recycled pulp, B = bleached, NB = unbleached

The energy supply of Finnish pulp and paper industry is allocated to the three production lines as follows:

- 1) By-product biofuels, black liquor and wood waste (bark etc), are used in those production lines, where they build up. For instance, black liquor is a by-product in chemical pulping, bark is a by-product when round wood is used as raw material, whereas recycled pulp as raw material does not afford by-product fuels.
- 2) Some specific parts of the processes use natural gas or oil as direct fuels for drying some pulp and paper grades or as a fuel in lime reburning kiln in chemical pulping. This fossil fuel use is allocated to the production lines under consideration.
- 3) The rest of the fuel demand for internal energy generation (heat and electricity) is supplied by purchased mainly fossil fuels.
- 4) The proportion of electricity generation of the total internal generation represents the average of Finnish forest industries of the given year and is the same for all production lines, which really form an aggregate in each production plant.

The amount of by-product fuels of pulping available in energy supply are given in Table 6 and Table 7 gives the mix of external fuels and the proportion of self-generated electricity to total internal generation and to external electricity from the national power grid.

Table 5. Total production in 1995 and estimated specific demand for direct fuels, heat, electricity, and raw material of the main paper grades in Finnish paper industry (Finnish Forest Research Institute, 1996; Carlson and Heikkinen, 1998; Lehtilä, 1995; A. Lehtilä, personal communication).

Main paper grades	Production	Direct fuels	Heat	Electricity
	1000 t/a	MWh/t	MWh/t	MWh/t
Chemical pulp board	600	0.03	1.92	0.85
Mech. woodpulp containing board	979		1.94	0.70
Fluting	475		1.56	0.52
Liner	317		1.64	0.54
Other papers (tissue etc)	372	0.86	0.89	0.84
Other papers (kraft etc)	484		1.97	0.89
Newsprint paper	1 425		1.44	0.57
Fine grade paper, coated	729	0.17	1.97	0.86
Fine grade paper, uncoated	1 200		1.89	0.66
Mechanical woodpulp paper, coated	2 496	0.17	1.44	0.78
Mechanical woodpulp paper, uncoated	1 889		1.44	0.63
Total paper production	10 966			

Table 6. The amount of by-product biofuels available in pulping process (Carlson and Heikkinen, 1998; A. Lehtilä, personal communication).

	Pulp grade	Wood waste	Black liquor
		MWh/t	MWh/t
MECHANICAL PULP	GWP, NB	0.45	0
	GWP, B	0.45	0
	TMP, NB	0.49	0
	TMP, B	0.49	0
	SCP	0.46	0.69
	HSUP, B	1.00	4.47
CHEMICAL PULP	SSUP, NB	0.93	5.44
	SSUP, B	0.93	5.44
Efficiency of heat production		86 %	82 %

Abbreviations used:

GWP = groundwood pulp, TMP = thermomechanical pulp,
 SCP = semi-chemical pulp, HSUP = hardwood sulphate pulp,
 SSUP = softwood sulphate pulp, REC = recycled pulp,
 B = bleached, NB = unbleached

Table 7. Energy supply of Finnish pulp and paper industry in 1995 (Carlson and Heikkinen, 1998; Statistics Finland, unpublished data, A. Lehtilä, personal communication).

External fossil fuels	
% of total fuel use	33 %
Efficiency of heat production	89 %
Fuel mix (% of external fuels)	
Natural gas	49 %
Heavy fuel oil	18 %
Peat	17 %
Coal	15 %
Other	2 %
Self-generated electricity	
% of total internal heat+electricity generation	19 %
External electricity	
% of total electricity use	60 %

External electricity and heat

Table 8 gives the C emission factor (kg C/MWh) and primary energy factor of electricity purchased from Finnish national grid in 1995. The factors are calculated on the basis of energy sources of domestic electricity generation and imported electricity is not considered. The transmission losses of electricity in the national grid, of the order of 4 %, are also taken into account. Factors both for average electricity and base-load power are presented. Conventional efficiency coefficients for each energy source (Statistics Finland, 1997) were used to convert electricity to primary energy. When calculating factors for base load electricity, district heat and power plants and some other peak load power were excluded. In model calculations the emission factor of average electricity was used as worst a case estimate although the electricity supply of forest industries more likely belongs to the base load. Small amounts of heat were purchased from district heating plants to production plants in mechanical wood processing, the emission and primary energy factors also given in Table 9.

Table 8. Fossil C emission and primary energy factors of external electricity supplied to Finnish forest industries in 1995 (Statistics Finland, 1997).

External electricity	Average electricity	Base load electricity
C emissions (kg C /MWh)		
Fossil C emissions	68	51
Non-fossil C emissions (wood)	5	5
Primary energy (MWh / MWh)		
Fossil	0.78	0.58
Non-fossil (wood)	0.04	0.05
Other	1.38	1.77

Table 9. Fossil C emission and primary energy factors of external heat supplied to Finnish forest industries in 1995 (Statistics Finland, 1997).

District heat	
<u>C emissions (kgC / MWh)</u>	
Fossil C emissions	96
Non-fossil C emissions (wood)	7
<u>Primary energy (MWh / MWh)</u>	
Fossil	1.16
Non-fossil (wood)	0.06

Harvesting and transportation

Aggregated results of a confidential case study of a big Finnish forest industry enterprise (Savolainen et al., 1999) were used to compare the emissions of harvesting and transportation of wood raw material and transportation of sawn wood with those of production stage. In this specific case the transportation distances of roundwood and sawn wood (Table 10) are essentially longer than in Finnish saw milling on average, a significant part of the smaller sawmills functioning on much more local basis. In addition, main branch of the enterprise is pulp and paper manufacture, and especially of imported roundwood a major part is actually pulpwood and not saw logs. However, the numbers from the case study might then give some upper estimate for the transportation emissions of sawn wood production.

Table 10. Aggregated numbers from a confidential case study of a Finnish forest industry enterprise: transportation distances of roundwood to production plant and sawn wood to consumers.

Roundwood transport	% of roundwood	Means of transport	Distance km
Domestic	65 %	truck	100
Domestic	13 %	truck, train	290
Domestic	2 %	truck, ship	320
Domestic	2 %	truck, floating	350
Imported	5 %	truck	280
Imported	11 %	truck, train	1120
Imported	3 %	truck, ship	930
Sawn wood transport	% of sawn wood		
Domestic	2 %	train	220
Domestic	14 %	truck	220
Exported	1 %	truck, train	1000-1300
Exported	4 %	truck, train	1800-2100
Exported	74 %	truck, train, ship	2400-2700
Exported	5 %	truck, train, ship	7300-7700

RESULTS

The calculated fossil C emissions (Fig. 3) and primary energy consumption (Fig. 4) of manufacture show the significant differences in HWP in proportion to the use of wood raw material and wood in end product. For example, the results show that the specific emissions of fossil C per wood based C in end products are of the order 0.07 for sawn wood and 0.3-0.6 for paper. This means that, if 1 t C is to be sequestered in paper products, 0.3-0.6 t of fossil C is already emitted in the stage of production. Sawmill industry is least energy-intensive and has clearly the lowest fossil C emissions, although a significant part of its wood residues is utilised elsewhere and not for its own energy

production. The primary energy use per wood based C in end product is of the order of 2 MWh/tC for sawn wood but for virgin paper grades it is 17-19 MWh/tC.

When the reference point is wood based C in raw material, we can see that the emissions of chemical pulping including also papermaking are relatively low, whereas the emissions in proportion to wood based C in end product are essentially higher. This is a consequence of the chemical pulping process, in which major part of the wood raw material is utilised as bioenergy (black liquor, bark) (Tables 4 and 6). Due to the bioenergy, its emissions are much lower than in the electricity-intensive mechanical pulping process (Table 4). However, when considering the specific consumption of primary energy in end product (Fig. 4), we notice that the product line of chemical pulping is the most energy-intensive, of the order 19 MWh/(tC in end product), around 60% of energy produced in this case from by-product wood wastes. Manufacturing of recycled pulp uses much less energy, but as the process raw material is not used for energy, external fossil fuels has to be used more in this production line. This is of course also associated with the allocation principles of the model applied to pulp and paper industry. In fact the allocation of fossil C emissions between different production lines within pulp and paper industry is not self-evident, as the manufacture processes are really very integrated. However, the above emission and energy rucksacks may be illustrative indicators when evaluating the greenhouse impact of integrated forestry for HWP and bioenergy.

Figure 3. Direct and indirect fossil C emissions of manufacturing of HWP in Finland in 1995 including the indirect emissions from purchased electricity, expressed as fossil C in emissions divided by wood based C in raw material and wood based C in end product, respectively.

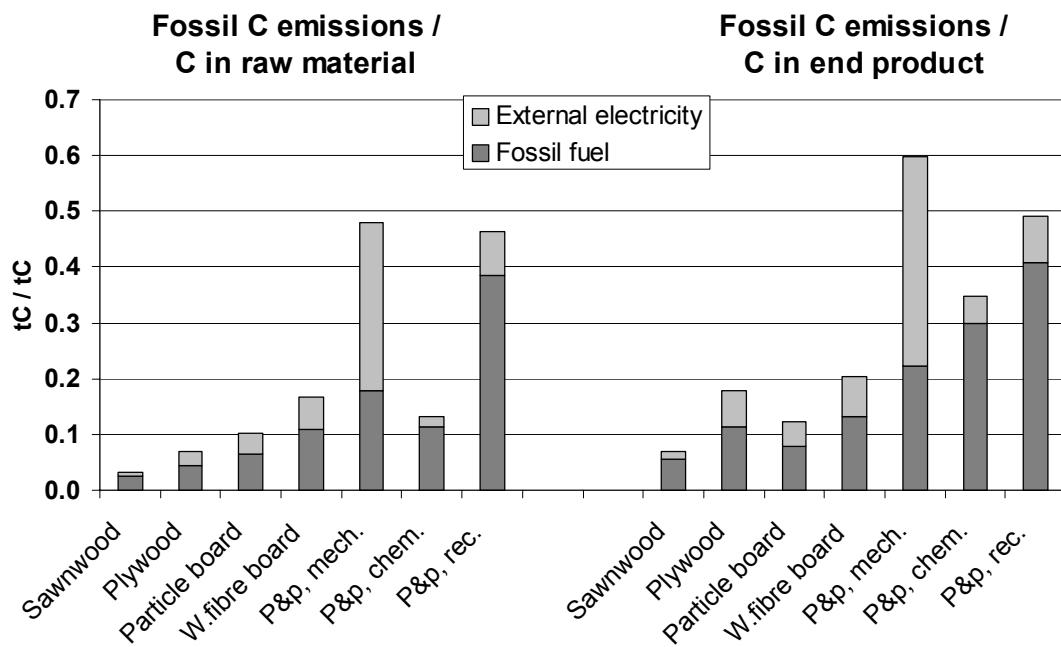
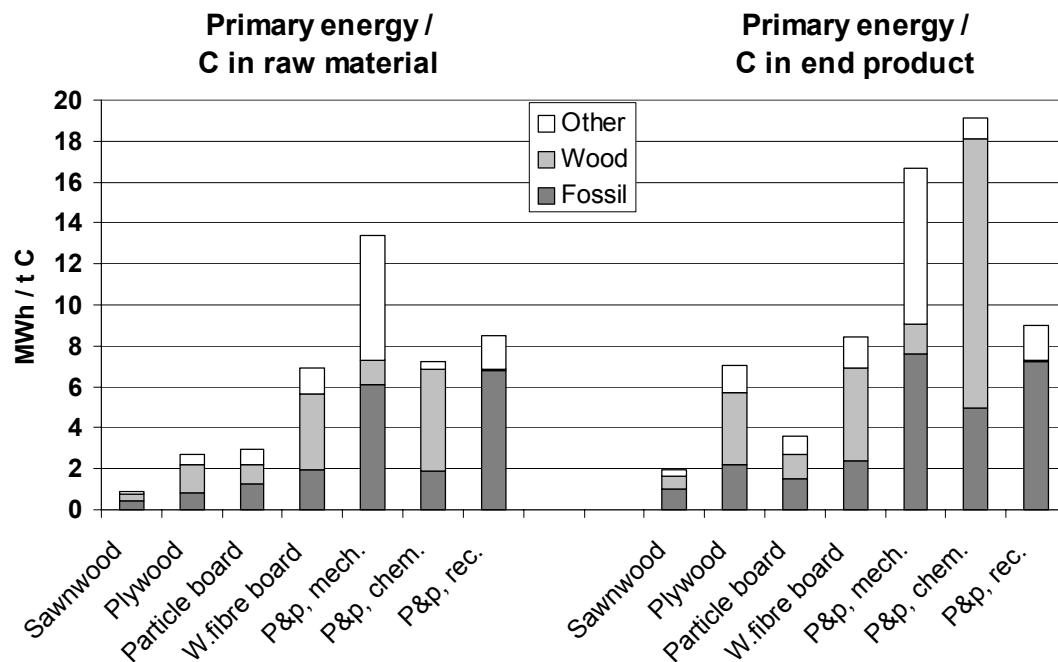


Figure 4: Primary energy consumption of manufacturing of HWP in Finland in 1995, expressed as primary energy divided by wood based C in raw material and wood based C in end product, respectively.



A case-specific example of fossil C emissions associated with harvesting, transporting roundwood, and transporting sawn wood is given in Table 11. As mentioned earlier, due to the long transportation distances (Table 10) these figures represent likely upper estimates of the real emissions in Finnish sawmill industry. The results show, however, that the emissions from harvesting and transport in total are of the same order as those of producing sawn wood. It is obvious that the production stage emissions dominate clearly in the life cycle of the other, more fossil C and energy intensive HWP.

Table 11. Fossil C emissions from harvesting and transportation compared with emissions of sawmill. Harvesting and transportation figures from a confidential case study of a Finnish forest industry enterprise.

	Fossil C emissions	
	tC/ tC in sawn wood	% of sawn wood emissions
Harvesting	0.012	17 %
Roundwood transport	0.031	44 %
Sawn wood transport	0.028	40 %
<i>Total</i>	0.070	
Sawmill	0.070	

DISCUSSION AND CONCLUSIONS

The emission rucksacks of producing wood products, specific emissions expressed as fossil C emissions per amount of wood-based C in end products, have an important impact on the C balance, seen from the atmosphere. They are one indicator on how favorable the C sequestration options into HWP can be really. In addition, even pure maintenance of C stocks of HWP in use require a continuous flow of new HWP to replace the old ones removed from service, and causes thus

continuous fossil C emissions. A long-lived product pool requires a smaller maintenance flow or flow-through than a short-lived, the maintenance flow being inversely proportional to the service life of the HWP considered. Consequently, one measure for the relative burden of maintaining a HWP pool would be the specific fossil C emission of manufacture HWP divided by the service life of the pool. Furthermore, as seen from the above results, some HWP like paper products, which are mostly short-lived, require essentially more energy and fossil C inputs in their manufacturing than generally long-lived ones like sawn wood. This is likely a strong argument against the applicability of e.g. paper products as a C sequestration option. On the other hand, maximal utilisation of wood residues for energy (fossil energy substitution) during the life cycle of HWP, including the energy use of decommissioned HWP, decreases the burdens.

When considering the results of Finnish forest industries, we should bear in mind that they are case- and country-specific, especially concerning energy sources, and represent the situation in 1995. For instance, it would be in principle possible to produce paper free from fossil energy sources, and in fact the development within pulp and paper industry might go in that direction due to the constraints induced by climate policy. Another question is the energy intensity of pulp and paper industry, which is even more a structural problem. Although the share of bioenergy and other fossil free energy sources would be increased, one could question why bioenergy as a limited energy resource could not be applied in a more useful way, and in this meaning pulp and paper industry could be considered as wastage of bioenergy. However, energy or fossil C emission per ton of C in end product is only one criterion for energy or emission intensity. Alternative measure for energy intensity could be the primary energy or emissions in proportion to the monetary value (or value added) in the final product, the monetary value rather than the amount of wood-based material describing the utility of the product.

Another interesting issue is the total C balance of the system including managed forests, soil, HWP in use and in landfills. Forest management strategies including rotation length determine strongly the mix of HWP, which can actually be produced, and has thus an impact on the C stocks in forest biomass, soil, and HWP in use, and indirectly also on the C emissions of manufacture HWP. Maximisation of HWP stock in use or minimisation of emissions of HWP manufacture does not necessarily lead to maximal C stock of the total system. The model presented in this paper has also been applied to this kind of a more comprehensive analysis (Liski et al. 2001).

The life-cycle view of this study is complementary to the national GHG inventories, where land use change and forestry (LUCF) and energy sectors (including e.g. emissions of producing HWP) are reported separately in their totalities. When evaluating different options of C sequestration into HWP, there is a risk of focusing only on the C balances of HWP stocks reported under the LUCF sector. As seen from the results of this study, specified estimation of fossil C emissions associated with the life-cycle of each type of HWP is necessary to get a view of the actual GHG impacts of different sequestration options.

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How Sinks in Wood Products Affect the Cost of Kyoto Protocol and World Trade of Forest Products: Results from a Global Economy-wide Model¹

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PowerPoint presentation: www.joanneum.at/iea-bioenergy-task38/workshop/canberra-data/pohjola.ppt

ABSTRACT

Forest carbon sinks were included in the Kyoto Protocol as a mechanism to mitigate global climate change. The size of the carbon sink in forests and forest products for different countries vary considerably depending on the definition and accounting methods. Thus the given definition or accounting approach might be very beneficial for some countries but quite costly to some others. Also the effects on world trade might differ. Thus the implications of various accounting approaches and appropriate economic instruments on world trade and the costs of Kyoto Protocol should be analyzed with economic models.

The first attempts to evaluate the implications of including sinks in forest products into Kyoto Protocol are taken in this paper by analyzing the atmospheric-flow approach. The following cases are compared: a) sinks cannot be credited; b) sinks can be credited; payment on carbon released; c) sinks can be credited, payment on carbon released and compensation for carbon uptake. Economy-wide and sectoral effects for various countries/regions, and world market effects are estimated by using a recursively dynamic global computable general equilibrium model. Trade of emission permits (including credits for carbon uptake) is allowed within Annex I countries.

Even though sinks in forests and forest products could not be credited, the wood products industry would be affected since payment on emissions from fossil fuels improves the competitiveness of wood products. The atmospheric-flow approach has been argued to have severe effects on world trade of wood products, since the carbon released would be accounted for importing country. Also the simulations demonstrate that trade in wood products would indeed decrease, providing that the users have to pay for release of carbon from wood products in consuming countries. However, according to the model results, the negative effects could be (partly) compensated by giving compensation for carbon uptake in producing country.

Keywords: wood products, carbon sink, world trade, Kyoto Protocol, computable general equilibrium model

INTRODUCTION

Various approaches have been suggested for estimating net emissions of CO₂ from forest harvesting and wood products (Brown et al, 1998). The approaches generate globally the same net carbon exchange with the atmosphere but at the national level their implications differ. The atmospheric-flow approach calculates the net carbon emissions to the atmosphere while the stock-change and production approaches calculate the net change in the forest and product pool. Another difference is related to system boundaries. The atmospheric-flow approach has a system boundary between the country and the atmosphere while the stock-change approach has a system boundary around a country and the production approach around the wood that was grown in a particular country. Also, net emissions of carbon or changes in carbon stocks are allocated differently among producing and

¹ Results are preliminary – please do not quote.

consuming countries. The atmospheric-flow and stock-change approaches accounts where emissions or stock-changes occur unlike the production approach. These differences have implications for managing forests and world trade of wood products.

It has been evaluated what kind of incentives suggested approaches would create for consumption of wood products and forest management. However, an accounting approach cannot usually act as an incentive as such. Under the stock-change approach the country can temporarily improve its carbon account by importing wood products and thus it can be said that it favors the imports of wood products. However, government has to set economic instruments, like taxes or subsidies, to give private agents like firms and consumers the incentive to import those products. Also it might be possible that the similar incentives could be provided also under some other accounting approach with appropriate set of economic instruments.

Various strategies to use biomass for GHG emission reduction, like carbon storage in forests, soils and forest products, and substitution of fossil fuels or other materials with biomass, have been analysed mainly with ecological models. However, in these models the cost-effectiveness of strategies has not been evaluated. A few exceptions include Gielen et al (1999) in which biomass strategies have been evaluated from systems engineering perspective by using MARKAL model. MARKAL model is an optimisation model that finds the least-cost solution subject to given constraints, like the emission target. To my knowledge, evaluation of accounting approaches have not been based on model simulations.

Economy-wide costs of Kyoto Protocol have been analyzed with single country models and global models. Very few of these analysis have so far taken into account carbon sinks. Few exceptions include e.g. Pohjola (1999) in which the economic effects of setting emission limit on emissions from fossil fuels are compared with setting limit directly on net emissions including forest sink. In Reilly et al (1999) marginal cost curves for tree-planting projects have been included so that model chooses whether it is more cost efficient to reduce emissions from fossil fuels or sequester carbon by afforestation. However, to my knowledge, sinks in forest products have not been included in any of the economy-wide models.

Thus there is an urgent need for both analytical and numerical economic analysis of different accounting approaches and economic instruments. This paper takes the very first attempts by analyzing the atmospheric-flow approach with different economic instruments.

MODEL DESCRIPTION

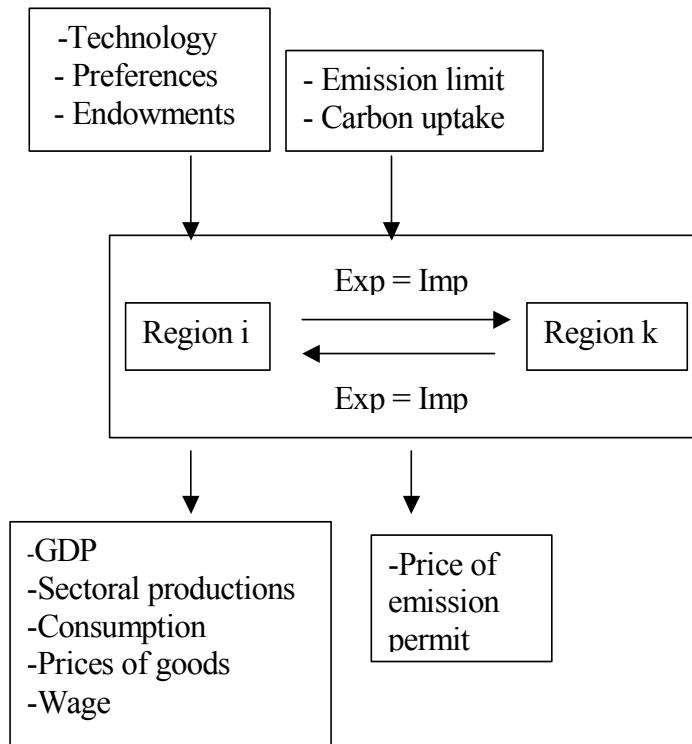
General properties

The model used in this study is global computable general equilibrium model (CGE model) for analysing the economywide and sectoral effects of the Climate Convention. The model covers the most important sectors in the economy, namely production, consumption and foreign trade. The model finds an optimal way to achieve the given emission level by choosing the least-cost options to reduce emissions. However, unlike the bottom up models (like energy sector models) that include a detailed description of existing and potential technologies, in CGE models more general functions are typically used to describe production technology. Thus they give much less accurate estimate of the direct costs of emission reduction than the energy sector models. On the other hand, since CGE models consist of the whole economy, they take into account also indirect costs that follows from adjustment in other parts of the economy, like in labor markets and trade balance.

The general structure of the model is represented in figure 1. Upper level consist of inputs of the model. Technology parameters include input shares and substitution possibilities between inputs. Household preferences are described by consumption shares of various goods and substitution among them. Endowments of the economy include labour, capital and natural resources. Since international emission trading within Annex I countries is allowed in simulations presented here, the

emission limit is set to Annex I countries as a group. The amount of carbon uptake is given as exogenous input. Lower level consists of outputs of the model. These include economywide variables, like GDP and prices of labour and capital, and sectoral variables, like output levels of various industries and prices of goods. The model also estimates the price of emission permit needed to achieve the given emission limit. Regions are linked with each other by foreign trade.

Figure 1 The general structure of the model



Regions and sectors

Since the focus of the analysis is on the carbon sinks and world trade of forest products, the regional and sectoral disaggregations have been chosen to be suitable for this purpose. The model includes 11 countries or regions. In the regional level, the model includes the most important exporters of forest products, namely Canada, USA, Finland and Sweden. An examples of wood product exporting countries includes at present stage Finland and Canada. Later on, also New Zealand is included. At this phase, UK is an example of a wood product importing countries but later on Japan will be included as a separate country.

Regions

- USA
- Canada
- UK
- Germany
- Sweden
- Finland
- The rest of Western Europe
- Eastern Europe and Former Soviet Union
- The rest of OECD
- Asia
- The rest of the world

In the sectoral level, model includes the production of pulp and paper, production of wood products and forestry as separate industries. Construction, which uses wood products, will be modelled separately in the next phase. The energy-intensive industries as production of iron and steel are treated separately.

Sectors

- Agriculture
- Forestry
- Paper and pulp industry
- The wood products industry
- Iron and steel industry
- Other industries
- Services
- Electricity and heat
- Production of oil
- Production of coal
- Production of gas
- Production of fossil fuel products

Production

The model takes into account a regional differences in factor intensities, factor substitution and the price elasticities of output demand. All non-energy sectors are modelled with the same production technology. Coal, oil, gas and fossil fuel products are combined at the bottom nest of the production function to create a fossil fuel aggregate. The fuel aggregate is combined with electricity and heat to create a energy aggregate. The energy aggregate is combined with capital, and the energy-capital aggregate is combined with labour. In the upper level the aggregate of primary and energy inputs is combined with aggregate of intermediate (non-energy) inputs. Each intermediate input is an aggregate of domestic and imported inputs, according to Armington assumption. Technical change is not included in the model. In most CGE models used in climate policy analysis, technical change is exogenous and thus emission limit has no (endogenous) effect on technical progress.

Households

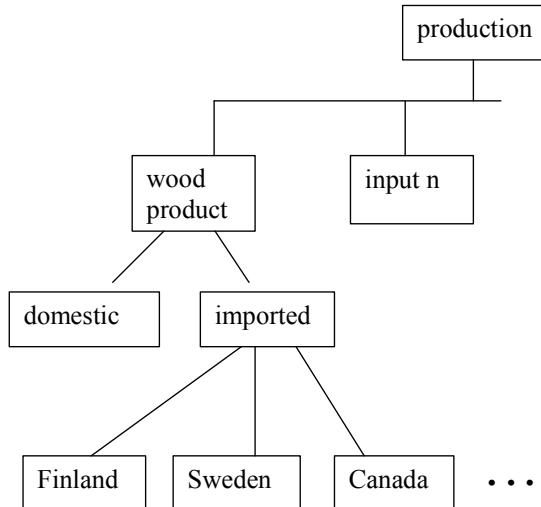
The representative household for every region allocates her income among consumption goods. The classification of consumption goods corresponds that of production sectors.

International trade

All goods are traded in the international market. On the import side, industries and firms choose between domestically produced and imported goods. Also, the imported goods are differentiated by origin. Thus, goods produced in different regions are imperfect substitutes. For example as shown in the figure 2, the construction sector in UK chooses first the shares of domestic and imported wood

products. Secondly, it chooses the shares of imported wood products from various countries. Exports are determined by the import demands in other regions.

Figure 2 Modelling the imports



The changes in trade flows are restricted by the values of elasticities. The lower the elasticities are the minor are the changes in trade flows. Also, the values of elasticities could capture to some point the features not described explicitly in the model like transport costs.

Factor markets

Labour and capital are primary factors of production. Both labor and capital are assumed to be homogenous in the national level and perfectly mobile between sectors. Thus, the wage rate and the price of capital are equalized across sectors in a given region. However, labour and capital are not allowed to move across regions. The price of labor is perfectly flexible balancing the demand and the supply of labour. Thus, there is no unemployment in the model.

Climate policy

It is assumed in the simulations that international emission trading is allowed within Annex I countries with no ceilings. Also credits from carbon uptake can be traded. Thus the payment for emissions from fossil fuels or wood, or income from carbon uptake is same in every Annex I country (i.e. the international price for emission permit). Sinks from JI and CDM projects are not included in the model.

Only a very small number of analytical papers have analyzed the efficient tax/subsidy policy in the case of net emissions including sinks. In the analysis of Tahvonen (1995), both a subsidy and a tax are needed to achieve a socially optimal outcome. On the other hand, in the analysis of Backlund et al. (1995), only a tax is needed. Both models are based on national level analysis. Hoel (1996) has analysed whether energy-intensive exporting sectors should be taxed at lower tax rates than other sectors. Even in a very simple model, the determination of the optimal set of CO₂ taxes is very complicated.

In this study, the uptake of carbon is exogenous and thus the compensation for carbon uptake has no effect on fellings. The emission permit is required for release of carbon. Also the tax/permit on emissions from fossil fuel affects the use of forest products.

Forest products and sinks

The forest products in the model include paper and pulp, and wood products. The time scale in which carbon releases from paper and wood products is quite different. The simple linear decay function is used in this stage. Later on, the more realistic decay function (e.g. like the one used in Karjalainen et al., 1994), might be adopted. Some elements, like recycling and landfills, are not included in the model at this stage.

SCENARIOS

In this paper, policy scenarios related to atmospheric-flow approach are represented. It has been argued that atmospheric-flow approach would give a disincentive to import forest products and thus disturb the world trade of those products. In the atmospheric-flow approach, the country in which forests are sequestering carbon can include the carbon uptake in its carbon account. On the other hand, carbon released is allocated to the country in which release actually occurs. Thus, in case that considerable amount of timber is used to produce wood products and they are mainly exported, the producing country get an considerable sink. On the other, the importing country is also importing a considerable amount of carbon that it has to add to its emissions when it releases to the atmosphere. Thus, since the amount of emissions increases, it is more difficult to achieve the emission limit. The importing country should compare whether it is less expensive to reduce emissions from fossil fuels or import less wood products. In order to give the industries and consumers disincentive to import wood products, the payment has to be set for release of carbon (in these simulations the emission permit is required). Thus the user price of forest products increases. On the another hand, in the producing country, forest owners receive income from carbon uptake that decreases the price of timber and thus the production costs of forest products. This in turn improves the competitiveness of forest products. Prices of timber and forest products are also affected by changes in their supply and demand. Thus the model including the markets for timber and forest products is needed to analyse the total effect on user price and imports of forest products.

Three Kyoto scenarios are represented in addition of baseline without Kyoto target, namely:

- No sinks
- Payment
- Compensation and payment

In the first scenario, carbon sinks in forests or forest products cannot be credited. In the third scenario ("Compensation and payment"), emission limit is adjusted with sinks. The economic incentives include income from selling carbon credits (emission permits) in producing country and payment on buying emission permits in the consuming country where carbon is released. The second scenario ("Payment") has been run mainly for illustrative purposes. In that scenario, emission limit is adjusted with sink similarly than in third scenario but incentives has been set only in the consuming country.

In all scenarios, international emission trading between Annex I countries is allowed. This implies that marginal cost of emission reduction is equalized within Annex I countries. Thus also the amount of carbon subsidy is same in all countries.

RESULTS

The results are very preliminary and improvements are needed in both model and data. Thus at the current phase of the study the results mainly demonstrate what kind of effects can be analyzed with global CGE model.

The effects of emission reduction on consumption and imports of wood products are represented in the table 1. Although the sinks were not taken into account in Kyoto Protocol, as it is assumed in the first scenario, the emission target would affect forest products industries. Since emission intensive

sectors have to pay for their emissions, the relative price of wood products fell and other inputs are substituted with wood products. The use of wood products is also affected by changes in income that is reduced due to emission reduction. The substitution effect dominates the income effect and thus e.g. in UK and Germany the consumption of wood products increases slightly. According to model results, the imported wood products would be substituted with domestic wood products in UK while the domestic wood products would be substituted with imported ones in Germany. On the other hand, the consumption of paper decreases. This is due to the fact that paper industry is quite energy-intensive and thus its relative price increases.

In the third scenario, forest owners receive income from carbon uptake while users of forest products have to pay for carbon released. The income on carbon uptake decreases the price of timber and thus in turn the prices of wood products and paper. The effect on the forest products prices depends e.g. the cost structures of industries and thus the data should be quite correct in order to make reliable country comparisons or analyze effects on the competitiveness in a reliable way. The tax on another hand increase the after-tax consumer price. According to model results, UK imports wood products about the same amount as in the first scenario. In Germany the imported amount would increase. The consumption of wood products would slightly decrease and thus domestic wood products are substituted with imported wood products. In the second scenario in which consumers have to pay for carbon released but no compensation payment are given for the carbon uptake, imports of wood products would decrease.

Table 1: Consumption and imports of wood products, change compared to reference scenario, %.

	No sinks	Payment	Compensation and payment
Consumption			
UK	+0.1	-0.3	+0.2
Germany	+0.1	-0.3	-0.1
Imports			
UK	+0.0	-0.2	-0.05
Germany	+0.4	-0.0	+0.9

Effects on exports of wood products are represented in the table 2. According to model results, the production of wood products would be relocated to non-Annex I countries. However, since wood product industry is not energy intensive, the outcome is not obvious and might follow from some problem in the model. In the third scenario, where income from carbon uptake is provided, the exports of wood products would increase both in Sweden and Finland. In both countries, the amount of carbon uptake and thus income from selling carbon credits is considerable implying the decrease in price of timber.

Table 2: Exports of wood products, changes compared to reference scenario, %.

	No sinks	Payment	Compensation and payment
Finland	-0.8	-0.7	+0.8
Sweden	-0.5	-0.6	+1.1
Europe	-0.2	-0.6	-0.2
Asia	+0.1	-0.03	-0.7
ROW	+2.1	1.6	+0.7

In the table 3, the effects of emission reduction on exports of paper and pulp are represented. In all scenarios the carbon leakage will occur and production is moving to non Annex I countries. In case of paper and pulp that uses energy as input, the outcome is expected since carbon payment increases

the production costs in Annex I countries. The results also reflect the differences in fossil fuel intensity in various countries. In Sweden, electricity is mainly produced with nuclear and hydro power and thus the exports are reduced much less than in Finland where electricity production is more fossil fuel intensive. In the third scenario, where income from carbon uptake is provided, the exports of paper and pulp would increase in Sweden. However, in Finland the exports of paper and pulp decreases compared to reference scenario since increase in energy cost exceeds the decrease in timber cost.

Table 3: Exports of paper and pulp, changes compared to reference scenario, %.

	No sinks	Payment	Compensation and payment
Finland	-1.5	-1.4	-0.4
Sweden	-0.6	-0.8	+0.7
Europe	-0.3	-0.7	-0.5
Asia	-0.02	-0.01	-0.2
ROW	+1.8	1.4	+1.3

CONCLUSIONS AND FUTURE WORK

According to very preliminary results, it seems that the atmospheric-flow approach would not decrease the imports of forest products, in case of appropriate set of economic instruments. In the simulation, forest owners received income by selling carbon credits for uptake of carbon while in the consuming country the users of forest products had to buy emission permits. However, what seems to work in the theory does not necessarily work in practice. Thus it is clear that policy recommendations cannot be based only on model simulations. However, they have an important role. With the economywide model it is possible to trace the various mechanisms affecting the outcome and evaluate their importance. Also, economic analysis of incentives and economic instruments is needed to clarify the discussion. This study is still in the preliminary phase and much work is needed before the above issues can be analyzed satisfactorily.

In the near future, the other accounting approaches will also be included in the simulations implying that a preliminary comparison between approaches can be performed. Related to data, FAO data of trade flows of wood products will be utilized later on. The main advantage of FAO data is that it is measured in tons, not in monetary units. Also the carbon content of wood products has to be modelled more carefully. After improvements in the data and the model, more detailed results on economywide, sectoral and world trade effects will be provided.

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Effectiveness of Carbon Accounting Methodologies for LULUCF and Harvested Wood Products in Supporting Climate-conscious Policy Measures

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ABSTRACT

The Kyoto protocol aims to meet the United Nations Framework Convention on Climate Change (UNFCCC) objective to reduce concentrations of greenhouse gases in the atmosphere. The Protocol permits countries to take into account vegetation based sinks and changes in these through Land Use, Land Use Change and Forestry, and potentially carbon dynamics in harvested wood products (HWP). A number of LULUCF carbon accounting methods, with special reference to forestry systems and HWP, have been developed.

This paper presents a method of analysis that could be used to evaluate any proposed accounting system in support of the objective of the UNFCCC. The analysis is illustrated using a hypothetical world of eight countries that vary in land area, percentage forest cover and consumption of fossil fuels. The relative impact of alternative methodologies on the potential carbon credits or debits accrued by the countries is assessed.

Large fluctuations were observed in projections of the predicted carbon net sink/source for the eight countries. Alternative methods of accounting for HWP resulted in differences in percentage changes of $\pm 15\%$, although including HWP had marginal influence on the relative ranking of the different countries over longer periods of up to 2150. However, the so-called Atmospheric Flow method of HWP accounting was observed to overestimate sources and underestimate sinks. Over a 5 year reporting interval, estimates of carbon net sink/source for the eight countries were sensitive to choice of baseline and LULUCF accounting index, but less so when a long period (1990 to 2150) was considered. For long periods, simple LULUCF accounting indices gave similar to those obtained using complicated annual sink/source estimates.

Key Words: Land-use, Land–Use Change and Forestry; Harvested Wood Products; accounting methods; United Nations Framework Convention on Climate Change.

INTRODUCTION

The objective of the United Nations Framework Convention on Climate Change (UNFCCC, 1992) is to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The Kyoto protocol (UNFCCC, 1998) aims to support the UNFCCC objective by committing participating countries to reductions in national anthropogenic greenhouse gas emissions, the most important being carbon dioxide (CO_2), arising mainly from the use of fossil fuels. Apart from accounting directly for changes in consumption of fossil fuels, the Protocol also allows countries to take into account vegetation based sinks and sources of greenhouse gases, and changes in these arising from Land Use, Land Use Change and

Forestry (LULUCF). These activities have not been clearly defined, and the sink and source accounting rules have not been comprehensively specified or agreed. Methods for estimating fossil fuel emissions are relatively easy to define and agree, but the estimation of LULUCF emissions is very complicated, particularly if carbon dynamics in harvested wood products (HWP) is to be included.

As part of elaboration of the Kyoto Protocol methodology, a number of LULUCF carbon accounting methods, with special reference to forestry systems and HWP, have been developed and articulated in the scientific literature (Kirschbaum et al., 2001; Fearnside et al., 2000; Fruit and Marland, 2000; IPCC, 2000; Maclaren, 2000; Jackson, M. 1999; Moura-Costa and Wilson, 1999; Chomitz, 1998; Tipper and de Jong, 1998; Winjum et al., 1998). Variants of these methodologies may be specified, depending on the definition of system boundaries, so-called ‘baselines’ and the treatment of ‘additionality’ as specified in the Kyoto Protocol, notably in Articles 2, 3.3 and 3.4.

The accounting system needs to directly support the ultimate policy goal of stabilising atmospheric greenhouse gas emissions, as well as ensuring equitable treatment of participating nations that have different levels of vegetation cover and fossil fuel consumption. In addition, potential for conflict with international conventions on protection of forests and biodiversity must be avoided. There may also be a need to provide a system that can deliver consistent results at project and national level.

This paper presents an analysis of different accounting methodologies for the forestry sector, and the impact of the different LULUCF and HWP accounting methods on the reduction estimates reported by participating countries.

Although an evaluation of accounting methodologies in support of the Kyoto Protocol is an important focus of this study, an aim is also to present a general method of analysis that could be used to evaluate any proposed accounting system in support of the objective of the UNFCCC.

METHODS

Definition of model system of countries

A hypothetical world consisting of eight model countries (named Circle, Diamond, Oblong, Oval, Pentagon, Star, Trapezium and Triangle) was defined. The model countries contrasted in terms of carbon emissions arising from national energy consumption, land area, areas of land covered by old-growth and commercially productive forests, and annual net change in forest area as specified for the base year of 1990 (Table 1). The model countries were also designed to be comparable with real-world countries listed in Annex I of the Kyoto Protocol, and ‘non-Annex I’ countries that might seek to participate in an endeavour such as Kyoto Protocol in the future.

Table 1: Land area, emissions from fossil fuel consumption, forest area and area change assumed for the eight model countries for the base year of 1990

	Land area (kha)	Total forest area (kha)	Total forest as percentage of land area	Net change in total forest area (%yr ⁻¹)	Fossil Fuel Emissions (Mt C yr ⁻¹)
Circle	90 000	36 000	40	-1.0	1
Diamond	30 000	9 000	30	0.6	10
Oblong	30 000	21 000	70	-0.1	15
Oval	900 000	540 000	60	-0.5	100
Pentagon	900 000	180 000	20	0.3	1500
Star	800 000	40 000	5	0.0	100
Trapezium	900 000	270 000	30	0.0	150
Triangle	20 00	2000	10	0.5	150

Fossil Fuel Projection

To simplify initial analysis it was assumed that the countries would carry on current practice over the period 1990 - 2150:

$$e_{i,t} = e_{i,1990}$$

[1]

where $e_{i,t}$ is the CO₂ emission (in units of tonnes carbon) from fossil fuel consumption in the i th country in year t .

LULUCF projection

For each country, land cover in the year 1990 was classified as being either old-growth forest, commercially productive forest or non-forest land. As the carbon sink/source due to vegetation in 1990 is likely depend to some extent on land cover changes that took place prior to 1990 projections of land cover were made from a set of initial conditions for each country that were specified for the year zero.

All ‘old-growth’ forests existing in the year 1990 were represented as having been created in year zero. Commercially productive forests existing in the year 1990 were represented as having been created by conversion from either non-forest or old-growth forests uniformly over a period between 1890 and 1990. Constant rates of conversion were assumed, and values were selected that would add up to the overall rate of deforestation or afforestation as shown for each country in Table 1. For years succeeding 1990, afforestation or deforestation was assumed to continue at the 1990 rate, subject to the following constraints:

1. The total forest area in any country was constrained to not fall below 50% of the total forest area for the year 1990.
2. The forest area in any country was constrained to not expand over more than 10% of the land area not currently under forest.
3. Loss of old-growth forest (through either deforestation or conversion to commercial forest) was constrained such that the area of old-growth forest should not fall below 2% of the land area of the country. Any deforestation was assumed to continue at the 1990 rate through loss of commercially productive forest areas subject to constraint 1.

All afforestation was assumed to take place through creation of commercially productive forests on non-forest land, while all deforestation was assumed to take place through loss of old-growth forests to non-forest.

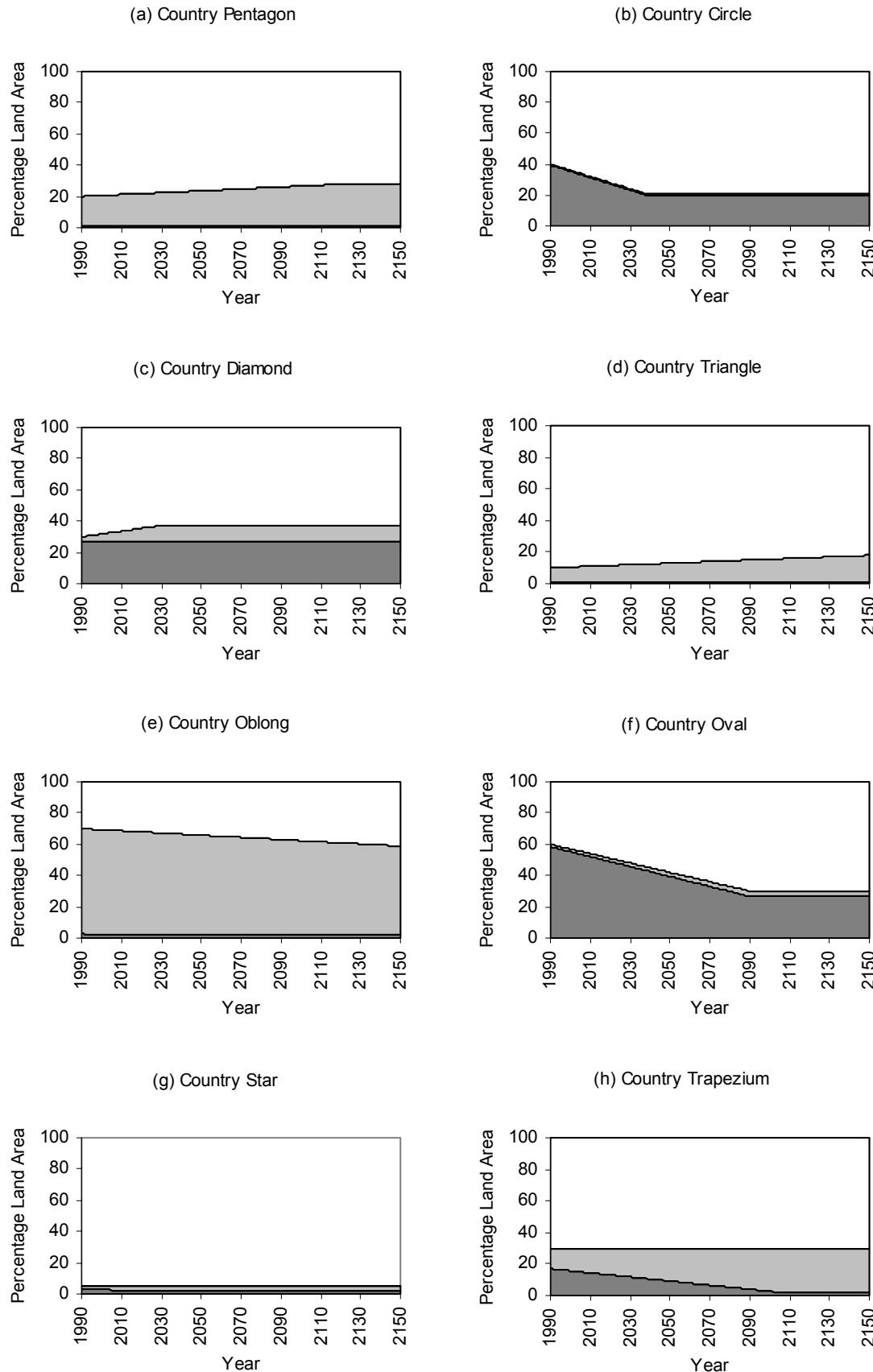
The resultant pattern of changes in percentage land cover assumed for each country over the period 1990 to 2150 is summarised in Figure 1a-h.

The UK Forest Research CARBINE model was used to simulate changes in carbon stocks in forests in each country, and annual estimates of carbon sinks and sources due to land cover changes were derived from the stock changes. The model also calculated changes in carbon stocks in HWP from stands in each country.

CARBINE was developed originally in 1989 as a model for simulating carbon accumulation in individual forest stands and in any associated HWP (Thompson and Matthews, 1989) and has undergone many modifications since then, with addition of a primitive sub-model representing soil carbon dynamics (Matthews, 1992), and sub-models to estimate the impact on fossil fuel consumption of changes in the supply of different categories of HWP including bioenergy, particleboards, paper and sawnwood (Matthews, 1994, 1996).

Figure 1. Projected changes in land cover for hypothetical countries from 1990-2150.

Key: white, non-forest land; pale grey, commercially productive forest; dark grey = old growth forest.



For this study, further modifications were made to represent progressive annual transitions between land cover classes, such as gradual afforestation, reforestation or deforestation and the gradual conversion of old-growth forest to commercially productive forest and vice versa.

The land cover data provided for the model countries considered here was very abbreviated as follows:

- Non-forest land was assumed to have zero carbon stocks.
- Changes in carbon stocks in soil were ignored.
- The same models were applied in all countries to represent conversion of harvested wood to products, displacement of fossil energy through substitution, and retention of carbon in HWP and landfill.

Carbon dynamics in forest stands and non-forest areas was represented using two models of stand growth. The first was based on yield tables for Sitka spruce stands of average productivity growing in Britain (Edwards and Christie, 1981), and was used to represent old-growth forests. The management prescription for this model was for no harvesting other than at time of clear fell, thus if no clear felling was carried out the accumulation of carbon stocks was very high. Conversion of old-growth stands to non-forest land (deforestation) was represented by complete removal of the carbon stock predicted by the model to have accumulated in the stand, with stem biomass and a fraction of branch biomass assumed to be utilised in HWP or to provide bioenergy. Non-forest land was therefore assumed to have zero carbon stocks. Commercially productive stands were represented using a model based on yield tables for Corsican pine stands of relatively high productivity growing in Britain (Edwards and Christie, 1981). The management prescription for this model included regular silvicultural thinning prior to final harvest of the stand at theoretical economic rotation age.

Harvested stem biomass and a fraction of branch biomass were assumed to be utilised in HWP or to provide bioenergy. For each species of tree simulated, harvested wood was allocated to the following wood product categories:

- Waste, bark, fuel
- Paper
- Board products
- Short-lived sawnwood
- Long-lived sawnwood.

Waste, bark and fuel were all assumed to decay or be destroyed, releasing any sequestered carbon within 1 year. Paper in primary use was also assumed to be disposed of in less than 5 years. At the end of primary use, a fraction of paper was assumed to be landfilled, where total loss of carbon was assumed to take up to 40 years. Retention of carbon in board products, short-lived sawnwood and long-lived sawnwood was modelled using nonlinear functions. The timecourses of these functions varied with species of wood and with product type, but in general a proportion was assumed to be lost within 1 year, while the remaining carbon was assumed to be released over a period between 5 and 50 years.

There has been some concern that in general this ‘flow modelling’ approach to estimating carbon sinks and sources due to HWP can lead to anomalous results when using short runs of input data (for example 30-50 years). In this study the model was run for the hypothetical countries effectively from ‘pre-history’, and results do not exhibit this artefact. To achieve this many simplifying assumptions were needed, not only about long-term development of forest areas and age class structure in the hypothetical countries, but also about patterns and methods of utilising wood over long periods. The approach of Pingoud et al. (2000) was used to calibrate CARBINE using estimates of stocks and fluxes for wood products for the UK derived by inventory methods (Alexander, 1997).

Clear fell was assumed to be followed immediately by establishment of commercially productive forest stands. Conversion of old-growth forest to commercial forest was represented by complete

removal of the old-growth forest carbon stock, as above, followed immediately by simulated establishment of an equivalent area of commercially productive forest. Conversion of commercially productive forest to old-growth forest was represented by continuing to project carbon stocks using the Corsican pine model, allowing silvicultural thinning to continue to take place up to time of clear fell but then retaining carbon stocks indefinitely and permitting them to accumulate. As for old-growth forests, conversion of commercially productive stands to non-forest areas was represented by complete removal of the carbon stock predicted by the model to have accumulated in the stand, with stem biomass and a fraction of branch biomass assumed to be utilised in HWP or to provide bioenergy.

CARBINE generated annual estimates of carbon stocks for each model country from which estimates of the LULUCF carbon net sink/source could be derived.

Carbon dynamics in HWP and attribution to countries

The wood products survival sub-model of CARBINE produced annual estimates of the carbon net sink/source attributable to HWP harvested in each of the eight model countries. In each year, the carbon net sink/source due to HWP for the hypothetical world was estimated as the sum of these eight estimates:

$$H_t = \sum_{i=1}^{i=8} h_{i,t} \quad [2]$$

where H_t is the carbon net sink/source due to HWP for the hypothetical world ($tC\text{ y}^{-1}$) and $h_{i,t}$ is the net sink/source due to wood products in year t harvested in the i^{th} country.

Treatment of HWP and allocation of carbon sinks/sources as part of any proposed system of greenhouse gas accounting is currently the subject debate, and four methods have been proposed, known as the IPCC, Production, Stock Change and Atmospheric Flow methods (Winjum *et al.*, 1998). The IPCC method involves simply ignoring carbon dynamics in HWP, the Production method attributes carbon net/sink sources due to HWP to the producer country, the Stock Change method attributes carbon net/sink sources due to HWP to the consumer country, while the Atmospheric Flow method effectively an unbalanced method, in that it attributes emissions of carbon from destroyed or decayed HWP to the consumer country but does not account for the original in-flow of carbon to the HWP pool of that country.

Calculation of $h_{i,t}$ and H_t was carried out separately for the Production, Stock Change and Atmospheric Flow methods. For the Stock Change and Atmospheric flow methods it was assumed that consumption of wood products for each country was directly proportional to fossil fuel consumption in that country for the base year of 1990. Thus, having the obtained sum H_t defined above, the net sink/source attributable to each country under the Stock Change and Atmospheric Flow methods was calculated using the following equations:

$$p_{i,t} = \gamma_i H_t \quad [3]$$

$$\gamma_i = \frac{e_{i,1990}}{\sum_{i=1}^{i=8} e_{i,1990}} \quad [4]$$

where $p_{i,t}$ is the HWP carbon net sink/source attributable to the i^{th} country in year t , γ_i

is the proportion of H_t attributable to HWP consumption in the i^{th} country. For the IPCC method, $p_{i,t}$ was set to zero for all countries in all years, while for the Production Method $p_{i,t}$ was set equal to $h_{i,t}$ as defined in equation 2.

LULUCF and HWP accounting indices

A selection of seven example LULUCF accounting indices, representative of the range proposed in the scientific literature or in position statements, were considered:

- Real-time accounting
- One-off accounting (McLaren, 2000)
- Tonne-year accounting (Fearnside et al., 2000; Chomitz, 1998; Tipper and de Jong, 1998, Moura-Costa and Wilson, 1999)
- Advance tonne-year accounting (Jackson, 1999)
- Rental accounting (Fruit and Marland, 2000)
- Benchmark accounting (Kirschbaum *et al.* 2001)
- Simplified benchmark accounting

The same index was used for HWP as was selected for LULUCF for Production and Stock Change calculation methods. One-off and benchmark indices for HWP were calculated according to the Atmospheric Flow calculation method. A real-time approach was adopted for HWP as calculated by the Atmospheric Flow method when considering tonne-year and rental LULUCF accounting indices.

Carbon net sink/source

Having computed estimates for each country of carbon emissions from fossil fuel consumption as well as estimates of the LULUCF and HWP carbon net/sink source, the overall carbon net sink/source for each country was calculated:

$$S_{i,t} = e_{i,t} + (l_{i,t} - L_{i,t}) + (p_{i,t} - P_{i,t}) \quad [5]$$

where $S_{i,t}$ is the carbon net sink/source for the i^{th} country in year t , $e_{i,t}$ is the emission of carbon due to fossil fuel consumption in the i^{th} country in year t , $l_{i,t}$ is the LULUCF carbon net sink/source (as evaluated by the accounting index selected) and $p_{i,t}$ is the equivalent HWP carbon net sink/source. The terms $L_{i,t}$ and $P_{i,t}$ represent projections of baseline variables for each country that are used to adjust LULUCF and HWP estimates.

LULUCF baseline

Employment of a baseline in the calculation of LULUCF carbon net sinks/sources is implicit in Articles 3.3 and 3.4 of the Kyoto Protocol. The purpose of the baseline is to represent the naturally-occurring and/or BAU component of the LULUCF carbon sink/source – subtracting the baseline estimate from the overall net sink/source as shown in equation 5 means that the contribution to $S_{i,t}$ from LULUCF does not include natural phenomena and comprises only sinks and sources that are regarded as human-induced over and above BAU activities.

Four alternative approaches to calculation of LULUCF baselines were evaluated in this study as described below.

- Zero. The value of $L_{i,t}$ is set to zero for all countries and for all years. Strictly, this is not in the spirit of the wording Articles 3.3 and 3.4 of the Kyoto Protocol, but a justification rests on the fact that the atmosphere does not care about the specific origins or causes of sinks and sources of carbon.

- 1990 value. This baseline represents an attempt to keep calculation of the LULUCF carbon net sink/source simple by not having to rely on any sort of hypothetical projection, but without resorting to the extreme option of a zero baseline.
- 1990 projection. For this baseline, projection of $L_{i,t}$ is made for each country by taking the areas of non-forest, old-growth forest and commercially productive forest for the year 1990 and holding these areas constant into the future. CARBINE was used to compute a projection of the LULUCF carbon net sink source that did not account for any deforestation and afforestation taking place in the years 1990 and beyond.
- BAU projection. Projection of $L_{i,t}$ was made for each country by constructing a BAU scenario for LULUCF and using CARBINE to compute the resultant carbon net sink/source for the year 1990 and subsequent years. Adoption of this baseline is consistent with the spirit of Article 3.4 of the Kyoto Protocol.

HWP baseline

Although it can be argued that all carbon sinks and sources due to HWP are clearly human-induced, to ensure consistency it was decided to adopt a baseline for HWP that was the same as that used for LULUCF.

Assigned amount

An important objective of the Kyoto Protocol is to provide a means for participating countries to demonstrate commitment to achieving percentage-based reductions in net emissions of greenhouse gases. Percentage changes in carbon net sinks or sources were calculated using equation 6:

$$C_{i,t} = 100 \frac{(S_{i,t} - R_i)}{R_i} \quad [6]$$

where $C_{i,t}$ is the percentage change in carbon-based emissions reported by the i^{th} country in year t , and R_i is the reference value of the carbon net sink/source used to calculate the percentage for the i^{th} country. In the Kyoto Protocol R_i is known as the ‘assigned amount’ which is to be calculated from estimates of sinks and sources for the year 1990 for each country. Strictly, calculation of a percentage of $S_{i,t}$ should employ a reference value of $S_{i,1990}$. However, Article 3.7 of the Kyoto Protocol stipulates that R_i should be set equal to $e_{i,1990}$ for countries for which $l_{i,1990} \leq 0$ (i.e. the LULUCF carbon net sink/source is not a source) but that R_i should be set equal to $S_{i,1990}$ when $l_{i,1990} > 0$. This study evaluated three alternative methods of calculating $C_{i,t}$, specifically:

- Gross-net approach. The value of R_i was set equal to $e_{i,1990}$ for all countries.
- Net-net approach. The value of R_i was set equal to $S_{i,1990}$ for all countries.
- Article 3.7 approach. For countries with $l_{i,1990} \leq 0$, the value of R_i was set equal to $e_{i,1990}$. For countries with $l_{i,1990} > 0$, the value of R_i was set equal to $S_{i,1990}$.

Problems may arise when calculating the carbon net sink/source according to the net-net approach, for example, if $l_{i,1990} < 0$ (i.e. is a sink) with magnitude comparable to $e_{i,1990}$, then $R_i \rightarrow 0$ and reported percentages will be very large even for small changes in $S_{i,t}$. The reported percentage becomes impossible to calculate in situations where $R_i = 0$. This may be seen as justification for adoption of gross-net accounting either in all cases or specifically for countries where LULUCF is a sink in 1990. On the other hand, gross-net calculation has the potential to misrepresent the magnitude of percentage net emission changes.

Commitment period

The Kyoto Protocol specifies that countries should report average values of $C_{i,t}$ for consecutive five year commitment periods, with the first period covering the years 2008 to 2012. In this study, averages for the full simulation period of 1990 to 2150 were also calculated.

RESULTS AND DISCUSSION

Selection and evaluation of ‘default’ calculation and projections

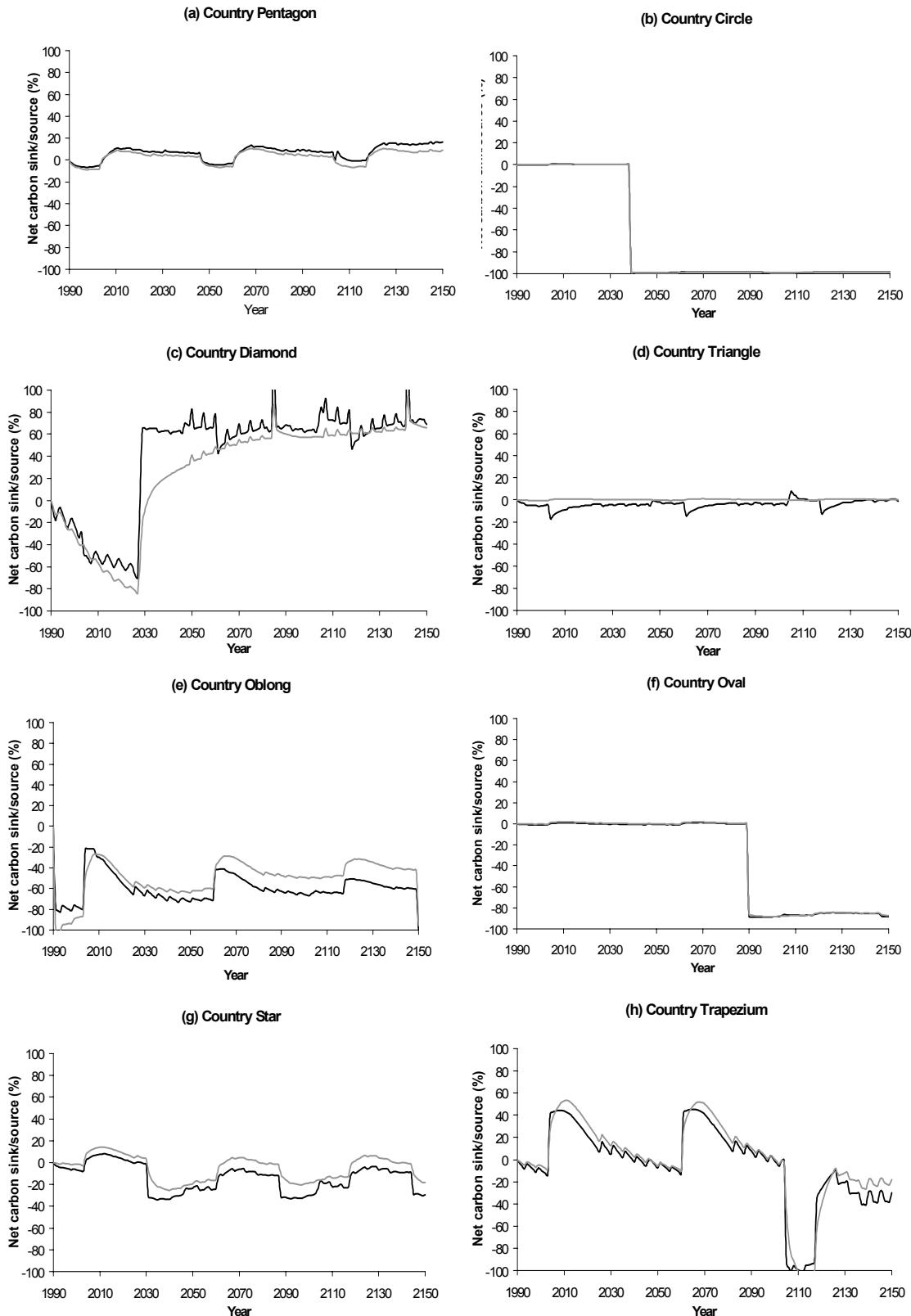
Figure 2a-h shows examples of projections of percentage changes in the carbon net sink/source for the eight model countries over the period from 1990 to 2150, calculated as follows:

- Percentage change was calculated according to the approach specified in Article 3.7 of the Kyoto Protocol.
- A baseline of zero was adopted.
- Separate projections were calculated by allocating HWP according to either the Stock Change or Production method.

The projections calculated and adopting the Stock Change approach to HWP were accepted as a ‘default’ for each country on the basis that the carbon net sink/source calculated according to this method represented most faithfully the true percentage annual carbon sink/source to or from the atmosphere attributable to each country, while avoiding potential problems arising from adoption of a comprehensively net-net approach.

Figure 2. Projected percentage change in net carbon sink/source for eight model countries under business as usual scenario over the period 1990-2150. Calculation is based on a percentage calculation according to Article 3.7, zero baseline and real-time accounting for LULUCF and HWP. HWP allocated to countries according to either Production method (grey line) or Stock Change method (black line).

Figure 2



Non-linearity of BAU projections

Although assumptions made about LULUCF and HWP for each of the eight countries were kept as simple as possible, construction of a BAU scenario was more complicated than for fossil fuel consumption. Despite simplified assumptions, the benchmark projections of changes in carbon net sink/source shown in Figure 2 exhibit considerable variability. This is in sharp contrast to the simplicity of BAU projections for emissions from fossil fuel consumption.

Projections for country Circle (Figure 2b) and country Oval (Figure 2f) exhibit relatively little change from zero in early years, but after this initial period a discontinuity in the projection occurs such that both countries report very large reductions in the carbon net sink/source. This might give the impression that, after some time, both countries have acted to more than comply with targets set in the Kyoto Protocol. However, from Table 1 and Figures 1b and 1f it is apparent that both countries start in 1990 with relatively high forest area which is deforested progressively in succeeding years. The drastic and rapid reduction in net carbon emissions predicted for these countries merely reflects the fact that these countries have deforested to the up to the practical limit set theoretically in this study. In reality the halting of deforestation due to practical constraints is likely to take place progressively, and sharp discontinuities in projections such as shown in Figures 2b and 2f will not be observed. In such cases, a deceleration in the rate of deforestation is more probable and as a result the reduction in carbon emissions due to LULUCF will be more gradual than illustrated here, but the ultimate outcome is the same.

Another example of an unexpected outcome can be observed in the projection country Trapezium (Figure 2h) which from 2105 and 2120 exhibits an episode during which uncharacteristically large reductions in the carbon net sink/source are achieved. From Figure 1h it is apparent that over the period 1990 to 2105 a progressive conversion of old-growth forest to commercially productive forest is assumed to take place, with resultant reductions in long-term carbon stocks. This only ceases around 2105 because the minimum constraint on the area of old-growth forest for this country is reached at this time. A similar episode with the same cause is observed for country Oblong (Figure 2e) from 1990 up to 2005. As a consequence, changes in carbon sinks/sources including LULUCF during the inaugural five-year commitment periods of the Kyoto Protocol reported by country Oblong would show particularly large fluctuations.

Unexpected or unintended results can also arise in cases where countries are actively afforesting under BAU assumptions. For example the projection for country Diamond (Figure 2c) exhibits a progressive reduction in the reported carbon net sink/source over the period 1990 to 2020. This is in response to an ongoing programme of commercial afforestation in country Diamond, however this is assumed to come to a halt around the year 2020 as the theoretical maximum limit for forest area of the country is reached. As with earlier examples, it is unlikely that such sharp discontinuities in projections would be observed in reality but the ultimate outcome such as illustrated for country Diamond may occur progressively for countries that attempt to meet commitments to the Kyoto Protocol in early years through afforestation measures.

Magnitude of trends and fluctuations

For a number of projections in Figure 2 the magnitude of fluctuations is large, notably for countries Circle, Oval, Diamond, Oblong, Trapezium and to a lesser extent Star. For these countries, the contribution of LULUCF and HWP to reported carbon net sinks/sources dominates any influence of fossil fuel consumption. Compared to these countries, the influence of LULUCF and HWP on projections for countries Pentagon and Triangle is much less. Countries Pentagon and Triangle have very high emissions from fossil fuel consumption relative to LULUCF and HWP carbon sinks/sources, and as a result the denominator used in calculating percentage changes (equation 6) is dominated by the contribution from emissions due to fossil fuel consumption. This has the effect of reducing the amplitude of jumps, cycles and fluctuations in projections due to the non-linear response to LULUCF. For the other countries, emissions from fossil fuel consumption do not make such a dominant contribution in the percentage calculation with the result that potentially large fluctuations in projections may be observed.

VARIATION OF REPORTED RESULTS WITH METHOD OF CALCULATION

Assigned amount

The impact of adopting different options for selection of R_i in equation 6 is illustrated in Figure 3 for two example accounting periods of 2008-2012 (Figure 3a) and 1990-2150 (Figure 3b). As noted in the description of Methods, adoption in general of gross-net accounting could misrepresent countries for which LULUCF was a source in 1990 (see results for countries Star, Oval, Circle, Trapezium and Oblong). The Methods section of the paper also raises the concern that, if net-net accounting is adopted universally, then R_i might in some cases tend to zero or even be negative, greatly distorting the reporting of emissions by countries in such cases. (Specifically this might occur where LULUCF is a big sink relative to fossil fuel emissions in 1990.) In principle this is a real problem that could occur in practice but it can only occur if LULUCF is a sink for the country in 1990. In the case of the model countries considered in this study this is only relevant to countries Triangle, Diamond and Pentagon. In fact these countries have very large fossil fuel emissions relative to their LULUCF sinks, and net-net accounting could be acceptable for these countries. On the other hand, a gross-net calculation for these countries overstates the size of the net emission reduction. For country Pentagon, an increase in net emissions compared to 1990 is reported as a decrease when gross-net accounting is used. Calculating percentage increases or reductions using net-net, gross-net and Article 3.7 rules all have potential problems. Although not perfect, adherence to Article 3.7 may avoid the worst of these.

Treatment of HWP

The impact of alternative methods of accounting for HWP is illustrated in Figure 4 for two accounting periods of 2008-2012 (Figure 4a) and 1990-2150 (Figure 4b). Percentage changes in the carbon net sink/source have been calculated for each country according to the default calculation defined above but allocating sinks and sources due to HWP according to either the IPCC, Production, Stock Change or Atmospheric Flow methods. The observed differences seem to make intuitive sense, for example country Triangle, a very high net consumer of wood products, reports the smallest percentage increase in net sink/source (or even a small percentage decrease) if the Stock Change method is adopted. Production of wood products in country Triangle is so small that percentages reported under the IPCC and Production methods are almost the same. On the other hand, the percentages reported for country Diamond, a very large net producer of wood, exhibit the strongest sink when the Production method is adopted. Percentages reported for country Diamond under the Stock Change and IPCC methods are progressively more conservative.

For a five year commitment period (Figure 4a), percentages reported under the Atmospheric Flow method may be drastically different to those reported using the other three methods. If a long accounting period is considered (Figure 4b) percentages reported under the Atmospheric Flow method are significantly different (and more pessimistic) for all but one country. The generally pessimistic results reported under the Atmospheric Flow method are a direct result of the inherent imbalance in the method, which may also be compounded by double counting with losses of carbon in forests due to harvesting. If comparison is restricted to the IPCC, Production and Stock Change methods, differences in percentage changes reported may still be as high as $\pm 15\%$, although the different HWP accounting methods have only marginal influence on the relative ranking of the different countries in terms of reported percentage change in carbon net sink/source, particularly if estimates are accumulated over longer periods (Figure 4b).

Figure 3. Influence of percentage calculation method on reported percentage change in net carbon sink/source for accounting periods of 2008-2012 (a) and 1990-2150 (b). Percentage changes greater than 100% or less than -100% are shown between the ranges 100% to 105% and -105% to -100% respectively (see next page).

Figure 3(a)

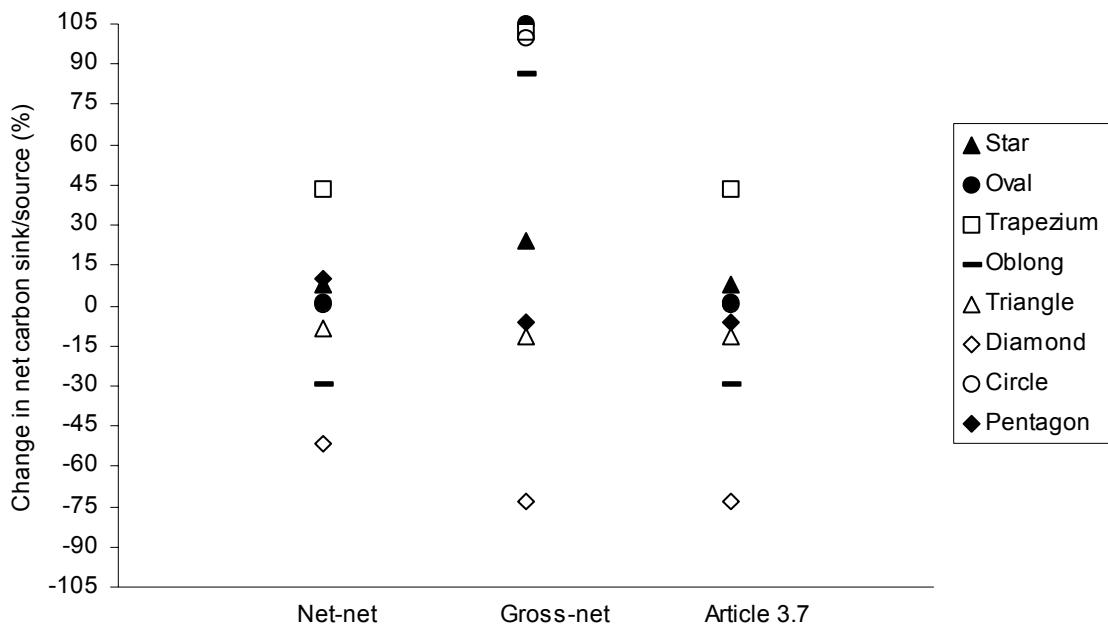


Figure 3(b)

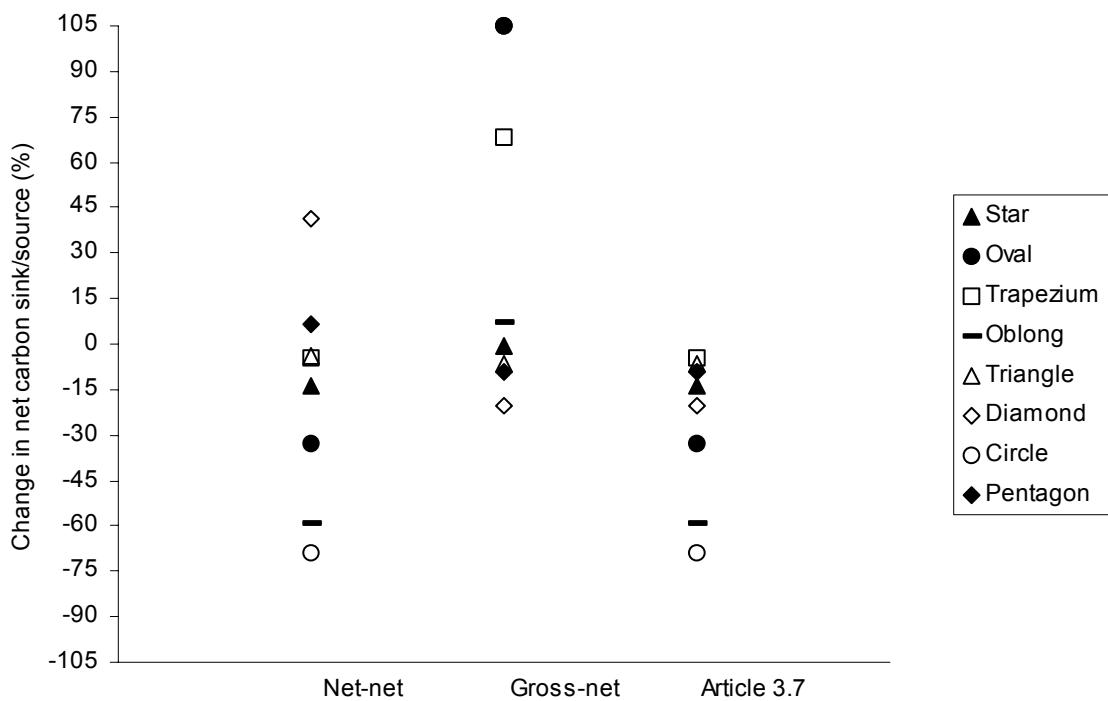


Figure 4. Influence of HWP accounting method on change in reported percentage change in net carbon sink/source for accounting periods of 2008-2012 (a) and 1990-2150 (b). Percentage changes greater than 100% or less than -100% are shown between the ranges 100% to 105% and -105% to -100% respectively.

Figure 4 (a)

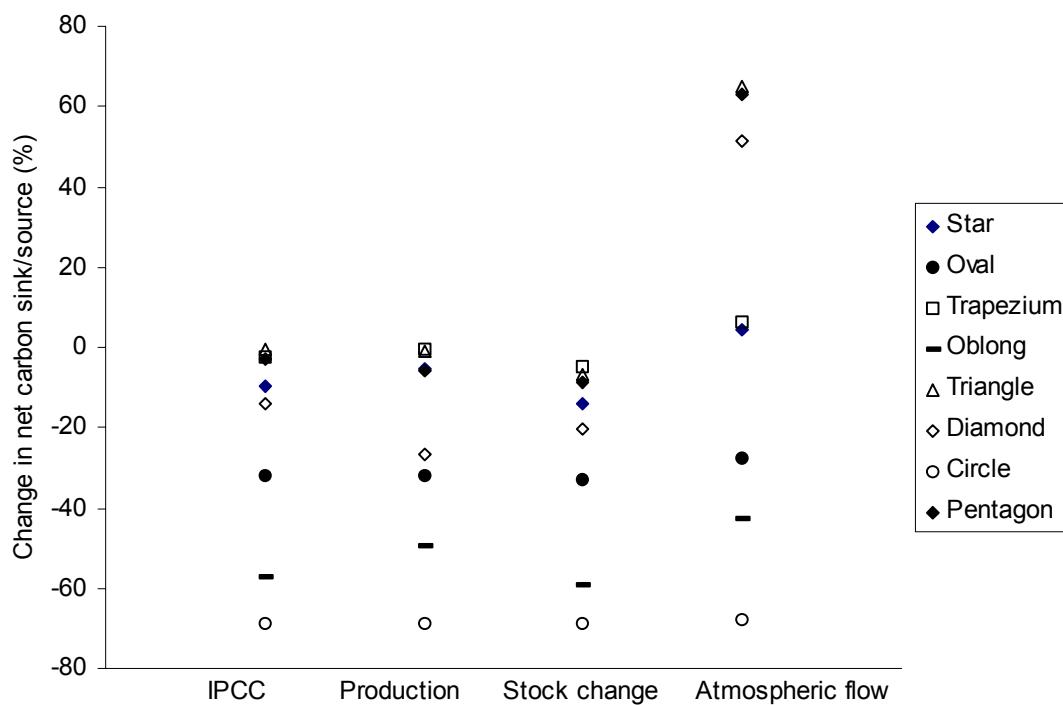
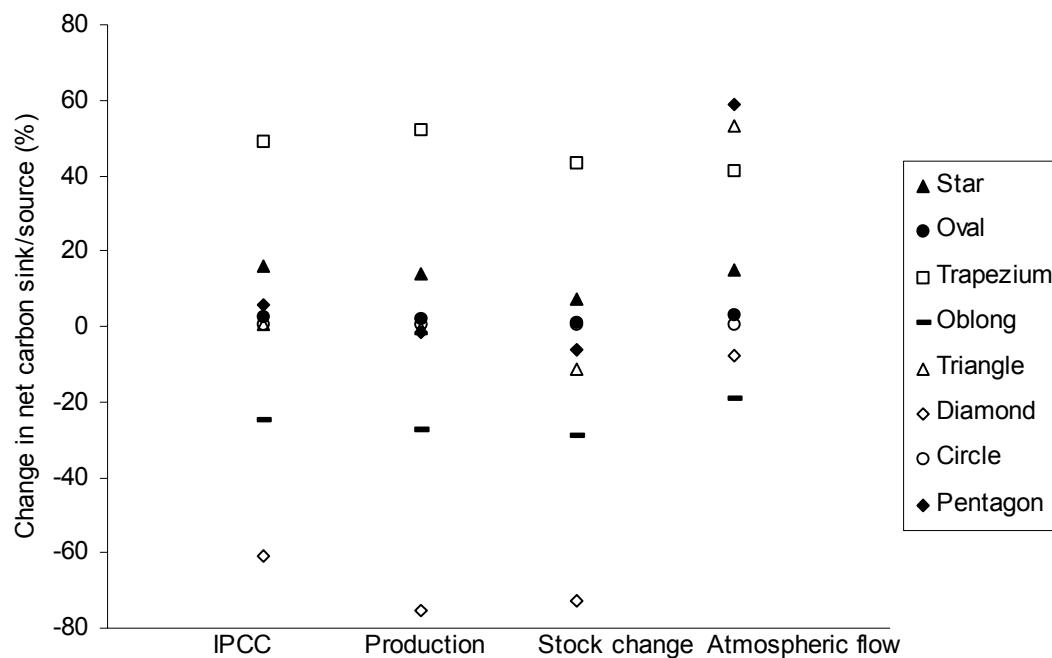


Figure 4(b)



Baseline and accounting index

Figure 5a-f illustrates the impact of adopting different accounting indices for LULUCF and HWP on the percentage changes in carbon net sink/source reported by the eight model countries. Figures are shown for calculations based on three alternative baselines and three alternative accounting periods of 2008-2012 (Figure 5a,c,e) and 1990-2150 (Figure 5 b,d,f). Percentage changes in the carbon net sink/source have been calculated for each country according to the default calculation, except that different accounting indices have been adopted for LULUCF (and where appropriate for HWP) as shown in the Figure. In Figure 5a,b the zero baseline was used, in Figure 5c,d '1990 value' baseline was used and in Figure 5e, f the '1990 projection' baseline was used.

Reported estimates of carbon net sink/source are highly sensitive to choice of baseline and in particular choice of LULUCF accounting index. The picture is confusing when combined with a short (5 year) commitment and reporting interval (Figure 5a,c,e). When viewed over long time intervals (Figure 5b,d,f), reported estimates of carbon net sink/source appear less sensitive to choice of baseline and reported estimates of carbon net sink/source fall into two groups, depending on choice of accounting index. The first group of indices consists of those based on tonne-years or rental systems, which appear to underestimate fluctuations in the carbon net sink/source. In the case of tonne-year indices this may be due to their time-integrative nature. In the very long term tonne-year and rental indices tend to underplay sinks and indicate sources, mainly as a result of assumptions about capping of credits. The second group of indices consists of real-time, one-off, and benchmark-type indices which give similar results, in particular with respect to relative ranking of different countries. However specific results reported for individual countries may vary significantly.

Figure 5. Influence of LULUCF accounting method and choice of baseline on reported percentage change in net carbon sink/source for accounting periods of 2008-2012 (a,c,e) and 1990-2150 (b,d,f). Percentage changes greater than 100% or less than -100% are shown between the ranges 100% to 105% and -105% to -100% respectively.

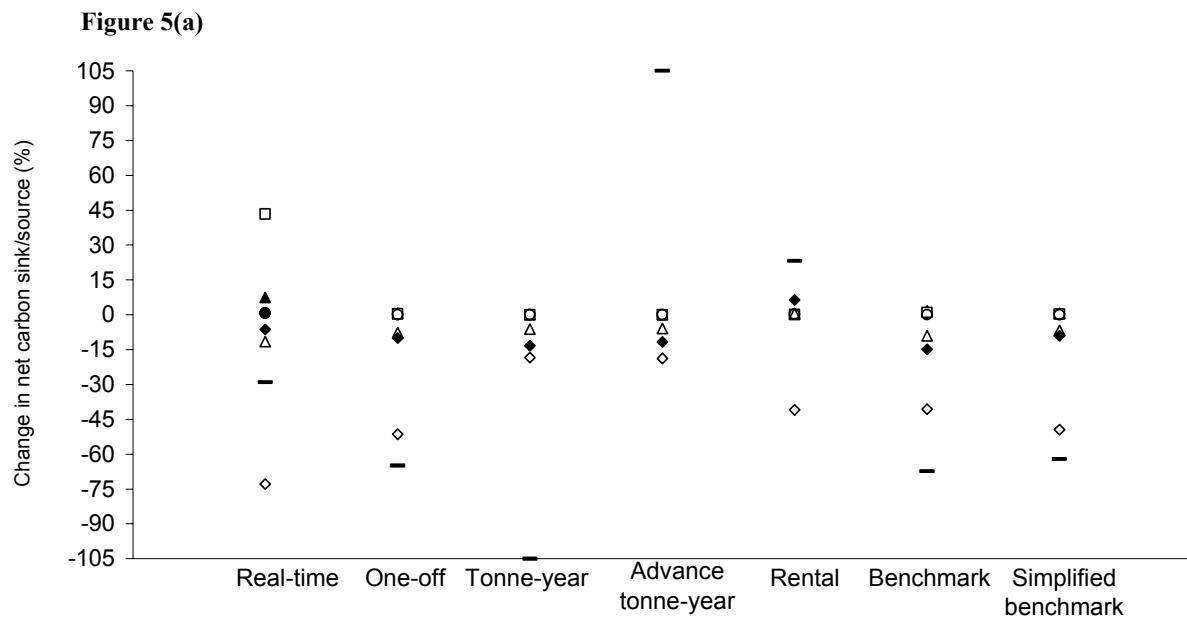


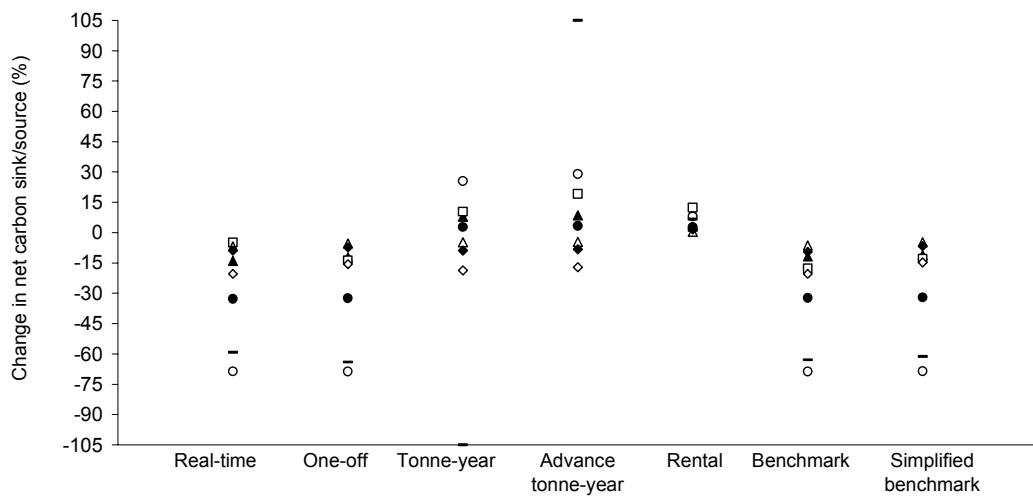
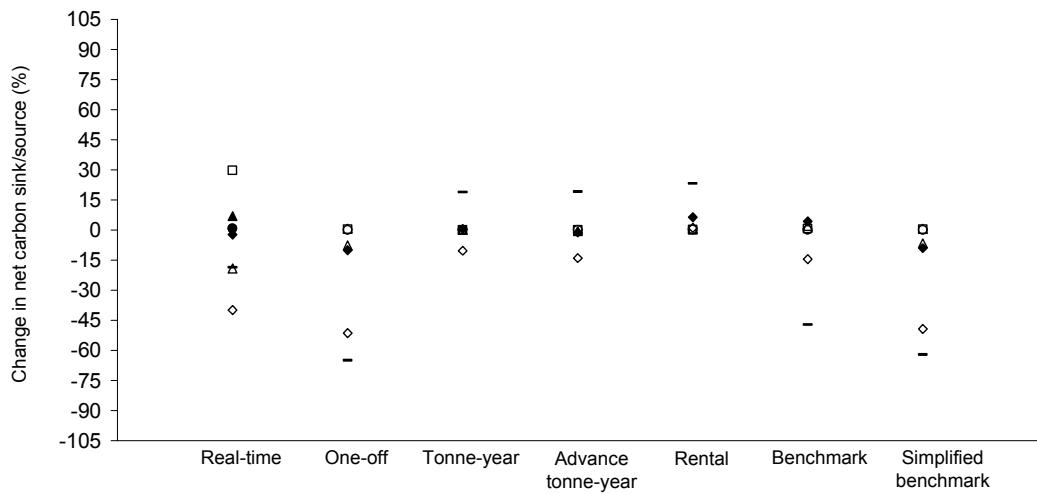
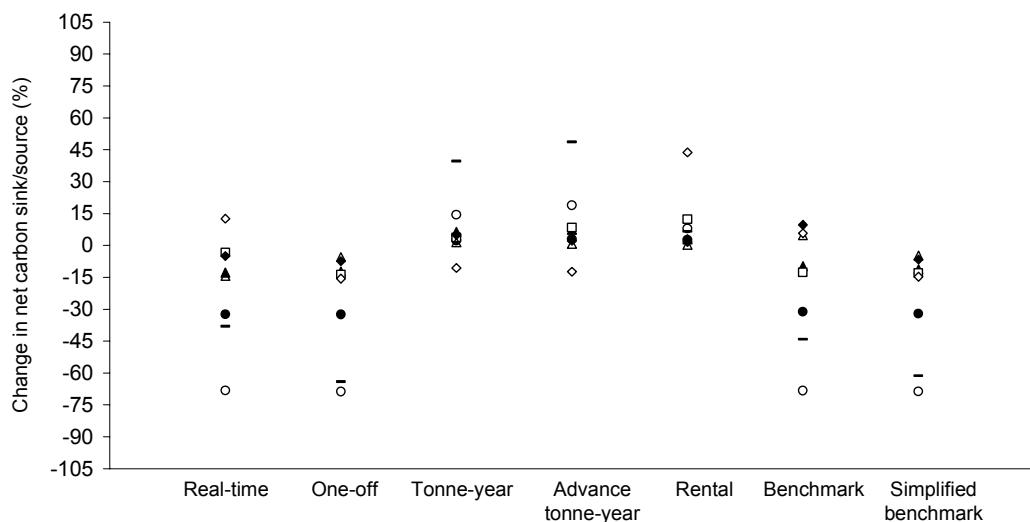
Figure 5(b)**Figure 5(c)****Figure 5(d)**

Figure 5(e)

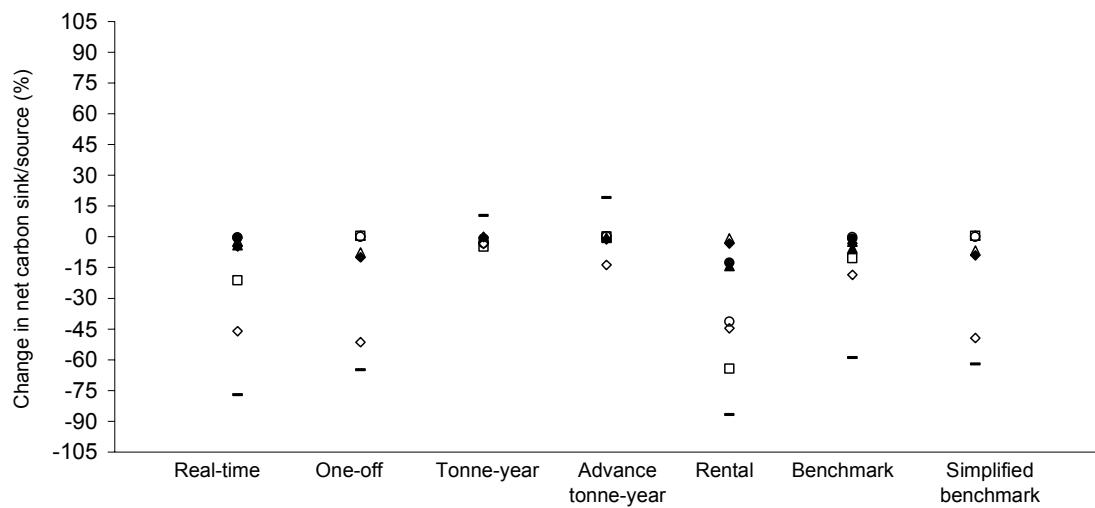
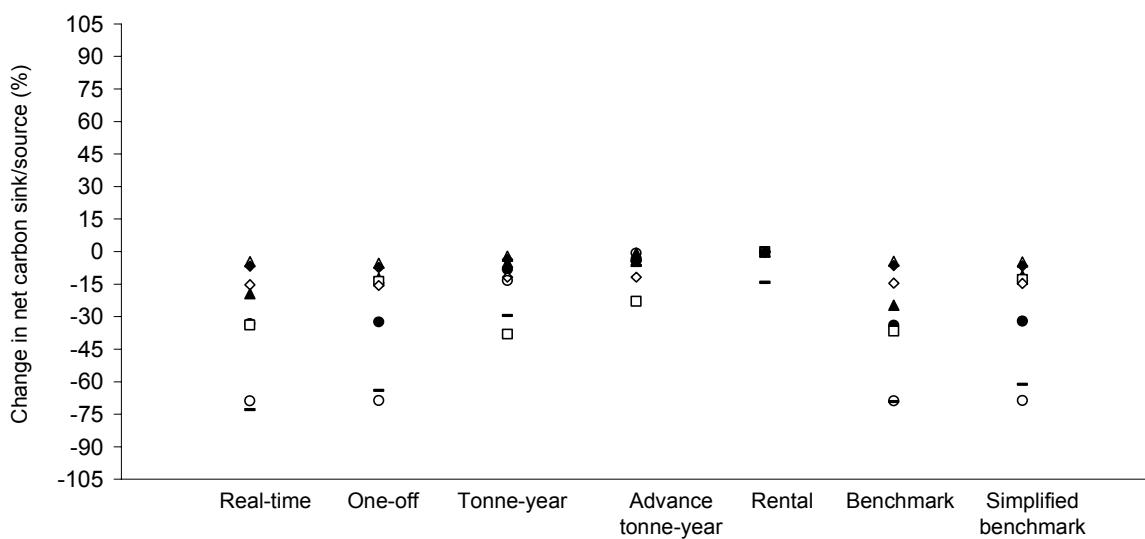


Figure 5(f)



Legend for Figures 5(a) – 4(f):

- ▲ Star
- Oval
- Trapezium
- Oblong
- △ Triangle
- ◇ Diamond
- Circle
- ◆ Pentagon

General observations

A number of extensions and improvements can be made to the analysis presented in this study. There is a clear need to verify whether the findings reported above are valid for scenarios other than BAU. More realism would be afforded if a greater range of countries was represented within the hypothetical world, if forests in different countries were represented, in particular countries for

which R_i is close to or less than zero. Further investigation of the forest area constraints is also needed. The analysis may be oversimplified by because it uses only two forest carbon models to represent all forests in all countries, and a single model for patterns of wood utilisation in each country, while soil carbon dynamics are ignored. Elaboration of these aspects of the model may be needed to provide a complete test of differences between one-off and benchmark accounting indices.

CONCLUSIONS

Compared to fossil fuel emissions, construction of baselines for LULUCF and HWP is complicated, and even if BAU assumptions about LULUCF are kept very simple, resultant projections can be highly non-linear, with very large fluctuations and discontinuities in the predicted carbon net sink/source. It is questionable whether very sophisticated assumptions would yield more reliable projections than simple assumptions

A five year commitment and reporting interval is extremely short relative to potential fluctuations in LULUCF/HWP carbon net sink/source.

Calculating percentage increases or reductions using net-net, gross-net and Article 3.7 rules all have potential problems. Although not perfect, adherence to Article 3.7 may in fact avoid the worst of these.

The Atmospheric flow method of allocating carbon net sink/source due to HWP is imbalanced and would result in an over-reporting of emissions. There is also a risk of double counting of emissions – as loss of forest carbon at time of harvest and then again as loss of wood-product carbon. Adoption of either the Production, Stock Change or IPCC method of HWP allocation can result in differences in percentage changes reported that are as high as $\pm 15\%$, although the different HWP accounting methods have only marginal influence on the relative ranking of the different countries in terms of reported percentage change in carbon net sink/source, particularly if estimates are accumulated over longer periods.

Reported estimates of carbon net sink/source are sensitive to choice of baseline and LULUCF accounting index when combined with a short (5 year) commitment and reporting interval.

When viewed over long time intervals, reported estimates of carbon net sink/source may not be very sensitive to choice of baseline and reported estimates of carbon net sink/source fall into two groups, depending on choice of accounting index:

- Indices based on tonne-years or rental systems tend to underestimate fluctuations in the carbon net sink/source
- Real-time, one-off, and benchmark-type indices give similar results, in particular with respect to relative ranking of different countries.

Although the above analysis is based heavily on the provisions of the Kyoto Protocol, the approach to the analysis is valid in general and many of findings would apply to any accounting system that may be adopted by countries in support of the ultimate objective of the UNFCCC.

ACKNOWLEDGEMENTS

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Are Managed Forest and Soils an effective Strategy for Climate Change Mitigation – an Example from Sweden

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ABSTRACT

Managed forest land has a potential to reduce GHG emissions through production of biomass for fossil fuel substitution, and sequestration and conservation of C. This is the case in Sweden, where managed forest land amounts to 52% of the total land area. The main strategy for GHG reductions is considered to be sustainable use of biofuels to replace fossil fuels. The use of forest biomass for this purpose is presently replacing around 4 Mton C of oil C emissions, approximately 25 % of present emissions of fossil fuel C. More effective use of harvest residues could replace another 3-4 Mton C. Other strategies are e.g. to afforest set-aside farm land and to fertilise forests. This would result in higher production and more harvest residues to replace fossil fuels. However, any strategy for biomass fuel production has to be evaluated regarding its consequences for sequestration and conservation.

Thus, harvesting residues, afforestation and fertilising have both positive and negative implications on GHG sequestering and conservation. The effects are time dependent. In the short perspective, sequestration is important whereas in a longer perspective substitution will be more important. We estimate that the implementation of new strategies in managed forests might replace oil-C and sequester C in an amount equal to > 30 % of the present C emissions from fossil fuels. If also business-as-usual is included, than managed forestry could reduce emissions corresponding to near 100% of present emissions from fossil fuels.

Carbon Pools in an Eucalyptus Forest Managed for Production or Conservation

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PowerPoint presentation: www.joanneum.ac.at/iea-bioenergy-task38/workshop/canberradata/payne.ppt

ABSTRACT

The idea behind using forests as carbon sinks relies upon knowledge of how forest management affects the associated carbon pools. It is essential to take into account not only the carbon storage capacity of forests ecosystems, but also the rate at which carbon is sequestered.

Information on the storage and sequestration of carbon is limited in native forest management in Australia. Collection of further information is essential in our commitment to the Kyoto Protocol. By using date collected from a native Blackbutt (*Eucalyptus pilularis*) forest before and after harvest, the amount of carbon stored can be calculated and modelled for conservation management or timber production. Modelling involved the use of CAMFor to simulate different harvesting and conservation parameters.

Actual Harvesting reduced the above ground biomass by approximately 50%. Of which 15% was removed offsite as wood products for short or long term storage. The relative amount of carbon stored by the forest ecosystem changed substantially as the remaining 35% is subsequently burnt.

The implications of this and alternative management practices for carbon sequestration are discussed.

Sustainable Steel Production – the Role of Forest Biomass

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PowerPoint presentation: www.joanneum.ac.at/iea-bioenergy-task38/workshop/canberradata/jason.ppt

ABSTRACT

With funding from the New South Wales State Government's Sustainable Energy Research Development Fund (SERDF), a project has been undertaken by BHP Minerals Technology and NSW State Forests to evaluate the use of forest biomass for steel production in Australia. The main driver for the study was to reduce Greenhouse Gas Emissions (GGE) from steel production, by partial replacement of coal.

A range of tree species from both native forests and plantations, were assessed for charcoal production, and the factors affecting charcoal properties defined. A tonnage quantity of charcoal was produced and used for full-scale trials as a source of carbon in electric arc furnace steelmaking (a market of around 10,000 tpa in Australia). Large-scale uses (such as an injectant in blast furnace ironmaking) were also considered.

Life cycle analysis was used to assess greenhouse gas emissions from the entire process chain (forestry operations, transportation, charcoal manufacture and steel production). These emissions are compared for steel produced from current steelmaking practice

Linkages between Carbon Sinks and Bioenergy: Trade-offs and Synergies

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ABSTRACT

Forest management-related carbon sinks in Article 3.4 of the Kyoto Protocol, and sinks in general under the Clean Development Mechanism were among the contentious issues that contributed to the breakdown of negotiations at COP6 in The Hague (November 2000). Forests and other lands fulfill many important roles besides being a carbon reservoir and possibly a carbon source or sink. Some of these roles can be valued economically, and some of the functions are correlated with the carbon source/sink function of the land. For example, new afforestation and reforestation activities on agricultural land will lead to greater future availability of woody material, and at the same time increase carbon stocks on the land. Increased levels of harvesting in existing forests may have a diminishing effect on carbon stocks, whereas decreased harvest levels could enhance carbon stocks over and above a reference scenario.

Carbon crediting for existing forests under Article 3.4 may introduce an economic incentive to maximize carbon stocks on the land. Continued sustainable management of existing forests, with the aim of producing timber and biofuels, would incur an “opportunity cost” that could partly offset the gains achieved through substituting fossil fuels with biomass fuels and energy intensive materials such as steel, glass and concrete, with wood-based materials.

Ways must be found which provide incentives for better management of the terrestrial biosphere, supporting (or at least not compromising) the substitution options such as using bioenergy as a replacement for fossil energy. This paper focuses particularly on options for linking bioenergy projects in the Clean Development Mechanism with crediting of carbon accumulation through afforestation and reforestation (and possibly revegetation with non-forest crops), by allowing bioenergy projects to include carbon stock changes on the associated lands from which the biofuels are derived.

Keywords: Carbon sinks, carbon sequestration, biomass, bioenergy, forest management, afforestation, reforestation, Kyoto Protocol, Clean Development Mechanism

INTRODUCTION

Biomass can play a dual role in greenhouse-gas mitigation related to the objectives of the UNFCCC, i.e. as an energy source to substitute for fossil fuels and as a carbon store. Modern bioenergy systems offer significant opportunities towards reducing greenhouse-gas emissions while providing additional benefits. Moreover, via the sustainable use of the accumulated carbon, bioenergy has the potential of resolving some of the critical issues surrounding long-term maintenance of biotic carbon

stocks (IEA Bioenergy, 1998). This paper discusses the impacts of various sinks-crediting provisions under the Kyoto Protocol on biomass energy, including possible trade-offs and synergies.

The matrix (Table 1) shows different bioenergy options, depending on a) whether biomass fuels are derived from forest or non-forest systems, and b) whether these options are implemented on former forest or non-forest lands. The matrix also shows which Articles of the Kyoto Protocol could apply.

Table 1: Overview of different biomass energy categories, and their relationship to the land-use related Articles of the Kyoto Protocol

	Previous forested land	Previous unforested land
Woody biomass	Managed forest extraction: (a) additional extraction (b) greater use of existing forest industry by-products <ul style="list-style-type: none"> • Article 3.4 (<i>forest management</i>) for (a) • (b) does not directly impact forest C stocks. • CDM (<i>forest protection</i>) 	Coppice or Short Rotation for energy <ul style="list-style-type: none"> • Article 3.3 (<i>afforestation, reforestation</i>), provided that these crops are “forests” • CDM (<i>afforestation and reforestation</i>)
Non-woody biomass	This option is not recommended from a carbon balance perspective because there is likely to be a decrease in carbon stocks on the land (deforestation). There may be some exceptions like agroforestry systems.	E.g. switchgrass for power / liquid fuels <ul style="list-style-type: none"> • Article 3.4 (<i>either cropland/ rangeland management, or revegetation</i>) • CDM (<i>activities other than afforestation and reforestation</i>)

ARTICLE 3.3 AND THE USE OF NEW FORESTS AND THEIR RESIDUES FOR ENERGY

Stock changes in the 2008-2012 commitment period, resulting from afforestation / reforestation / deforestation activities since 1990, are accounted under Article 3.3. Following discussion on the definitions of terms like “forest” and “reforestation”, and with information from the IPCC Special Report on land use, land-use change and forestry (LULUCF) (IPCC, 2000) and recent technical papers (UNFCCC, 2001) it is likely that afforestation and reforestation will be defined as conversion of non-forest to forest, and deforestation as conversion of forest to non-forest; the term “forest” will be defined as land that has a crown cover above an agreed threshold (e.g. 10-30%) or that will reach such a status with continuation of ongoing management (i.e., bare land after clear cut, but planned for regeneration, is also considered forest). With these definitions the regeneration of forests after clear-cut harvest does not qualify as reforestation because it is part of an ongoing forest management regime.

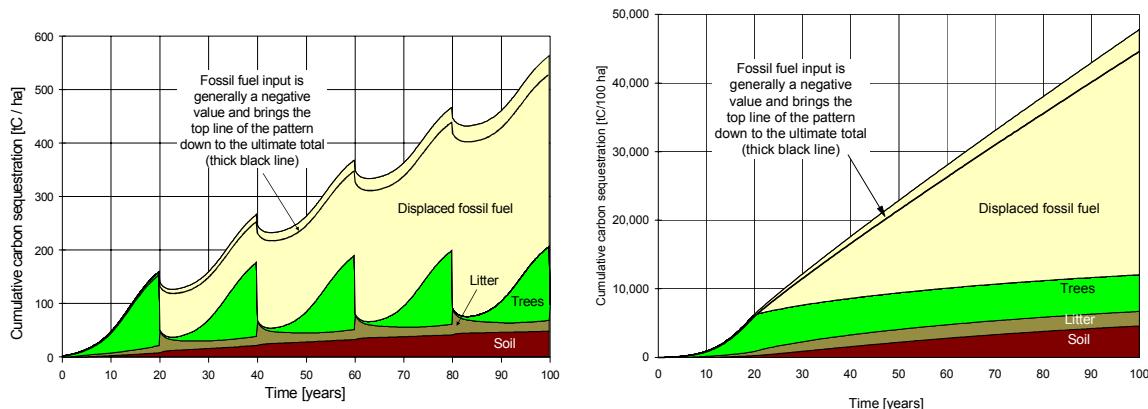
How might Article 3.3 affect bioenergy?

Article 3.3 provides an additional incentive to establish new biomass plantations if they fulfill the definition of a “forest” and are created since 1990 on former cropland, pasture land, or other non-forest land. Carbon credits (in addition to credits for any emissions reduction due to biomass fuels displacing fossil fuel) would be equal to carbon stock increases on such lands between 2008 and 2012. If the plantation is in equilibrium by the year 2008, i.e., harvest equals regrowth, there would be no LULUCF credits and thus no additional incentive. A net increase of carbon in the plantation would occur if a) it is not yet harvested during the commitment period, b) the rate of harvest is lower than the rate of growth, or c) if the harvest equals regrowth but there is a net increase in soil carbon. Obviously any increase in the level of harvesting for biofuels or other forest products will be at the expense of LULUCF credits that can be earned for afforestation or reforestation in the first commitment period and in practice owners of plantations would be free to balance carbon stock increases and bioenergy sales to maximise returns. There would of course be a general increase in time average carbon stocks from the plantations, consistent with the concept of the normal forest (box 1) and because of this Article 3.3 is generally favorable for biomass energy - in the long term the incentives for afforestation and reforestation will create a new source for bioenergy and timber.

Box 1: The concept of a “normal forest”

Energy (and other) plantations will usually not consist of one single stand that is harvested every n years, but of an ensemble of n stands, n equaling the rotation length in years. This allows one stand to be harvested each year, while n-1 stands are regrowing. Such a system is often referred to as “normal forest”. If, for example, each stand is growing from zero tC carbon to 50 tC carbon per ha, then the average carbon per hectare in the normal forest is 25 tC/ha. This is the time-average, as well the spatial average, of carbon stocks per hectare. Therefore, if carbon accounting is done for the full normal forest, there will be no debit as would be the case for an individual stand. Carbon credits in the first commitment period would accrue to the extent that the carbon stock in the normal forest is still increasing during the commitment period. Figure 1 shows the carbon stored in trees (in green) for a stand (left) and a normal forest (right) managed with 20-year rotation length.

Figure 1: Reforestation with subsequent use of harvested biomass for energy on the stand level (left) and landscape level – that is a plantation system producing a constant stream of biomass (right).



The carbon stock in standing trees reaches equilibrium after 20 years. Credits for C sequestration in trees will occur if the equilibrium state is reached after the beginning of the first commitment period. In general, any new “since 1990” plantations that have not yet reached their equilibrium state by 2008 are eligible for carbon credits. The equilibrium level of carbon stocks is the greater, the longer the rotation length of the forest. Therefore, there may be an incentive, from a carbon-credit perspective, to delay harvesting, because harvest is associated with the opportunity cost of not being able to claim further carbon sequestration. However, new plantations that are encouraged by carbon deliberations will in any event provide an additional timber and possibly biofuel resource that would not have been available otherwise.

The trade-off between maximizing on-site carbon stocks and maximizing output will depend on the relative prices of biofuels/timber vs. the price of CO₂ credits, but also on the amount of carbon in fossil fuels that can be displaced with one ton of carbon harvested for bioenergy. The more carbon can be displaced that way, the more likely harvesting for biofuels will be favored. For further details on the trade-offs between on-site sequestration and fossil-fuel substitution see Marland and Schlamadinger (1997).

ARTICLE 3.4 ANALYSIS IN RELATION TO BIOMASS ENERGY PRODUCTION

Two broad groups of options have been proposed for LULUCF activities in Article 3.4: narrowly defined activities (such as improved forest thinning, longer rotation periods etc.) and broadly defined activities (forest management, cropland management, grazing land management) (IPCC, 2000). Recent negotiations have focussed mainly on the latter. The current negotiating text (UNFCCC, 2001) proposes to include forest management, discounted by 85%, up to a cap for each Party which would also limit agricultural activities (cropland and grazing land management and revegetation), afforestation and reforestation sinks in the CDM, and “Joint Implementation” sinks.

How does Article 3.4 crediting affect bioenergy?

For the sake of this discussion we distinguish between bioenergy uses that increase carbon stocks in forest management / cropland management / grazing land management, and those that decrease stocks.

A) Biomass energy increases carbon stocks

An example is cultivation of herbaceous energy crops on former cropland, such as miscanthus or switchgrass. This activity is likely to increase soil carbon stocks and/or carbon in vegetation. Adequate consideration of such bioenergy projects in terms of their sinks component seems to be ensured with draft decisions as proposed in (UNFCCC 2001). These draft decisions propose a net-net accounting approach for cropland and grazing land management ("net-net" means that the sink strength in the first commitment period is compared with that in 1990, and any increase of sink being credited and any decrease debited). Such an incentive through Article 3.4 crediting would be in addition to the reduction in carbon emissions from substituting fossil fuels with biofuels.

Biomass energy production leading to greater carbon stocks may also occur within the narrowly defined activity "revegetation", which has also been proposed as a separate activity under Article 3.4.

B) Biomass energy decreases carbon stocks

Carbon credits for sequestration in existing forests ("second Tier" in proposal for Article 3.4, UNFCCC 2001) may create disincentives for biomass harvest that decreases equilibrium carbon stocks. Examples are the increased removal of logging residues, enhanced thinning, or a shortened rotation length possibly combined with a change in tree species, for increased output of timber and biomass fuels. However, the disincentive will be small if only a small fraction of carbon uptake is credited using broadly-defined activities (such as in the 15% discount proposed for existing forests, UNFCCC, 2001). Moreover, so long as the discounted uptake (plus third Tier in Art 3.4, and relevant JI and CDM credits) exceeds the cap, any reduction in biomass because of energy uses would be compensated by crediting of uptake elsewhere in the forest and there would be no disincentive.

Due to the perceived disincentive some wood-based industries are concerned about carbon crediting under Article 3.4. They see a competitive use of forests emerging that may move the equilibrium towards less harvesting and that could increase wood prices. The same concerns apply to the bioenergy objectives in the EC White paper on Renewable Energy. Bioenergy, pulpwood and carbon credits are often competing for the same lands and for the same biomass. However the commercial value of the timber harvest is likely to be greater than its carbon value under Article 3.4 and so the effect may not be so significant in practice.

Furthermore, associated sink crediting in the first commitment period may allow to increase the resource for future bioenergy uses, and may therefore prove beneficial for bioenergy in the long term. The overall conclusion is again that the Art 3.4 proposals in the Consolidated Negotiating text (UNFCCC, 2001) are reasonably favourable to the development of forestry options which would increase the use of biomass fuels in the longer term, but that the short-term trade-offs should be kept in mind when selecting rules for national implementation of Article 3.4.

Additional observations on forest management in Article 3.4

The following discussion focuses on biomass fuels derived from the land-use category "forest management" (Second Tier in proposal for Article 3.4, UNFCCC 2001). If at some future stage parties wanted to address the trade-off between bioenergy (and other industrial wood uses) and sinks enhancement in the first commitment, and to provide better incentives for truly additional forest management projects for carbon sequestration, then some options would be:

- 1) allowing very limited credit (e.g., 10 or 15%) for existing sinks in managed forests. This is low enough not to compromise enhanced removals for bioenergy, low enough to minimize windfall credits, but still high enough to provide (politically important) carbon credits to some countries. In

addition, one could allow an increase in the discount factor to the degree that the use of bioenergy (possibly excluding residues from various wood-based industries, because they are not directly derived from the land) is increased since 1990 on the national level. This could be done with a simple conversion factor that relates the increase in the amount of bioenergy (or the increase in total harvest share that is used for bioenergy) with the additional carbon credits for sinks in Article 3.4 (Second Tier, “forest management”).

This option could offset a disincentive for bioenergy that results from Article 3.4 crediting. However, an impediment may be the poor data availability on bioenergy use in many countries. And this option would not create a full incentive for new, and truly additional, carbon mitigation projects in managed forests.

Formula as a start for discussion:

$$\text{Discount factor} = 10\% + \text{Constant} \times [B_{2010} - B_{1990}] \quad / \text{LULUCF sink in managed forests in 1990}$$

B_{2010} : Bioenergy use in 2010 (PJ)

B_{1990} : Bioenergy use in 1990 (PJ)

If bioenergy is measured in the form of end-use energy such as electricity, heat or liquid biofuels, then there would also be an incentive for improving the efficiency of biomass conversion, besides that for using more biomass. The constant in the above formula could be chosen such that an increase in the share of bioenergy by 1 PJ could yield an increase in the discount factor by 1 (5, 10, 15 ...) %. However, this would mean that a large, forest-rich country could get more credits for each PJ of increase in biomass use than a small country. Therefore, one could introduce the additional part in *Italics*, thereby ensuring that the bioenergy increase is considered in relative terms to the sink strength.

2) using narrowly defined activities, i.e. to allow full crediting for new land management projects which are truly “additional”. Such projects would have to address concerns of leakage, and thereby address the negative effects for wood industries and bioenergy explained earlier. A LULUCF project would have to show that it can provide the same, or a greater amount, of goods and services (such as timber and biofuels) than the reference land use, before stock changes on the land can be credited. For lands not undergoing a “project” there is no disincentive for biomass energy because no carbon crediting occurs on such lands.

Very importantly, option 2 would provide a 100% incentive for Article 6 (Joint Implementation) sinks projects that are not afforestation or reforestation projects - whereas option 1 would not.

3) discounted crediting for activities between 1990 and 2000 combined with a full project-based crediting for new LULUCF activities since 2000 or a subsequent date, provided that these activities meet an additionality test and similar criteria as in the CDM. This would imply limited credit (e.g., 10 or 15%) for existing sinks in forests, which could be seen as a proxy for sink activities initiated between 1990 and 2000. In addition, any new sinks projects since 2000 would be credited according to option 2 (narrowly defined activities). In terms of calculation procedure, the (10 or 15%) credit for forest management would apply to (national balance minus credits for new projects since 2000).

Option 3 would create a full, undiscounted, incentive for new projects (including LULUCF projects under Article 6 Joint Implementation) while not compromising the bioenergy use on other lands.

4) individual countries could refrain from implementing Article 3.4 in the first commitment period, thereby removing any adverse impacts on forest industries and bioenergy.

5) individual countries could claim credits for Article 3.4 activities internationally, but refrain from national implementation, thus giving no price signals that would discourage forest management for timber and biofuels.

ARTICLE 6 AND POTENTIAL TREATMENT OF SINKS AND BIOMASS ENERGY UNDER JOINT IMPLEMENTATION

Projects under Article 6 (“Joint Implementation”) could encompass activities covered by Articles 3.3, 3.4, or covered by neither of these two articles.

(1) Afforestation and reforestation projects

Such projects would be credited to the country where they occur, with credits being transferred to the investor country thus resulting in a neutral result for the host country.

(2) Projects under Article 3.4 that are subject to discounting.

The viability as joint implementation projects depends on the discount rate applied in national crediting.

In the Article 3.4 category “forest management” the carbon accumulation due to a project would be credited to the host country with a discount of about 85%. However, the transfer of credits to the investor country according to Articles 3.10 and 3.11 would likely encompass the entire amount of carbon accumulated. Thus the host country is likely to incur a deficit of carbon credits. In order to overcome this, the host country could use the pool of the 15% credits from national forest management accounting, and transfer part of these credits to the investor countries. But nevertheless, any new JI project will decrease the amount of emission credits that is available to the host country, and will take it further away from compliance.

(3) Projects under Article 3.4 that are not subject to discounting

In the categories “cropland and grazing land management”, if a net-net approach is used, there does not seem to be a problem as in category (2) because genuinely new projects would fully enter the equation under Article 3.4.

(4) Projects that fall neither under Article 3.3 nor under Article 3.4

If a project is covered by neither of Articles 3.3 and 3.4, or if the project falls under Article 3.4 but the host country decides not to report Article 3.4 activites in the first commitment period, then the project will not create carbon credits to the host country, and therefore a transfer of credits to an investor country will create a negative outcome – in terms of compliance –to the host country.

ARTICLE 12 AND OPTIONS FOR LINKING SINKS CREDITING WITH BIOMASS ENERGY PROJECTS IN THE CDM

The consolidated negotiating text (UNFCCC, 2001) introduced in June proposes to include afforestation and reforestation as eligible for project crediting under the CDM. The effect of afforestation and reforestation on incentives for bioenergy would be similar in the CDM as it is under Article 3.3. In the CDM the incentive to establish biofuels plantations would be somewhat greater due to the banking of carbon credits starting in 2000.

An alternative option for the CDM could be to allow associated sink crediting of mainstream bioenergy projects only. For example: project activities under the CDM that use new biomass-derived fuels to displace the use of fossil fuel could include in the project boundary the stock change between 2000 and 2012 resultant from associated LULUCF activities (afforestation, reforestation, and revegetation) that produce the biomass fuels. To avoid tokenism it might be necessary to specify that the proportion of carbon credits from LULUCF may not exceed the fossil fuel carbon displaced by the biomass energy project by more than a factor of between, say, 1 to 4.¹

¹ The “factor” [1, 2, 4] is put forward based on numerical simulations (see Appendix). For plantation establishment, there are two independent variables to be considered in the modeling: 1) start date of

The expansion of the project boundary to include a LULUCF component must be within the same country. Biofuel use in other countries could be considered based on future SBSTA methodological work, including decisions on accounting for harvested wood products.

This proposal might help address concerns of:

Market leakage. This is minimized through use of a significant part of harvested biomass in new local markets. Local bioenergy uses may also enhance the acceptance of the project by the local population. Leakage due to displacement of food and feed production may remain a concern, but that is also true for unrestricted afforestation and reforestation.

Permanence. LULUCF activities that are part of bioenergy projects may well produce more permanent emission credits than stand-alone LULUCF activities, because the usefulness of the product should help guarantee continuation. Remaining concerns about the permanence of the “land-use carbon” could still be addressed through an equivalent to the Colombian proposal. Also, a possible loss of C stocks in the land-use part of the project would reduce the opportunity for continued generation of emission credits from the bioenergy produced, so that there is an additional incentive to maintain these carbon stocks.

Technology transfer. Implicit in the bioenergy linkage is the need for conversion technology associated with the bioenergy component; given this, there is an intrinsic incentive for the investor to use efficient and reliable equipment to ensure continuing production of energy and CERs.

Scale. The problem of excessive potential scale of LULUCF activities leading to a price collapse is limited because, within all afforestation and reforestation projects, only those that are associated with new uses of biomass for energy would be eligible.

Of course a plantation system, once subject to harvesting, does not generate any further increases in C stocks, with the possible exception of soil carbon, and the crediting regime would need to ensure that carbon credits were only issued for real increases in the time-average carbon stocks.

Finally, the question arises how to handle cases where biofuels are a co-product with other outputs (such as pulpwood)? In such a case only the bioenergy fraction of the harvested wood enters the calculations. If the bioenergy component is very small, then the “factor” should limit crediting of LULUCF (see Footnote 1 and Appendix for a detailed discussion).

A connection between carbon sinks crediting and bioenergy, as proposed here, may be easier to implement in the CDM than in Article 3.3 because the CDM requires, on the international level, the existence of legally defined projects with an agreed duration and scope. Therefore the future use of biomass for energy could be fixed in such a contractual agreement.

plantation establishment, and 2) harvest-cycle length. For any combination of these two, it is possible to calculate the carbon accumulated on the site, and the amount of carbon in biofuels produced, between 2000 and 2012. A third consideration is whether all harvested wood is used for biofuels or whether other co-products (e.g., pulpwood or timber) are produced from the plantation. The ratio of (carbon accumulated / carbon in biofuels produced) will be at high levels if a) harvesting starts very late (e.g. in 2010) and b) if a considerable fraction goes to uses other than biofuels. The numerical simulations have shown that in order to credit stock changes associated with most dedicated biofuels plantations that are operational before or in the first commitment period, the “factor” would have to be greater than 2 or even better greater than 4. On the other hand, in order to limit credits from most plantations where biofuels are a minor by-product, the “factor” would have to be less than 1. Whatever value is finally chosen, there will always be some errors on both sides. One option would be to select the “factor” at a higher level (about 4) for dedicated biofuels plantations, and at lower levels (1 or below) for plantations not mainly established for biofuels production. The use of a formula for deriving the threshold factor is recommended, such as:

Threshold factor = 4 x (share of biomass fuels produced, relative to total biomass harvested).
With this the factor will usually be between 0.5 and 4. In cases where biomass for energy is produced along with other products like timber or pulpwood, only a portion of associated stock changes - corresponding to the share of bioenergy relative to total use of wood - is credited.

Some implications for the economics of biomass energy

The change in carbon stock due to afforestation and reforestation projects is roughly equal to the average carbon stock in the newly established tree crop. For a typical project in a developing country, this may be around 20 tones C/ha/yr, averaged over entire plantations.². It should also be noted that forests established on previously cultivated lands are likely to enhance soil carbon stocks (the exact magnitude is more uncertain; including soil carbon could thus increase crediting but would be more costly to verify at given confidence levels).

Carbon credit prices in the range 10 – 100 \$/tC would then imply that accumulated revenues from carbon credits of roughly 200-2000 USD/ha could be generated for the type of plantation discussed above. This can be compared to the costs of plantation establishment, which typically range between 200 and 900 USD/ha (Amatayakul and Azar, 2001, for Thailand; and Azar and Larson, 2000, for Brazil). Thus, crediting the carbon sinks component of plantations could potentially provide a significant push for biomass energy. It would also favor longer rotation periods and some types of crops over others, with annually harvested crops such as corn, sugar cane or grasses having less incentive than short rotation forests.

On the other hand the additional incentive for plantation establishment may increase concerns about intensified land-use conflicts in many developing countries (see e.g., Carrere & Lohman 1996). Thus, it remains important that adequate attention is paid to sustainable development criteria in the CDM when designing carbon abatement projects, including socio-economic and biodiversity criteria. These issues would apply with at least equal force to any LULUCF crediting. Creating a linkage to productive use of accumulated carbon, namely generation of energy to displace fossil fuels, would enhance the wider sustainable attributes in respect of both local employment and contribution to wider national goals of sustainable development – as well as addressing a number of other concerns surrounding the more general crediting of sinks in the CDM.

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² The carbon content in a plantation depends on the rotation period (Trot) and the yield (tons C/ha/yr) and is roughly equal to yield*Trot / 2. Typical yield levels on well managed plantations in Brazil, for example, are 10-20 tons dry matter/ha/yr, half of which is carbon, and the rotation period (for pulpwood or charcoal) is typically around six years (Azar & Larson 2001). Assuming the central value for the yield, we get a carbon stock of 22.5 tons C/ha.

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APPENDIX

Example 1:

Reforestation of a “normal forest system” with annual growth rate of 7 tC/ha/yr, initiated in 2002 (1 parcel planted in 2002, 1 parcel in 2003, 1 parcel in 2004 etc.). Harvest cycle length 8 years. 70% of harvestable material is assumed to be used as biofuels. Each parcel is assumed to comprise 12.5 ha, so that the totals system size is $8 \times 12.5 = 100$ ha. Such a plantation system would produce 12.5×39.2 tC/ha harvested = 490 tC to biofuels in each year 2010, 2011 etc.

Figure 2 shows the C budget at the stand level (1 ha), Figure 3 at the landscape level (assumed size 100 ha). Further analyses below focus on the landscape level. Several examples are used to demonstrate how the ratio of carbon sequestered, and biomass harvested, can differ. Finally these results are discussed with relation to possible limits of carbon credits for afforestation and reforestation.

Figure 2: Stand level carbon balance of reforestation for biofuels: maximum C per ha is 56 tC, trot = 8 years. Initial stand establishment in 2002.

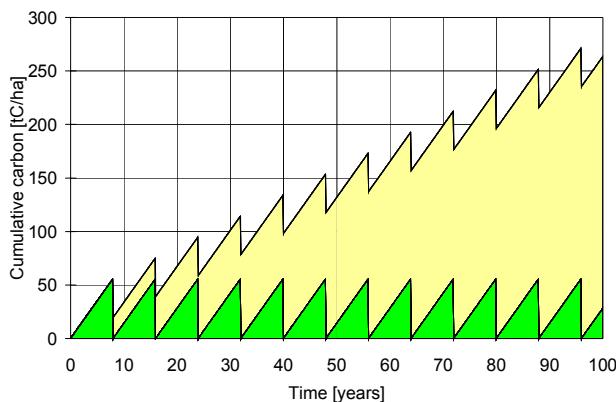
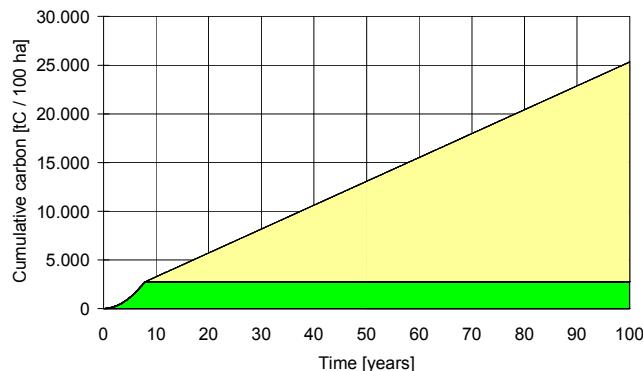


Figure 3: 100 ha of “normal forest” (8 stands comprising 12.5 ha each). The average C stock of the plantation is $56/2$ tC/ha $\times 100$ ha = 2800 tC. This is approached between 1 Jan 2002 and 1 Jan 2010. Due to “banking” in the CDM the full amount may be eligible for credits.



LULUCF stock change: 2800 tC (see caption of Figure 2). Biofuel produced by 2012 from this system: 3 years in which harvest occurs (2010, 2011, 2012) on 12.5 ha each.

Biofuels produced: $0.7 \times 56 \times 12.5 \times 3 = 1470 \text{ tC}$

The ratio of stock change on the land, and biofuels produced (2800 / 1470 in this example) is independent of growth rate. The example excludes changes in soil carbon. If soil carbon were to increase due to the project, then the potential LULUCF credits would also increase.

Example 2:

Same plantation system, but established in 2004, and for the first time harvested in 2012:

LULUCF stock change: 2800 tC

Biofuels produced: $0.7 \times 56 \times 12.5 = 490 \text{ tC}$

Example 3: (extreme case):

Harvest cycle length is 12 years, plantation initiated in 2000, first harvested in 2012. Growth rate 7 tC/ha/yr, LULUCF stock change: stock accumulated on 100 ha: $7 \times 12 = 84 / 2 = 42 \times 100 = 4200 \text{ tC}$

Biofuel produced: $84 \times 0.7 \times 8.333 \text{ ha per stand} = 490 \text{ tC}$

The difference to the previous example is that now the total accumulated stock is greater (whereas the amount of biofuels produced is the same as in example 2). This is an extreme case because the growth phase of the plantation covers the full time period for which credits are possible (13 years, 2000 – 2012).

Example 4:

As example 1, but stand establishment in 2000 (instead of 2002), and first harvest in 2008 (instead of 2010). This is a pulpwood plantation with only 20% of the harvestable biomass used for energy.

LULUCF stock change: 2800 tC

Biofuels produced: $0.2 \times 56 \times 12.5 \times 5 = 700 \text{ tC}$

Example 5:

Plantation established in 2004, harvesting starts in 2008.

LULUCF stock change: 1400 tC

Biofuels produced: $0.7 \times 28 \times 25 \times 5 = 2450 \text{ tC}$

Table 2: Summary of the five examples which have been chosen to include some extreme cases. A more thorough analysis of all possible cases can be found in the Figure 4.

All carbon numbers in this table are for the period 2000 - 2012	LULUCF stock change (tC)	Biofuel Produced (tC)	Ratio (LULUCF stock change / biofuels produced)
Example 1: Bioenergy starts in 2010 ($t_{rot} = 8$)	2 800	1 470	1.9
Example 2 Bioenergy starts in 2012 ($t_{rot} = 8$)	2 800	490	5.7
Example 3: Bioenergy starts in 2012 ($t_{rot} = 12$)	4 200	490	8.6
Example 4: Bioenergy starts in 2008 ($t_{rot} = 8$)	2 800	700	4.0
Example 5: Bioenergy starts in 2008 ($t_{rot} = 4$)	1400	2450	0.6

The ratio (LULUCF stock change / biofuels produced) is between 0.6 and 8.6 in the five examples. If one were to fully credit the stock changes in all five cases, then the threshold “factor” would need to be 8.6 or greater. On the other hand, if one were to begin limiting LULUCF credits from the

pulpwood plantation (with biomass for energy as a by-product) in example 4, then the threshold “factor” would need to be below 4.

In more general terms, the “factor” needs to be large enough to allow credit for all projects that have a reasonable biofuels component. The main point of using the factor is to prevent projects that have a biofuels component just for the sake of qualifying afforestation/reforestation for crediting. I.e., the biofuels component should be significant in itself. On the other hand, the factor should be low enough to exclude projects where biofuels only constitute an insignificant project output.

It becomes clear that single cases are not sufficient to systematically analyze this problem. The two parameters that have been modified in the above examples are:

- The year in which plantation establishment begins, and
- The harvest-cycle length.

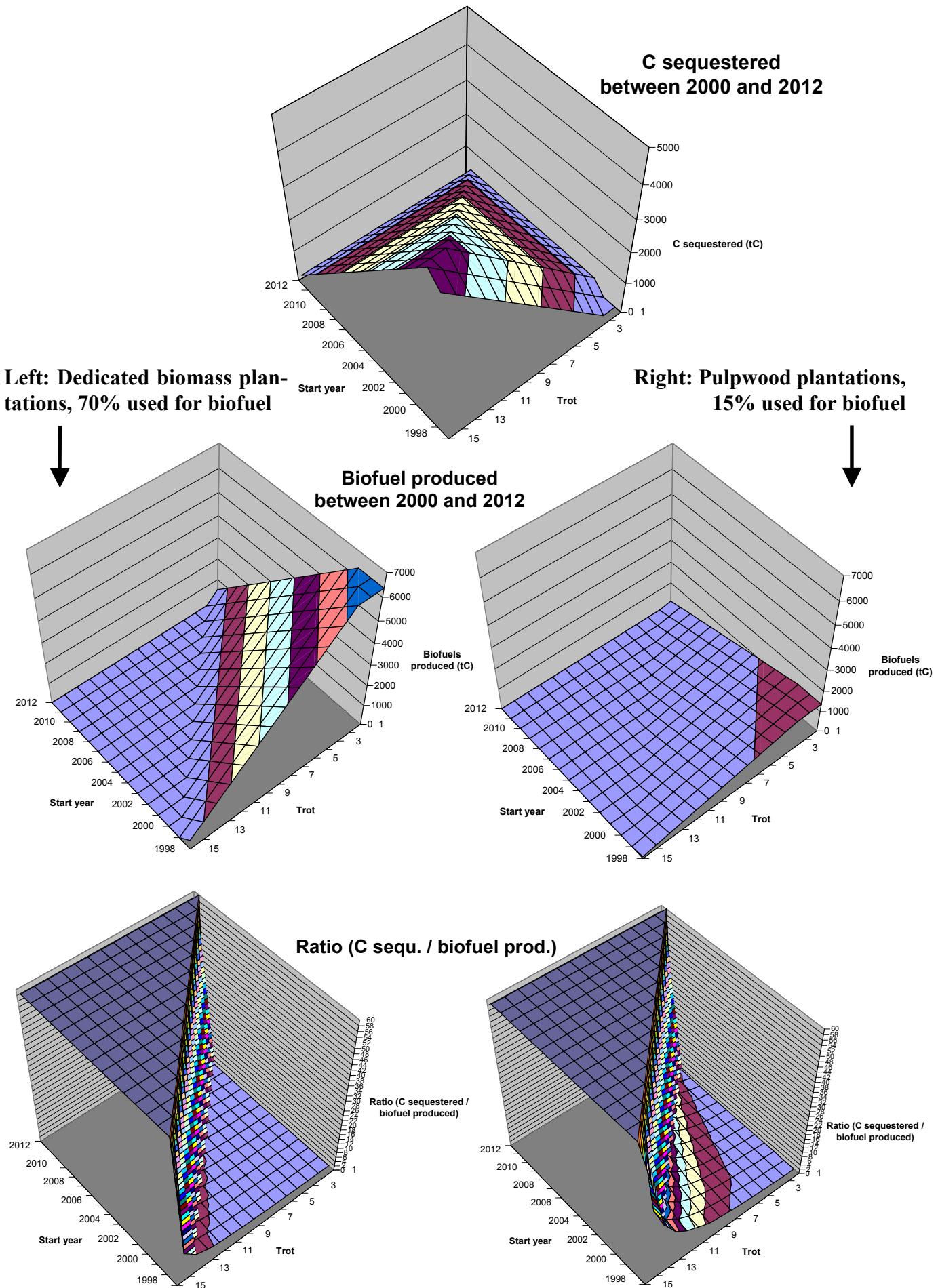
These two parameters have been modified simultaneously and all possible combinations have been calculated. The output can be shown in three-dimensional diagrams in Figure 4. The top diagram shows the carbon sequestered in an LULUCF project as a function of the two parameters. The two diagrams in the center show the amount of biofuels produced as a function of the same parameters (the left diagram is for a biomass plantation with 70% of the harvested material used for fuel, whereas the right one is for a pulpwood plantation with only 15% of the harvested material used for fuel). The two diagrams at the bottom are a combination of the top and middle diagrams and represent the ratio of (LULUCF carbon stock change between 2000 and 2012 / carbon in biofuels produced between 2000 and 2012). These diagrams provide a comprehensive overview of all possible cases that could occur in the proposed linking of carbon sinks and bioenergy.

In deriving recommendations about the threshold factors, the bottom diagrams will be most important. Taking the example of dedicated biomass plantations (bottom left), it can be seen that the uniformly shaded area in the lower part of the diagram corresponds to those cases where the ratio of (LULUCF stock change / carbon in biofuels produced) is below 2. I.e., if the threshold factor were chosen to be 2, then all these projects would be fully credited. If the factor were chosen to be 4, then also the projects in the dark purple area of the 3-dimensional surface would be fully credited. It appears that a threshold factor of 4 is sufficient to fully credit all projects (except those where the combination of plantation establishment year and harvest-cycle length results in an initial harvest only very late in the first commitment period, so that these projects would not likely be bioenergy projects in the first commitment period. These are the combinations shown on the left of the diagram).

The bottom right diagram shows the same situation, but for a pulpwood plantation where only 15% of the harvested biomass is used for energy, 55% is used for pulpwood, and 30% remains on the site. For pulpwood plantations the area of the three-dimensional surface that is below “4” (two different shadings in the lower part of the diagram) is smaller. This means that not as many plantation cases would be fully credited at a threshold factor of 4. However, crediting does not appear sufficiently restricted. For example, a pulpwood plantation established in 2000 and first harvested in 2008 would still fully qualify. It seems more appropriate, in cases where bioenergy is a by-product, to award credit for only a portion of the carbon stock changes on the land. If one quarter of usable biomass is used for energy, and three quarters are used for pulpwood, then a quarter of the LULUCF stock changes could be allocated to the bioenergy project and thus credited – This would suggest an adjustment of the threshold factor depending on the relative share of bioenergy:

Threshold factor = 4 x (share of biomass fuels produced, relative to total biomass harvested).

Figure 4: Carbon sequestered in the plantation (top diagram), carbon in biofuels produced (two center diagrams) and the ratio of (carbon sequestered / carbon in biofuels produced) (two bottom diagrams), at differing harvest-cycle length and plantation establishment year.



Implications of Different COP Decisions for Bioenergy, Wood Market and Land Use Patterns in Italy

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ABSTRACT

The presentation, after providing some background information on the Italian forestry sector, includes a discussion of the recent trends in consumption of wood for energy in Italy.

The increased domestic consumption is mainly due to three factors: the high prices of fossil fuels, the availability of innovative conversion technology at household level (boilers, stoves), the new regulations that are favouring the recycling of final wood products through voluntary agreements between industrial producers of woody products, consumers and municipalities.

Official statistics are underestimating the current consumption wood products for energy and the production potentials, mainly for the dispersed structure of the supply and the large number of small-scale consumers. However, only a limited part of the domestic fuelwood consumption has clear substitution effects with fossil fuels or other non-renewable energy resources. Large quantities of wood products is currently used in fireplaces or in family cooking stoves with serious pollution effects.

In the conclusions 5 possible scenarios deriving from different COP decisions on articles 3, 4 and CDM: (a) the business as usual scenario, (b) a scenario based on a price premium for domestic production of wood for energy, (c) a carbon accounting in forest stocks scenario, (d) a carbon accounting in forest stocks and in wood products scenario, and (e) a scenario based on the development of flexible mechanisms connected with forest activities. Consequences of different decisions are analysed in relation to fossil fuel consumption, wood market development, land use patterns, externalities (i.e. non market services) provided by domestic forests. As a conclusion the paper is suggesting that non market effects connected with reduced abandonment of forestland (i.e.: fires, uncontrolled grazing, soil degradation, etc.) are remarkably increasing the positive effects of fuelwood consumption as an instrument to reduce carbon emissions in the atmosphere.

Scenario	Fossil fuel consumption	Wood market development	Land use patterns	Externalities provision
business as usual	No trend changes: stabilisation	No trend changes: increased external dependence	No trend changes: forest abandonment, increased forest land, coppices conversion to highforests	No trend changes: reduced biodiversity
price premium for domestic production of wood for energy	Reduced consumption	Increased external dependence for industrial wood products	Reduced coppice abandonment	Reduced forest fires and of semi-natural forests
C accounting in forest stocks			Increased coppice conversion	
C accounting in forest stocks and in wood products scenario				
flexible mechanisms connected with forest activities				

What Prospects for Soil C Sequestration in the CDM? COP-6 and Beyond

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ABSTRACT

Although generally supported by international experts and the United Nations Intergovernmental Panel on Climate Change, carbon (C) sequestration has long been a contentious and difficult issue in global climate negotiations. As the recent sixth Conference of the Parties (COP-6) held in The Hague in November 2000 demonstrated, the 'sinks' issue currently divides both the industrialized countries and the developing countries. To understand the background for the carbon sink controversy, and in order to assess the political acceptability of direct foreign investments in soil C sequestration in developing countries as an eligible climate policy measure, this paper briefly summarizes some of the main issues in the international policy debate on sinks. The paper also analyzes the informal outcomes of COP-6 and the coming COP-6 bis to be held in the summer of 2001.

THE TREATMENT OF SOIL C SINKS IN THE KYOTO PROTOCOL

The ultimate objective of the 1992 United Nations Framework Convention on Climate Change (FCCC) is to achieve 'stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'.¹ A Protocol to be attached to the FCCC establishes commitments for all the developed countries and former centrally planned economies—the so-called Annex B countries—to reduce their GHG emissions by the year 2010 with a total of about 5% compared to the 1990 level of emissions.² The Protocol, which was negotiated in December 1997 in Kyoto, Japan, does not establish commitments on the part of the developing countries (the non-Annex B countries) to mitigate GHG emissions. It has yet to be ratified by a sufficient number of countries before it can enter into force.

Article 12 of the Kyoto Protocol establishes the Clean Development Mechanism (CDM) as a mechanism for direct foreign investments in greenhouse gas (GHG) mitigation projects in developing countries.³ The CDM is designed to give developed countries with high domestic mitigation costs access to low-cost mitigation projects in developing countries, and to benefit developing countries by supplying projects to investors in developed countries. Developed countries are able to count emission reductions achieved overseas in developing countries against their national climate commitments. The CDM offers an opportunity to increase financial resource flows from developed to developing countries.

¹ Article 2.

² Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, Great Britain, and the USA.

³ Formally, the objective of the CDM is 'to assist [developing countries] in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist [developed countries and former centrally planned economies] in achieving compliance with their quantified emission limitation and reduction commitments.'

Article 3.3 of the Kyoto Protocol explicitly mentions emissions from sources and removals by sinks as a direct consequence of human intervention affecting land-use change and forest-related activities—deforestation, reforestation and afforestation—undertaken since 1990. Article 3.4 identifies agricultural land as a possible carbon sink or source, and agricultural land should be included in the emission inventories that are prepared by the Annex I Parties. However, the Kyoto Protocol does not include provisions for national crediting for C sequestration in soils. And it is still unclear whether the CDM will provide credit for sink enhancement and permit broader sink activities.

It is also unclear how carbon sink offsets are to be determined.⁴ Essential issues still lack definitional precision:⁵ How are afforestation, reforestation and deforestation defined?; Which carbon stock changes are verifiable?; Which additional activities for sources and sinks are meant under article 3.4?; How should carbon stock changes be measured during the commitment period in order to arrive at comparable and verifiable figures? And how can the impact of human-induced activities in land-use change and forestry be distinguished from natural impacts and from indirect human-induced activities (e.g. CO₂ fertilization)?

Perhaps C sequestration in soils in non-Annex B (and in Annex B) countries could become an eligible activity under the Kyoto Protocol, but several regulatory and technical issues remain unresolved. Moreover, as documented in the next section, a number of additional issues are influential in the international policy debate on C sinks under the CDM.

THE COMPLEXITY OF SINKS

The policy debate on C sinks dates back to the beginnings of international cooperation on climate protection in the late 1980s and early 1990s. Many issues have been raised since then. It is possible to divide the main issues and questions into three groups: issues that are primarily technical and scientific; issues that are more ‘deep’ and fundamental; and economic and distributional issues. The issues are listed and briefly summarized below. This non-exhaustive list is neither supposed to indicate their relative significance nor how frequently they have been raised.

Scientific and technical issues

Some reservations concern scientific-technical issues and generic issues in regard to sinks and sinks-related activities and projects. Among some of the oft-mentioned reservations are the following:

- High scientific uncertainty and even ignorance surrounds sinks, making C sequestration an uncertain and risky option. Viewed from a scientific viewpoint, it is problematic to utilize sinks because the scientific and technical basis for policy-making is too uncertain. Among other things, the hypothesis about CO₂ fertilization is not sufficiently scientifically sound and is insufficiently supported by empirical evidence.
- Under changed environmental conditions (e.g. due to a changing climate) soil (and forest) sinks may instead act as sources.
- There is a risk of bogus sinks because well-known biogeochemical processes (e.g. CO₂ fertilization), and probably some as yet unknown processes, could stimulate sink enhancement. The precautionary principle adopted in the FCCC should instead provide the

⁴ Article 3.4 states that ‘the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, decide upon modalities, rules and guidelines as to how, and which, additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land use change’ shall be taken into account. But the global climate negotiations have not yet produced a solution to this issue.

⁵ See Nabuurs et al. (2000).

basis for policy-making and it is necessary to be conservative.⁶ Promoting environmental integrity justifies erring on the side of safety and reducing environmental risks.

Comments

The IPCC has addressed, more or less directly, these issues in its recent special report on *Land Use, Land-Use Change, and Forestry*.⁷ The International Geosphere-Biosphere Programme (IGBP) has also examined many of these issues.⁸ However, it seems clear that these international scientific-advisory initiatives have not been sufficiently successful in demonstrating that these risks are either manageable or are relatively minor. But it is also evident that more research, experiments and demonstration projects are necessary.

Fundamental or basic issues

Some of the more fundamental issues raised in the context of C sequestration are the following:

- C sinks are a risky and intermediate step rather than a permanent solution to the global climate change problem. It is very problematic to rely on sinks because they could easily be reversed (e.g. by forest fires or by reverting to intensive tillage in agriculture). It is only too likely, because of their long lifetime, that they would be subject to negative human, or non-human, interference.
- It is a fundamentally misguided approach to continue emitting GHGs even though terrestrial aboveground and below-ground C sinks absorb CO₂ emissions. Sequestration does not lead to a net removal of CO₂ from the atmosphere because crediting sinks enables a parallel increase in fossil fuel CO₂ emissions.
- Sink opportunities would delay the necessary shift from a fossil fuel-based energy system to a system that is not based on fossil fuels. Sinks are a sidetrack and would simply slow down the necessary transition to non-fossil energy technologies and systems.
- Offset policies and programs allowing international trade in ‘pollution’ should be entirely prohibited under the global climate regime.

Comments

The first issue is concerned with permanency—which arises because sinks are potentially reversible—an issue that it clearly is more difficult to devise satisfactory solutions to.⁹ The key rebuttal to the next two issues is that sequestration offsets are time-buying and cost-saving devices that would avoid premature retirement of the capital stock. Thus they could reduce the potentially massive economic costs of changing the energy system to become less fossil-fuel based and they would buy time for the development of cleaner energy technologies. Sinks projects would therefore be an attractive but limited complementary option to GHG emissions reductions options. The fourth issue is normative, thus it cannot be solved on scientific and technical grounds. Tradable pollution permits schemes are often criticized for being irresponsible and anti-environmental.¹⁰

⁶ According to Article 3.3 of the FCCC: ‘The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures (...).

⁷ Watson, R. T., I. R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verardo, and D.J. Dokken, (eds.), *Land Use, Land-Use Change, and Forestry*. Special Report of the Intergovernmental Panel on Climate Change (Cambridge, U.K.: Cambridge University Press, 2000).

⁸ See IGBP Terrestrial Carbon Working Group: 29 May 1998, ‘The Terrestrial Carbon Cycle: Implications for the Kyoto Protocol’, *Science* 280, 1393-1394; Falkowski et al., 2000.

⁹ See, e.g. Chomitz, 2000.

¹⁰ For an example from marine pollution prevention, see Lasse Ringius, Radioactive Waste Disposal at Sea

Economic and distributional issues

This group of issues is concerned with economic and equity aspects of C sequestration. An important, but not uncontested, underlying assumption is that a large amount of inexpensive C sequestration options exists in developing countries¹¹:

- Annex B countries would primarily make investments in the inexpensive sequestration options that exist today in developing countries and developing countries would therefore be left with costly options when they later need to control GHG emissions. This argument about international fairness in a 'North-South' perspective suggests that Annex B countries would unfairly pick 'low-hanging fruits' or 'skim the cream' in developing countries.
- The present generation would pick up the cheap sequestration options in non-Annex B countries and it would therefore impose heavier burdens on future generations. This argument concerns intergenerational fairness and the responsibility of the present generation towards future generations.
- The rent generated by sink projects would be unevenly and unfairly distributed among the non-Annex B host countries and sellers. According to this argument, countries and sellers that offer attractively priced (i.e. low cost) sink projects would benefit, whereas countries and sellers that are unable to compete in the global GHG offset market would lose. This is unfair seen from an intragenerational and international perspective.
- Annex B country investments would be concentrated in the attractive low cost forestry, agriculture and land-use sectors. Thus the CDM would not lead to sustainable development in other sectors such as energy, industry, and transport. But attracting foreign investments in the latter sectors are high national priorities in developing countries.
- Sequestration projects would because of their low cost advantage be more competitive than energy, industry, waste, and transportation projects, and, since large amounts of these options would be available, they would flood the global GHG offset market.¹² As a result, developing countries' earnings from Annex B country investments in CDM project would be significantly reduced.
- It is not desirable or acceptable if (some) Annex B countries achieve their targets at little costs.¹³ The supporting argument is seldom stated explicitly but could be that only a costly 'stick' would be able to stimulate society, the private sector, and governments to undertake the necessary changes. Perhaps it is perceived as simply unfair if protecting the climate system is inexpensive for 'polluters', especially the major ones.¹⁴ But by excluding the high-cost options from the CDM, Annex B countries would have to utilize the medium and high-cost options available in Annex B countries.

(Cambridge, Mass: MIT Press, 2000), p. 65.

¹¹ The costs and local economic benefits are better documented for forest C options than for soil C options. For an overview over prices and potential, see Fanny Missfeldt and Erik Haites, 'The Potential Contribution of Sinks to Meeting the Kyoto Protocol'. Manuscript, 2001.

¹² It is estimated that 1,698 MtC/y from conservation projects would be available in developing countries by 2010. See I.R. Noble and R. J. Scholes, 'Review: Sinks and the Kyoto Protocol,' *Climate Policy* 1 (2001), pp. 5-25.

¹³ According to a leading environmental non-governmental organization, 'it is also clear that a number of Annex I countries support the inclusion of sinks in the CDM, primarily in order to gain access to even 'cheaper tons' of carbon than would otherwise be available through a clean technology orientated CDM'. Greenpeace, August 2000, p. 4.

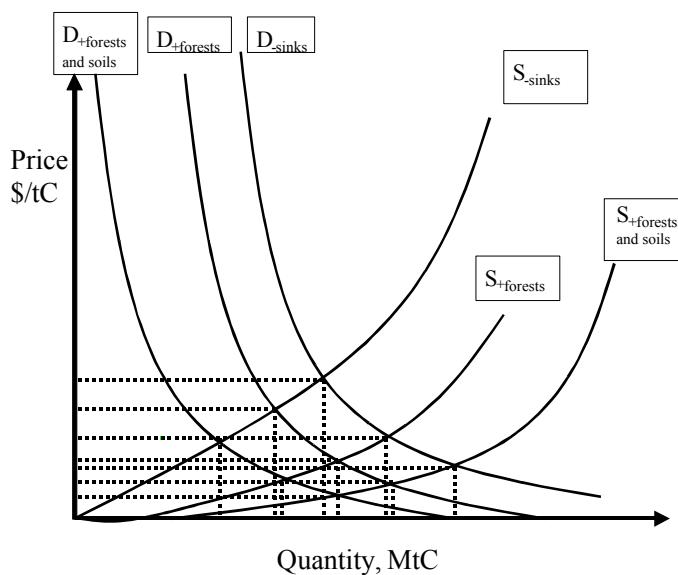
¹⁴ For example, an analysis of the COP-6 actually claims that 'some European ministers made it clear that they wanted Americans to feel some economic pain more than they wanted a workable agreement'. *The Economist*, 'Oh No, Kyoto', 7 April 2001, p. 81.

The argument is illustrated diagrammatically by Figure 1. It shows three different supply curves (marginal costs), three demand curves (marginal costs), and nine different global offset prices and quantities of offset being traded globally. Demand and supply are measured in million t C, while the global offset price is expressed in US\$/t C. Figure 1 shows that Annex B countries' demand for offsets and non-Annex B countries' supply of offsets would influence both the global C offset price and the quantity traded. It is assumed that the willingness of Annex B countries to buy international C offsets depends on the costs of domestic GHG mitigation options. Annex B countries' willingness to buy C offsets from non-Annex B increases when the costs of domestic GHG mitigation options in Annex B countries increase, and vice versa.

The curve labeled S-sinks shows the quantity of offsets supplied and at which costs when sink enhancement projects in non-Annex B countries are not eligible under the CDM. The S+forests cost curve shows the quantity of offsets supplied and their costs when forestry (i.e. afforestation, reforestation, and avoided deforestation) projects in non-Annex B countries are eligible under the CDM. The S+forests and soils cost curve shows the quantity of offsets supplied and their costs when both forest and soil C projects in non-Annex B countries are eligible under the CDM. Similarly, the D-sinks cost curve shows the global demand curve for offsets if sink enhancement projects in Annex B countries are not eligible under the Kyoto Protocol. The D+forests cost curve shows the demand curve for offsets if forestry projects in Annex B countries are eligible under article 3.3. The S+forests and soils cost curve shows the demand curve for offsets when forest and soil C projects in Annex B countries are eligible under article 3.3 and 3.4.

As Figure 1 shows, depending on the supply of sink enhancement projects by Annex B and by non-Annex B countries, the global carbon offset price could vary significantly, given changes in the supply of and demand for offsets. A number of GHG abatement opportunities available in non-Annex B countries (e.g. relatively more expensive solar PVs) would not be picked up by Annex B countries if sink enhancement projects are eligible under the Kyoto Protocol. Although the quantity of offsets that is traded is reduced if sink enhancement projects are not eligible, the energy options have significantly higher prices, resulting in more profit to the non-Annex B countries.

Figure 1: Impact on the Global C Offset Price and Trade of Including Forest and Soil C Sinks in Annex B and Non-Annex B Countries in A Global Trading Regime.



Comments

The assumption that underlies the first and second issue is that cheap mitigation options are scarce and will be exploited relatively quickly. But this is a static and rather pessimistic view of future technology development and of the opportunities for shaping fossil energy demand and social behavior more broadly. If it becomes clear (issue 3-5) that the CDM revenues are very unevenly distributed among developing countries, then the FCCC Parties may decide to influence the CDM investment patterns to become more equitable, e.g. through establishing co-financing programs to reduce the incremental costs of medium- and high-cost mitigation opportunities in developing countries. Some have proposed to set a minimum price for CDM options in order to level the playing field. As to the final point, the argument that it is desirable if climate targets are economically costly runs counter to the CDM's aim to achieve global cost-effectiveness and ignores basic principles of environmental economics. At the same time, it is important to develop mechanism and instruments under the FCCC that will increase investments in decarbonization of energy systems, including investments in research and development and market-integration of cleaner technologies and energy systems.

REGULATORY ISSUES UNDER THE KYOTO PROTOCOL

Although partly overlapping with the issues touched upon above, an additional group of issues concern the emerging regulatory framework in the Kyoto Protocol and the rules and modalities that are likely to be applied if CDM sinks projects would be eligible under the Kyoto Protocol. These issues are in many cases genuine to all project types—they are not concerned only with sinks projects but also other abatement and mitigation project types:

- Project eligibility, i.e. which project types are acceptable?

As mentioned initially, the eligible sink-related human activities are still undecided. There is need for definitions of the human-induced eligible activities in forestry, agriculture and other land-use sectors.

- Uptake should be real, measurable, and long-term.

The issue of the measurability of C stock changes has often been raised in the international policy debate. More recently the opportunities for cost-effective measurements have received more attention, e.g. combining satellite images and on-ground measurements, existing land-classification systems and statistical approaches in order to produce reliable, cost-effective measurement of changes in C stocks. The complex issue of permanency is, as mentioned, one that distinguishes sinks projects from fossil energy projects.

- Additionality, i.e. C uptakes must be additional to what would have otherwise occurred.

The baseline establishes the reference for the assessment and calculation of the project performance in terms of emissions reductions or amount of CO₂ sequestered compared with the 'without-project' situation. No internationally prescribed method or standardized guidelines exist for baseline-setting in the area of C sinks. It is likely that there will be put more emphasis on development of international sector guidelines in the context of the FCCC.

- Supplementarity, i.e. to what extent should targets be achieved through domestic measures? Should the regulatory emphasis be placed mainly on domestic measures?

The supplementarity issue evidently concerns all the three so-called flexibility mechanisms in the Kyoto Protocol, i.e. joint implementation (JI), the Clean Development Mechanism, and international emissions trading.

- Leakage, i.e. mitigation achieved in one place is outweighed by releases of emissions elsewhere.

Some argue that it will be possible to capture and measure leakage through application of sufficiently wide project or systems boundaries. Too narrow boundaries will ignore leakage effects. The issue is particularly important in the context of the CDM because the host country is under no obligation to reduce or limit GHG emissions. The issue may usefully be addressed in international project guidelines.

- Perverse incentives. For instance, it has been suggested that host countries would have incentives to clear primary forests so that they subsequently can produce credits from plantation projects established at the cleared sites.

Most project types are prone to some measure of free-riding, gaming and cheating. But standardized international guidelines may reduce some of these problems, especially at more aggregate levels.

COP-6 AND SINKS IN THE CDM

Similar to many other issues on the negotiating table, soil C sequestration in the CDM is negotiated as a part of a broader agreement or package deal. To a large degree, Parties' positions on other key issues determine their positions on the narrow, more specific question of soil C sinks in the CDM.

COP-6

C sequestration and human-induced changes in C fluxes from terrestrial C pools was a very complex and contentious issue at COP-6, and was an important reason for the lack of overall agreement.¹⁵ According to Jan Pronk, the environment minister of the Netherlands who was appointed as the COP president, the question of whether to allow the CDM to include sinks activities was a 'difficult' and 'tough political issue'.¹⁶ He addressed it in informal notes and in plenary presentations that, however, put forward a rather inconsistent solution.¹⁷

On the one hand, the conference president assigned a modest role to forests and sequestration projects in the CDM. It was suggested that the priority projects in the CDM should be in the areas of renewable energy (i.e. small-scale hydro) and energy efficiency. No mention was made of forests, agriculture, or sequestration projects. On the other hand, Mr. Pronk also proposed that afforestation and reforestation projects should be included in the CDM, and that these could generate credits. Projects targeting prevention of deforestation and land degradation, however, should be excluded from the CDM and would not create GHG credits.

Mr. Pronk stressed that issues concerning non-permanence, social and environmental effects, leakage, additionality, and uncertainty should be addressed, and that land-use, land-use change and forestry (LULUCF) projects should conform to the objectives of other multilateral environmental agreements. The conference president also identified a need for developing the 'modalities' for such projects, taking into account the methodological work by IPCC. But these proposals did not help to narrow the considerable gap that divided the key parties, i.e. the USA and the European Union, on this issue.

LOOKING TOWARDS COP-6 BIS

Several technical issues in the negotiations were addressed at talks in Ottawa in early December. With respect to the CDM, three different proposals were proposed (since there was no agreement on

¹⁵ See 'Critical Politics of Carbon Sinks', *Nature* (30 November 2000) vol. 408, no. 6812, p. 501. According to the International Institute for Sustainable Development (IISD), 'disagreement on sinks was a principal stumbling block' at COP-6. See IISD, 'Summary of the Sixth Conference of the Parties to the Framework Convention on Climate Change, 13-25 November 2000,' *Earth Negotiations Bulletin*, 12:163 (27 November, 2000). <http://www.iisd.ca/vol12/enb12163e.html>

¹⁶ 'Informal Note by the President of COP 6', p. 4 and p. 6.

¹⁷ For the 'Note by the President of COP-6. 23 November 2000', see: <http://www.unfccc.int/resource/docs/cop6/dec1-cp6.pdf>; Informal Note by the President of COP 6.

the proposals, all three were bracketed in the text). The first proposal was ‘no sinks in the CDM’. The second was ‘no decision on LULUCF in the CDM–SBSTA (i.e. the Subsidiary Body for Scientific and Technical Advice) will study issues of permanence, additionality, leakage with agreed deadline’. And the third proposal was ‘no language on sinks in the CDM’. It was also suggested to follow a number of principles¹⁸:

- Decisions should be based on sound science,
- IPCC should develop good practice guidelines for estimation and reporting of LULUCF emissions and removals,
- Credits would be dependent on reliable national systems for estimation of GHG fluxes. Independent review teams should verify national inventories prior to issuance of credits,
- Necessary to separate out human effects on sinks
- Work on separating out natural effects and pre-1990 activities in the second and subsequent commitment periods, and
- Control for time consistency and double counting of LULUCF.

It was furthermore suggested to discuss the eligibility of forest management, cropland management, grazing land management, and revegetation.

After conducting a series of consultations with key countries and key regions, the COP-6 president recently suggested a set of new proposals for reaching agreement at COP-6 bis.¹⁹ It is proposed that forest conservation, rehabilitation of degraded land and combating desertification are not eligible as CDM projects, but that such projects will be eligible under a new Adaptation Fund. The only eligible LULUCF project activities under the CDM during the first commitment period will be afforestation and reforestation. The proposed exclusion of forest conservation projects from the CDM is a response to the potential problem of a large amount of cheap sink options flooding the CDM. The decision on other LULUCF activities, including agricultural soils, will be postponed and it will instead be part of the negotiations on the second commitment period (2013-2017).

CONCLUSION

The issue of forest C overshadows the issue of soil C in the international policy debate on sinks as well as in the global climate negotiations. This paper has documented that a number of issues are being raised in the context of C sinks, and that several of these issues have influenced the treatment of soil and forest C sinks in the global climate negotiations. Unless a significant change in the negotiating dynamics takes place, it is very unlikely that COP-6 bis will include soil C sinks in the CDM.

More broadly, given the lack of progress on key political issues at the talks held prior to COP-6, and a feeling that the climate issue has lost some of its political prominence since Kyoto, it is perhaps unsurprising that COP-6 failed to reach an agreement on how to implement the Kyoto targets, including the role of C sinks. It is extremely difficult to predict if negotiators will finally succeed to reach an agreement at COP-6 bis. The attempts to salvage the COP-6 made immediately after the COP-6 failed, and since the Bush administration’s position on climate change seems to be far from the EU’s position, it appears increasingly unlikely that a meaningful global climate agreement can be reached at COP-6 bis.²⁰

¹⁸ See ‘Technical Talks on Climate Change’ (12 December, 2000). Document prepared for a meeting of a group of officials from the Umbrella Group and the European Union held in Ottawa on December 6 and 7, 2000.

¹⁹ ‘New Proposals by the President of COP 6’, 9 April 2001. See: http://www.unfccc.de/sessions/cop6_/unfccc_np.pdf

²⁰ For the Text of the Letter from the President to Senators Hagel, Helms, Craig, and Roberts on March 13, 2001, see <http://www.globalclimate.org/BushLetter.htm>.

Note. The views expressed in this paper are those of the author. They should not be attributed to the organization with which the author is affiliated.

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Ecologic Foundation Of New Zealand Proposes Linking Sinks With Domestic Action on Biofuel

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ABSTRACT

A paper circulated by the Ecologic Foundation at COP6a proposed a biofuel obligation to be attached to sinks in the KP. Additionally Ecologic has proposed a comprehensive positive lists of discounts for Art 4.3 activities. These proposals reflect a view that the key to avoiding another – and likely long term – breakdown at COP6b, is to package LULUCF in such a way that it is not primarily a ‘loophole’. Acting as a lever for the take-up of biofuel technology, it actually makes an important contribution to energy sector transformation. Since emissions from imported oil are regarded as domestic emissions, sinks in the CDM can be seen as a form of ‘domestic action’ if linked to the prospect of importing biofuel-based transportation fuels in lieu of oil. The proposed positive list could allow the full amount to be claimed for activities which involve enhanced management since 1990 where overall sequestration and biofuels benefits are readily and accurately verifiable. An intermediate proportion could be claimed for activities that involve enhanced management, but with less certainly verifiable benefits. If necessary to achieve agreement with the Bush administration, a low proportion also to be claimed for those activities which are essentially in the business-as-usual category. Thus a comprehensive positive list of discounts can wrap up both measurement uncertainty and non-additionality

Keywords: COP6bis; negotiating balance; sinks-biofuel linkage; energy transformation; precautionary action.

INTRODUCTION

COP6 President Pronk intends an initial political compromise at COP6a, with officials then left to ‘work it out’. But without new ideas – and with a Bush team maybe less committed to action – push and shove over the same ground may lead to another collapse, possibly long term. This article expounds new thinking, circulated at COP6 by New Zealand’s Ecologic Foundation, and now before policy advisors, both in Europe and the umbrella group.

The Proposal

Ecologic’s proposal is:

- Each 100 tonnes of CO₂-equivalent credit, from both Art. 3.3 and Art. 3.4 related projects, should be linked to a proportionate biofuel-using project contemporary with credit measurement. This ‘biofuels obligation’ would be a few tonnes initially but increase as incremental costs of using biofuel decrease.
- All Art. 3.4 activities should be measured and monitored. Credit against Annex 1 Party commitments in 2008-12 should be up to a comprehensive positive list of discounts with the excess of credits, above the discounted amounts, usable after 2012

The intuition is that avoiding another collapse may require a LULUCF package where land use change is not just a ‘sink,’ but actually makes a real contribution to the domestic action sought by the EU, e.g. helping transform energy sector technology by producing gasoline

substitutes. The use of biofuel liquids, wherever produced, is as much ‘domestic action’ as the importation and use of petroleum is domestic emissions.

Why specifically a biofuel obligation?

A real contribution to domestic action might come from linking sinks to any renewable energy technology. The *specific link with biofuel* is because biofuel intrinsically involves land use change, i.e. sinks, and because a particular problem of market co-ordination arises with biofuel. Biofuel raw material cannot be used unless it is grown previously: neither will it be grown unless landowners can foresee a market. There is no obvious market mechanism to co-ordinate the decisions of landowners and energy sector investors, two very different types of risk-averse decision taker, maybe in different countries.

Also, dispersed collectors of CO₂ – sinks – are needed to collect dispersed emissions from transportation. Biofuel closes the cycle, yielding a sustainable system (with increased vehicle efficiency hopefully matching increased vehicle ownership worldwide). So low emissions scenarios – sponsored by industry, NGO’s, governments, international organizations, etc – show a large and increasing role for modern biofuel in the new century, for which there is urgent need to begin growing raw material.

And the feature of sinks that makes them objectionable to those who ‘want policy to hurt’ – that they are a low cost way to get greenhouse levels down – is a precautionary bonus if a low threshold for catastrophic climate change is revealed. Large scale carbon storage in new forest sinks both enables an urgent response to start from a lower level of carbon in atmosphere, and provides a ‘buffer stock’ of potential biofuel that can quickly displace fossil fuel in the existing energy supply system, with the cleared land then available for intensive biofuel production.

Sinks in the CDM

Suitable land for growing biofuel raw material is mostly in developing countries, where risks and interest rates are high, deterring investment. So the exclusion of sinks from the CDM (under which carbon credit cash flows can sustain low income land-owners through the initial rotation, when there is no saleable product) is crucially damaging to the timely growth of a modern biofuel industry. Such growth prospectively yields sustainable development to some land-rich but otherwise impoverished G77 Parties.

Biofuel plantations use land on which people live, pointing to the importance of maintaining flexibility to design individual projects that are suited to the requirements of local participants. However, the biofuels-using project could be quite separate, possibly in another country. All that is implied for the CDM project is that a minor additional cost element (relative to the volume of sink credits) is incurred.

The negotiating balance

Ecologic’s proposal for Art. 3.4 combines EU language about positive lists with US language about discounting. Delayed use of the balance of 3.4 credits, in excess of the discounted amounts used in the first commitment period, lends environmental integrity to Article 3.4 since it would enable greater certainty to develop regarding the magnitude of carbon reductions, including baseline issues. The corrected magnitude would be taken into account when negotiating allocated amounts beyond 2012. Such an approach would thus wrap up both measurement uncertainty and non-additionality.

This approach also allows the US to win an agreed proportion of 3.4 credits in the interim, reflecting the impact of the definitions of Art. 3.3 activities recommended by the IPCC relative to the less restrictive expectations of US negotiators at Kyoto. Without violating Kyoto’s environmental integrity, the aim would be to encourage desirable activities that

- A. were not taken into account when the first commitment period allocated amounts were negotiated
- B. involve substantial uncertainty and may yield CO2-equivalent credits that are large in relation to allocated amounts in the first commitment period.

Owners of credit balances carried over to beyond 2012 may expect to benefit from higher CO2-equivalent prices under more ambitious commitments for the second and later commitment periods.

Summary

The broad trade-off proposed is that the umbrella group accepts a minor cost increment on sink projects and the EU accepts the US getting from Art 3.4 what it thought it was going to get from Art 3.3. A general benefit comes from resolving the co-ordination failure that hampers the development of biofuel, and from accelerated progress with a key technology for reducing transportation emissions. There is specific benefit to a number of developing countries.

IMPLEMENTATION ISSUES

If the Ecologic proposal is to be used it needs to be formulated in negotiable text capable of legal interpretation..

Familiar wording of 3.4 proposal

As regards the second part of the proposal, for a comprehensive positive list of discounts in relation to 3.4 activities, all of the words have been used by European or Umbrella group negotiators in the past. Presumably they have a well-defined meaning, at least in the minds of those that have used them, that can be formalised through negotiation. The process would appear to involve quantifying each of the activities listed in Chapter 4 of the IPCC's SR_LULUCF on a by-country basis [i.e. dividing-up the global totals established by the IPCC]. This would be to establish in the minds of negotiators an understanding of the extent to which each Party stands to win or lose from these activities under different levels of discounting. Discounts would then be agreed as an exercise in political horse trading, leaving the balance after discounting, that is banked for crediting after 2012, to become better defined, both as regards magnitude and additionality, in advance of negotiating allocated amounts for the second commitment period. Such negotiations would recognise that various individual Parties should benefit from banked credits in the determination of their allocated amounts after 2012, while enabling the overall total of allocated amounts to be adjusted [reduced] to reflect the aggregate quantity of banked credits arising from action outside the second commitment period.

Novel wording in 3.3 proposal

Each 100 tonnes of CO2-equivalent credit, from both Art. 3.3 and Art. 3.4 related projects, should be linked to a proportionate biofuel-using project contemporary with credit measurement. This 'biofuels obligation' would be a few tonnes initially but increase as incremental costs of using biofuel decrease.

The Ecologic proposal for linking sinks to biofuel projects involves novel language that needs to be clarified before the proposal can be introduced into negotiations. However, elements of the proposal involve language that is already in use and may thus be taken to be definable, with nothing new involved. These are "CO2-equivalent credit, from both Art. 3.3 and Art. 3.4 related projects" – i.e. all credits for removals from the atmosphere due to sink activities – and "biofuel-using project" – i.e. reductions in emissions due to a biofuel project. As with all projects there are additionality and baseline issues. These are crucial for environmental integrity in relation to projects credited under the CDM, but merely redistributive in relation to project based credit trading between entities within an Annex 1 Party, or JI related crediting involving entities under the jurisdiction of different Annex

1 Parties. But nothing new arises. The specifically new element arises from underlined words in the following extract “a proportionate biofuel-using project “contemporary with credit measurement””.

The proportionate word can be made effective by defining a mechanism for determining the proportionality. A workable mechanism could be that “the proportionality is to be determined from time to time by the COP/MOP for a number of years ahead, in response to recommendations of the SBSTA, with previously determined values remaining in force in the absence of such recommendations, and with an initial default value of 100 per cent for all years ahead”. The effect of this would be that, until the SBSTA had proposed otherwise, and the COP/MOP had accepted the proposal, all sink activities would be burdened by an equal biofuel-using project. It is anticipated this would substantially block the crediting of sink activities until time had elapsed to enable the SBSTA to negotiate agreed proportionalities for a number of years ahead. The purpose of this is to enable the Ecologic proposal to be agreed in principle at COP6b, if it is needed then in order to avoid an impasse, whilst leaving it to subsequent discussion what proportionality values are appropriate.

It is envisaged that negotiations in SBSTA would lead to agreement at COP7, or COP8 at the latest, on a set of proportionality values that might, for instance, increase from 5 per cent in 2003 with 5 per cent increments annually. This would lead to 30 per cent proportionality in 2008, 50 per cent in 2012, etc .

The meaning of “contemporary with credit measurement” then requires to be defined.

- Suppose sink project A, initiated in 2003 in a non-Annex 1 country, leads to removals from the atmosphere of 100 tons in 2004, 2005 and 2006, with the 300 tons of stored carbon then being permanently secured. (We abstract from the practical difficulties involved in ensuring permanence and from the transactions costs of permanent monitoring).
- Suppose also that project X, located in an Annex 1 country, incinerates garden waste in a district heating scheme, displacing natural gas, and results in a 5 tons emissions reduction annually for ten years, from 2004 onwards. Then project X could be linked to project A in the UNFCCC registry of projects and would enable (5ton/5 per cent) = 100 tons of carbon to be credited in 2004, 2005 and 2006, i.e. 300 tons of carbon credits to be banked under the CDM until 2008-2012.
- Suppose further that sink project B, also in a non-Annex 1country, and initiated in 2006 when the proportionality is 20 per cent, results in emissions reductions for twenty years, beginning in 2007, of 25 tons annually. Then the remaining seven years of emissions reduction from project X of 5 tons annually could be linked to the first seven years of removals by project B. This would enable 25 tons (= 5tons/20 per cent) credits to be claimed annually from 2007 to 2013 (with the 2007 credit banked till 2008 or later).
- Additionally, project X would generate 5 tons of emissions reductions credits annually through the first commitment period which could be traded to an entity at the point of policy obligation in the same country or, through JI, to an entity in another Annex 1 country.
- In 2014, it would be open to the owners of project B, if they wished to continue to get carbon credits for their sink project, to seek a different biofuel using project, say project Y initiated in 2013, and to purchase linkage equivalent to (5 tons per year/ 55 per cent) for 13 years ahead from the owners of project Y.

By ‘initiated’ in the above example is intended the substantial commencement of the physical actions (and financial expenditures) that lead to the creation of the sink, e.g. the establishment (planting) of a new plantation, or the fencing off of a conservation area. Paper activity such as the planning or contractual commitment for a removal from the atmosphere would not count as initiation.

Markets for credits and for linkages

Clearly the one-for-one seeking out of trades by the owners of sink projects and owners of biofuel using projects, barter-style, involves high and unnecessary transactions costs. As with other trading

activity, linkage, along with projects based credits, would come to be mediated through markets, including futures markets. These would establish through arbitrage, and over the relevant time horizon for projects:

1. the price of dated credits for absorption from the atmosphere by sinks
2. the price of dated credits for reductions in emissions through biofuel-using projects, and
3. the price of dated linkages between the first and the second.

Then an entity that starts a sink project would need to purchase linkage (3.) on the world market for linkages, before selling the credits created by its sink on the world market for project based credits at price (1.). And an entity that invests in a biofuel-using project would be able to sell both linkage at price (3.) and credits at price (2.) on the appropriate world markets. *Prima facie* 1. and 2. would be the same.

The prospective cost of sinks projects would thus be increased by a stream of cash outlays corresponding to the future prices of linkages (3.) multiplied by the proportionality applying at the time of initiation. This would effectively be a partial offset against the benefit from credits for absorption by sinks priced according to (1.).

The prospective cost of biofuel using projects would be offset both by a stream of cash outlays corresponding to the future price of a linkages (3.) and, from 2008, by a stream corresponding to the future price of credits for emissions reductions through biofuel using projects (2.).

A consequence would be that biofuel using projects would receive the enhanced incentive that appears to be needed, relative to other emissions reducing projects (*prima facie* the same as (1.) and (2.)) in order to secure the evolution of biofuel technology in line with low emissions scenarios. The basis for such enhanced incentive would be

- A the significant beneficial features of biofuel noted below
- B the evidence of slow take-up of biofuel using technology, relative to, e.g. photo-voltaics, and
- C the existence of specific barriers to entry facing biofuel systems, also noted below

Apart from – and more effective than – incentives, entities seeking to take advantage of sinks as a low cost option would also incur a physical obligation. This would ensure that physical experience is being gained of biofuel using technologies somewhere within the energy sector and consequentially that their costs reduce in line with the ‘learning by doing’ process.

It may be noted that, under proposals for ‘allocating permits usefully’, the prices for project related credits (which constitute incentives for mitigating innovations that yield a beneficial inter-temporal externality through learning by doing) would all be greater than the penalty on emissions reflected in the traded price of emissions permits. For more on such asymmetric measures see web-site <http://econ.massey.ac.nz/apu>. Allocating permits usefully has the effect that entities reluctant to risk taking a lead with renewables innovation, in order to be in a position to learn from the mistakes of pioneer innovators (a specific example of the general problem of under-investment in innovation) would pool this risk, innovating together.

Features of biofuel energy systems:

Energy relevant aspects

- 1 Precautionary: biofuel is one of two renewable technologies that are particularly relevant to the potential need for urgent measures – smokestack sequestration (so called ‘clean coal’ – not quite sustainable for ever, but good for a few centuries) and biofuel (possibly combined with smokestack sequestration)

- 2 Both are compatible with the existing fossil fuel based system and can therefore be deployed quickly subject to modest precautionary expenditures to achieve necessary land use changes and initiate learning with these technologies to secure cost reductions
- 3 Additionally, biofuels
 - sequester carbon during the growth of the first rotation of a biofuel plantation, reducing the GHG level and giving urgent policy a head-start
 - can, under urgency, be directly substituted in fossil fuel boilers at minimal cost
 - collect dispersed emissions from the transportation system

Non energy aspects – problems:

- a) co-ordination failure between energy sector managers investing in plant to use biofuel, and landowners, investing in biofuel plantations several years earlier, maybe in other countries;
- b) small-medium scale and variability of biofuel supplies;
- c) need for on-going relation with land based producers in context of local environmental and socio-economic impacts, both beneficial and detrimental;
- d) no ‘one size fits all’ solution and need for local community commitment, with good project design delivering continuing local benefits.
- e) need for capacity building for country-driven projects

Non energy aspects – opportunities:

- f) sustainable development for rural communities, rural electricity, enhanced life styles and slowed drift from the land;
- g) redesigned farm support strategies with lower costs to taxpayers in the North but likely continued high farm product costs;
- h) carbon credit initiated growth of least developed African and Latin American economies;
- i) subsequently sustained by biofuel liquid exports and South-South trade with industrialising Asian economies;
- j) increased capitalisation of land use activities, replacement of unsustainable traditional land use patterns, and protection of biodiversity and other values;
- k) climate treaty driven carbon credits as the financial springboard for other multilateral environmental agreements objectives.

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Issues in Forest Carbon Crediting

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ABSTRACT

While the Kyoto Protocol was primarily a greenhouse gas emissions reduction agreement, forest sequestration offsets were allowed for new forests, and Article 3.4 allowed for inclusion of offsets from existing forests and agricultural activities. Many forest management activities are documented in scientific papers as sequestering incremental carbon, including pest and disease control, thinning and tree improvement. Carbon trades have already occurred for reduced impact logging and reduced tillage.

Several factors have prevented meaningful market activity. A lack of guidelines on forest carbon crediting and trading has forced buyers of carbon offsets to establish their own, hindering effective trading. There is confusion around the term “business as usual” which is difficult to assess, is often meaningless, and leads to paradoxes. An effective way to account for carbon in plantations and other forestry activities is a methodology proposed by M. Kirschbaum et al, whereby carbon uptake is credited equally and annually over a period until the new long-term carbon storage level is reached. This method eliminates the problems associated with repeated buying and selling of credits over several rotations, and also reduces the need for costly annual measurements.

This methodology has been applied to Domtar’s juvenile spacing activity 1991-2000, and the results are being reviewed by Clean Air Canada Inc for effectiveness in carbon trading. Similarly, Domtar’s jack-pine budworm spray program for forest protection is about to undergo the same review process. It is anticipated that risks associated with crediting emissions reductions for forest management projects that have short term emissions will be managed using a pool of offsetting forestry projects.

In New Zealand, Dr. Ken Skogg presented an analysis for US waste which showed that 24-28% of carbon in wood products remains as stored carbon in perpetuity, supporting the notion that the wood products carbon pool is increasing in size. This notion is supported by analysis from the EFI website.

Because of the carbon sequestering potential of forest management and wood products, these areas should not be ignored in future climate change agreements or in policy. Uncertainty in the agreement regarding forest management is keeping the price of forest carbon artificially low, hindering an increase in this activity. To promote these activities will require;

- putting forests and forestry into the Kyoto Protocol
- standard carbon accounting system(s)
- understanding and acceptance of forest measurement techniques (sample plots)
- use of amortization methodologies
- recognition of 1991-2007 activities

An International Forest Carbon Accounting Framework: A System for Managing, Measuring, Reporting and Trading Forest Carbon from an Operational to an International Scale

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ABSTRACT

The 'Kyoto Protocol', signed by the parties to the United Nations Framework Convention on Climate Change (UNFCCC) in 1997, allows countries to use carbon sequestered in forests as a means to meet internationally binding Greenhouse Gas reduction quotas.

To provide a transparent and verifiable means of measuring and reporting forest carbon, an international forest carbon accounting framework is required. This report outlines and describes a forest carbon accounting framework that is designed to meet the reporting requirements of the Kyoto Protocol. It also provides step-by-step guidance on defining, measuring, managing and reporting carbon stocks while maintaining a link between the operational, national and international levels of reporting. The framework is designed to adapt to the dynamic nature of climate change negotiations, promote emissions trading, interface with existing vegetation inventories, and be useful to all countries interested in establishing carbon markets.

Keywords: Forest carbon accounting, Kyoto Protocol, emissions trade

INTRODUCTION

In an effort to combat the effects of climate change, a pioneering agreement known as the 'Kyoto Protocol' was signed in 1997 by many of the developed (Annex I¹) nations of the world, committing them to implementing measures in order to meet legally binding GHG reduction quotas. One way that Annex I countries can help meet their quota is by promoting sustainable forest management practices through forest carbon sequestration, conservation and substitution. Interest in such Forest Carbon Projects (FCP's) is growing, as companies are discovering that planting and conservation of forests represents a cost-effective and environmentally sensitive solution to the climate change problem.

To provide a transparent and verifiable means of measuring, reporting and trading forest carbon, an international forest carbon accounting framework is essential. This report describes a forest carbon accounting framework that is designed to meet the reporting requirements of the Kyoto Protocol. It provides step-by-step guidance on defining and measuring carbon stocks at the operational level, while maintaining a link between the operational, national and international levels of reporting. The framework is designed in order to adapt to the dynamic nature of international climate change

¹ Annex I countries refer to the countries that are listed in Annex I of the UN Framework Convention document. This is a list of 24 developed countries belonging to the Organisation for Economic Cooperation and Development (OECD) as well as 12 countries classified as 'economies in transition' (UNFCCC 1994).

treaties, promote emissions trading, interface with existing vegetation inventories, and be useful to all countries interested in establishing carbon markets.

The framework has three main phases and eleven steps. The first phase, ‘Design and Evaluation’, outlines the preliminary planning considerations and actions that must be taken prior to project implementation. In phase two, ‘Implementation – Inventory and Management’, describes the operational level forest management and inventory practices that should be undertaken in order to efficiently run a FCP. It also explains the methodology for scaling up operational level forest inventory to a regional, national and international level. Finally, phase three, ‘Emissions Trade’, outlines the procedures needed to commence trade of forest carbon.

PHASE ONE: DESIGN AND EVALUATION OF A FOREST CARBON PROJECT

1. DEVELOP PROJECT PROPOSAL

The planning stages of the FCP are critical to ensure that land, labour and capital resources are allocated to maximum efficiency and climate change benefit. This section provides details on some of the factors that must be considered for inclusion in an operational level project proposal.

1.1 Identify management objectives

The goals of the FCP owner should be clearly stated at the beginning of the project proposal. Operational level management objectives should be devised to describe short-term goals. It is also advised that a section of the project proposal should contain a strategic level plan; describing long-term objectives. Some of the principal management objectives for FCP owners might be to: Maximize climate change mitigation; maximize wood production; maximize profit from the sale of forest carbon credits; increase biomass production; and broaden the range of forest values considered in management. Through careful design, an optimal solution can be achieved for the FCP owner both in terms of revenue flow and positive environmental impacts.

1.2 Outline accounting objectives

The ultimate objective of a Kyoto credible forest carbon accounting system would be to provide an accurate description of the changes in forest carbon stocks, in full compliance with the guidelines, methodologies and reporting requirements as specified by the UNFCCC. This implies that a forest carbon accounting system should be consistent, complete, accurate and verifiable (GHG Protocol Initiative 2000).

1.3 Details of the Project

The project proposal should include a concise description of the nature of the FCP, including details on the relevant sections of the Kyoto Protocol and how the project actually mitigates climate change.

1.3.1 relevant articles of the kyoto protocol

Within the Kyoto Protocol, there are potentially four articles that allow forest owners a means to obtain emission offsets from a FCP. Article 3.3 of the Kyoto protocol allows an Annex I country to receive ‘credit’ to a country’s emission reduction quota for carbon sequestration due to afforestation² and reforestation³ activities; and a ‘debit’ for deforestation⁴ activities. This is restricted, however, to afforestation, reforestation or deforestation [ARD] activities that have occurred since 1990. The full text of Article 3.3 is presented in Appendix 1.

² ‘Afforestation’ is defined as the “direct human-induced conversion of land that has not been forested for a period of at least 50 years to forest land through planting or seedling” (SBSTA 2000).

³ ‘Reforestation’ is defined as the “direct human-induced conversion of non-forest land to forest land through planting or seeding, on land that was forested but that has been converted to non-forest land” (SBSTA 2000).

⁴ ‘Deforestation’ is defined as the “direct human-induced conversion of forest land to non-forest land” (SBSTA 2000).

Article 3.4 of the Kyoto protocol expands upon Article 3.3, by suggesting that a set of ‘additional human-induced’ forest management activities may be used towards meeting Kyoto commitments. Article 6 of the Kyoto Protocol defines ‘Joint Implementation’ [JI], which allows Annex I parties to supplement their domestic GHG reduction activities, with emission reduction or sink enhancement activities conducted in other Annex I countries.

Article 12 of the Kyoto Protocol defines the ‘Clean Development Mechanism’ [CDM]. The CDM provides a means for Annex I countries to fund and implement GHG reduction projects in non-Annex I [developing] countries. This is under the proviso that the Annex I country must contribute to the sustainable development of the developing country. [Eg: By training forest managers in developing countries in advanced silvicultural practices]. At present, it is uncertain whether sink projects will be eligible for inclusion in the CDM. This issue is due for resolution at the COP6 meeting in Bonn, Germany [July, 2001].

1.3.2 Carbon sequestration, conservation or substitution?

There are three main ways in which FCPs can mitigate climate change (Vine et al. 1999): Through carbon sequestration; conservation or substitution. Forest carbon sequestration projects aim to create new areas of forest, or increase the rate and amount of carbon uptake by existing forests. This has the overall effect of increasing the amount of carbon removed from the atmosphere by storing it in the tree biomass.

Forest conservation projects aim to prevent the release of carbon emissions from a forest. This is can be achieved by a variety of means such as preventing deforestation; placing forests in parks and reserves; modification of forest management practices [eg: shelterwood harvesting and utilization of wood protection technologies]; and increased control of fires, insects and disease (Vine et al. 1999). Forest carbon substitution projects aim to promote the utilization of sustainably produced forest biomass as a direct energy source, or by replacing products that are fossil-fuel intensive to produce. When forests are managed sustainably, forest biomass energy is classified as ‘carbon neutral’. [ie: neither a carbon emission nor sequestration]. Thus, if carbon neutral forest biomass is used to replace fossil fuels that are traditionally used for heat and power production, then total carbon emissions are reduced (IEA Bioenergy 2001).

1.4 Address Leakage Concerns

Leakage is defined as the unexpected loss of GHG reduction benefits when activities or markets are displaced, resulting in emissions elsewhere (Schlamadinger & Marland 2000). All potential sources of leakage should be identified, and can be addressed by measuring all carbon pools that are a source of carbon emissions, and by carefully considering the temporal lifetime and company and project boundaries.

1.4.1 Measure all sources of carbon emissions

Leakage becomes problematic when emissions are transferred to a carbon pool that is not measured [see Box 1 for the forest carbon pools that are measured under the Kyoto Protocol]. Therefore, leakage can be addressed by measuring all carbon pools that are a source of carbon emissions.

- Forest carbon pool components that must be measured*:
 - Aboveground Biomass
 - Belowground Biomass
 - Litter
 - Dead Wood
 - Soil Organic Carbon
- Greenhouse Gases that must be measured (expressed as CO₂ equivalents)**
 - CO₂
 - All non-CO₂ greenhouse gas emissions
- Forest carbon pools that are a source of GHG emissions must be measured***

*At present, carbon storage in forest wood products is not measured in the Kyoto Protocol. However, future COP meetings may decide to include carbon storage in wood products.

**An equivalent of CO₂ may include any of the greenhouse gases (Carbon Dioxide, Methane, Nitrous Oxide, Hydrofluorocarbons, Perfluorocarbons or Sulphur Hexafluoride), weighted according to their global warming potential, to give the amount of global warming equivalent to one ton of CO₂ (Environment Canada 2000).

*** Forest carbon pools that are not a source of GHG emissions do not have to be measured if sufficient proof is provided that the pool is not a source.

Box 1: Forest carbon pools that must be measured to ensure Kyoto compliance.

1.4.2 Determine Temporal Lifetime of the Project

One of the key sources of debate in recent climate change negotiations, has been the issue of temporal leakage, or ‘permanence’ of emission offsets from FCPs. There is some concern that forest carbon sinks may undermine the integrity of the protocol, since it is possible that carbon sequestered in forests may be released back into the atmosphere [by harvesting or natural disturbance] at a later date (Schlamadinger & Marland 2000)⁵.

Carbon should be stored in forests for a sufficient duration such that the warming effect of carbon in the atmosphere is offset (Moura Costa & Wilson 1999). Given that one ton of CO₂ stored as forest carbon for 55 years is sufficient to counteract the effects of a one ton pulse emission of CO₂, it could be argued that FCPs should have a carbon storage lifetime of at least 55 years (Moura Costa & Wilson 1999). This carbon storage is then equivalent to a permanent removal of CO₂ from the atmosphere. A similar method of solving the permanence issue is the ‘ton-year’ approach, explained in Section 5.2.3.

1.4.3 Define Company and Project Boundaries

To avoid leakage via geographic displacement of GHG emissions, the company and project boundaries of the project should be carefully defined. ‘Company boundaries’ include all GHG emissions and abatement activities for which the FCP owner is directly responsible for (AGO 1998). ‘Project boundaries’ could be defined as the geographic location within which direct⁶ and indirect⁷ forest carbon emissions and sequestration are affected by FCP activities.

⁵ Special mention should be made regarding the permanence of FCPs under the CDM. Permanence in CDM projects is especially concerning, since the CDM results in the creation of new ‘Certified Emission Reductions’ [CER’s] in Annex I countries, without subtraction from the assigned GHG amounts in a developing country [since developing countries do not have GHG reduction quotas]. At present, the Kyoto Protocol contains no provisions for the Annex I country to account for potential carbon losses after the project activities lifetime. COP negotiators must be careful to define the accounting lifetime of forest carbon CDM projects, to ensure the integrity of the Kyoto Protocol is not undermined (Schlamadinger & Marland 2000).

⁶ Direct emissions or sequestration are due to activities within the company boundaries that occur on the FCP site.

⁷ Indirect emissions or sequestration are due to activities within the company boundaries that occur on lands

In the event of shared ownership of a FCP, or if some of the project activities are to be carried out by outside contractors, the responsibility for carbon emissions and sequestration should be specified in a contract (GHG Protocol Initiative 2000). Concise specification of company and project boundaries is also crucial in FCPs where 'carbon rights'⁸ are established (Blair 1999)

1.5 Investigate Management Alternatives

The management implications of the three types of FCP's are described in the sections below.

1.5.1 Managing Carbon Sequestration and Timber Production

One of the challenges in managing a FCP, is to allow for the dual pursuance of the goals of sustainable timber production and climate change mitigation. The following management strategies can be adopted to maximize timber volume and carbon storage:

- Maintain a range of forest age classes such that the amount of carbon sequestered in actively growing stands is equal to or greater than the amount of carbon being emitted due to harvesting (AGO 1999a).
- Harvest at a frequency that emulates the natural rate of disturbance (Kurz et al 1998),
- Thin regularly and at a light to moderate intensity [between 5 to 25% of total biomass] (Thornley and Cannell 2000)
- Consider the price of timber and carbon when prescribing rotation length (van Kooten *et al.* 1997).

1.5.2 Managing Carbon Sequestration and/or Conservation

In addition to consideration of harvesting frequency, age-class distribution and rotation length of forests, there are a number of other forest management activities that are suitable for achieving the goals of carbon sequestration, conservation and protection of non-timber values. These activities [listed below] may or may not prove to be eligible under Article 3.4. This issue is due for resolution at the COP 6 [Part II] meeting in Bonn, July 2001.

- Increase intensity of insect and disease protection activities. This is estimated to be one of the cheapest ways to increase forest carbon storage (NCCS 1999).
- Implement activities that increase the site index of the forest, such as fertilization.
- Increase the use of a genetic improvement program to allow planting of species that are faster growing, disease-resistant species, contain more carbon, or are capable of producing greater quantities of biomass (NCCS 1999).
- Implement density management and commercial thinning regimes to prevent carbon loss due to mortality, promote increment on the fastest growing species, shorten rotation lengths and allow greater carbon storage in wood products⁹. Commercial thinning may also extend wood supply, and therefore may result in reduced harvest activities elsewhere (NCCS 1999).
- Conduct enrichment planting to improve stocking of existing stands
- More careful consideration of matching appropriate species to site and micro-site, thereby maximizing productivity of the stand
- Plant frost-resistant species
- Increase intensity of fire prevention activities.
- Develop wood preservation technology, allowing carbon to be stored in wood products for a longer time⁹
- Remove introduced grazing animals from the forest, thereby allowing greater biomass accumulation in the understory
- Investigate low soil disturbance planting and reduced impact logging techniques.

⁸ not managed by the FCP owner.

^{8c} 'Carbon rights' involves the legal separation of carbon ownership from the land and trees.

⁹ Carbon storage in wood products is not recognized in the Kyoto Protocol at this time.

- Restore degraded forest land [e.g.: management to alleviate the effects of erosion or restoration of salt-affected and polluted lands]
- Investigate use of biowastes to increase forest productivity and soil carbon storage.
- Implement natural wildlife conservation schemes, thereby increasing overall ecological productivity and carbon content of the entire forest system.
- Consider implementation of urban tree planting schemes. Planting trees in city centres has the dual purpose of increased tree carbon storage, and also for the value of urban trees in breaking up ‘urban heat-islands’, thereby reducing energy requirements and demand for fossil fuels (IPCC 2000).
- Consider disposing of harvesting and mill residues and timber waste, by burying in landfills. This limits the rate of carbon decomposition in wood products to less than 3% per annum (Meil 2000).
- Conduct research and development into improving the efficiency of timber recovery, re-use and recycling processes, thereby increasing the wood product use-life (NCCS 1999).

1.5.2.1. Forest Protection Projects

Forest protection projects may prove to yield the maximum carbon benefit at least cost on some sites. Forest protection projects are particularly suitable to old growth forests, which typically have a high initial level of carbon storage. Forest sites that are low in productivity, sensitive to disturbance, aesthetically or socially significant, or have a high ecological importance are also well suited to forest protection projects.

One problem is that forest protection projects are particularly susceptible to leakage. Protection projects that do not address the principal causes for harvesting, may simply shift the harvesting to another forest elsewhere. It is crucial that these leakage issues are identified and addressed.

1.5.3 Carbon Substitution Projects

Once a forest is harvested, the biomass can be used as an energy source instead of fossil fuels. This can result in significant *avoided* GHG emissions. This is because biomass energy produced from sustainable forests is classified as ‘carbon neutral’. This means that the amount of carbon released when the wood is burned for energy, is equivalent to the amount of carbon sequestered when the forest was planted. There is thus no net carbon effect on the atmosphere. Emissions avoided from carbon sequestration projects will not be re-emitted. Carbon substitution projects can also mitigate climate change through using sustainably produced wood products in place of products which are fossil fuel intensive to produce, such as aluminium or concrete (IEA Bioenergy 1998).

A FCP owner should manage carefully to ensure other forest values are not compromised when undertaking a carbon substitution project¹⁰. A FCP owner should avoid locating biomass plantations on sites of high aesthetic and ecological significance. Visual buffer zones around biomass plantations can also make the forest more aesthetically pleasing.

1.6 Publish the Project Proposal

Each of the factors outlined from section 1.1 to 1.6 should be addressed in the project proposal, and published as a clear, well-written document to be distributed to all relevant parties.

2 PRELIMINARY CARBON YIELD PROJECTIONS

To determine an appropriate FCP design for the site, preliminary estimates of future forest carbon yields from each of the potential management regimes [Section 1.5] should be produced. Carbon and timber volume estimates produced at this stage will be based on the data which are already available and are therefore intended for use only as a rough indication of expected yields. Preliminary carbon yield projections can be obtained either by using rough estimates from literature (Birdsey & Heath

¹⁰ Forest biomass plantations are generally single-age, single species, short-rotation stands. These stands are generally regarded as being of low ecological and aesthetic value.

1995; Bonnor 1985; Lowe 1996; Penner et al 1997; Rombold 1996; TBFRA 2000;), IPCC default values¹¹, rough inventory estimates and/or using computer modeling software packages. A number of forest volume, biomass and carbon projection models are currently available (CCRS 1999; Ecosystems 1999; Harmon et al. 1996; IEA Bioenergy 2001; Kurz et al 1992; Mohren et al. 1990; Mohren et al. 1999; Richards & Evans 2000; West 1997;). These can be divided into three types: Simple allometric models, Growth and yield models, and physiological-based models (Spittlehouse 2000). Simple allometric models¹² are generally used to predict carbon on an individual tree basis using a biomass or volume equation specific to the species, then converting to carbon using a range of expansion and conversion factors, [Section 6.1.1]. Growth and yield models use stand-level biomass tables to calculate carbon yield for a number of trees. Physiological based models use equations to simulate the processes such as photosynthesis, respiration, decomposition, Net Ecosystem Productivity and Net Primary Productivity.

Unfortunately, most of the allometric, growth and yield, and physiological models outlined above do not consider the influence of market demand on future forest carbon levels. Market effects can be taken into account by incorporation of a demand-driven model, which are capable of simulating the effect of social, economic and other demand-side factors on future carbon storage. A forest carbon sink owner would be also well advised to incorporate predictions of plant growth response to climate change in their carbon modeling procedures. A range of climate change simulation models are discussed in Bortoluzzi (2000).

3 DEFINE AND MEASURE BASELINE

In order to quantify the amount of carbon that has been sequestered [or emitted] due to a FCP, changes in carbon should be measured in relation to some baseline or reference (Schlamadinger & Marland 2000). The ‘baseline’ or ‘business-as-usual’ [BAU] carbon balance is defined as “the pattern of greenhouse gas emissions and carbon sequestration that would have been expected to take place on a project site over time, without implementation of the new project.” (AGO 1998). Comparison of expected carbon benefits of the project [Section 2] to the baseline is useful to ensure that all GHG reductions are real and verifiable. Determination and measurement of the baseline is also necessary for projects registered under the JI or CDM mechanisms, to comply with the ‘additionality’ specification¹³.

3.1 Defining the baseline

A baseline can be defined in either of two ways: A fixed path of emissions, or a dynamic forecast of projected emissions (Pape & Rich 1998). A fixed baseline assumes the rate of emissions remains constant, relative to emissions in a benchmark year (Pape & Rich 1998). A fixed baseline should be calculated based on analysis of historical forest growth trends, rates of land use change, and causes for land use change (Brown et al. 1997).

A dynamic forecast of projected emissions takes into account a range of assumptions about future patterns of emissions, and is continually adjusted as new information and technology becomes available. Defining a dynamic forecast of baseline emissions involves analysis of historical data [as for the fixed baseline]. The baseline is then adjusted over time to reflect anticipated future emissions [or storage] (Pape & Rich 1998). Dynamic baseline projections should be regularly adjusted to reflect changes in laws, regulations, population dynamics, economic growth, market trends and future land use patterns (Vine et al. 1999).

¹¹ The Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories published a set of default carbon conversion factors, specific to forest type and country. These conversion factors can be used to convert merchantable biomass to estimates of belowground biomass. The IPCC Guidelines are available for download from the IPCC website: <http://www.ipcc.ch/pub/guide.htm>

¹² Allometric equations provide a means of estimating tree biomass from readily measurable tree parameters such as diameter and height.

¹³ The requirement for ‘additionality’ of JI and CDM projects implies that the carbon storage achieved from the FCP must be in excess of the carbon storage that would have occurred under the BAU scenario.

3.2 Measuring the baseline

There are four ways a FCP can measure or estimate the baseline carbon balance: Direct measurement, computer modeling, use of default values or retrospective measurement. In order to directly measure the baseline carbon stocks, , a series of sample plots can be located and measured using a statistically sound sampling method. Regardless of the BAU land-use, carbon pools should be measured according to the regulations specified in Box 1. If the project site is forested, the methodology specified in Section 6.1 should be used. If the BAU land-use is non-forested, then the methodology for the appropriate land use in the *Revised 1996 Guidelines for National Greenhouse Gas Inventories* (IPCC 1996) should be used.

For larger or more complex stands, one of the three types of computer models [Section 2] can be also be used to model baseline carbon balance. Default values can also be used to give a rough estimate of baseline carbon storage. Preferably, regionally specific default values, suitable to the BAU land use should be used. As a last resort, the IPCC Guidelines (IPCC 1996) give approximate carbon storage values for a range of soil types, geographic locations and land uses.

‘Retrospective measurement’ is necessary if project activities have commenced before the baseline was measured. Retrospective measurement requires the FCP owner to estimate the carbon balance of the former land use. If historical carbon inventory data is available, this can be used. Where no data is available, baseline carbon balance can be estimated by measuring the carbon storage of neighboring lands that are subject to the BAU land use. As a last resort, default values can be used.

4. PROJECT EVALUATION AND REGISTRATION

4.1 Final Project Appraisal – Evaluation of project design

Prior to implementation of project activities, it is useful to evaluate the project according to a number of project eligibility criteria. This is advisable to ensure that the project is Kyoto compatible, economically feasible and does not negatively impact other forest values.

4.1.1 Kyoto Compatibility’ of the project

Moura Costa et al. (2000) suggests that there are four elements that should be assessed in determining the ‘Kyoto compatibility’ of a project: acceptability, additionality, leakage and capacity.

‘Acceptability’ implies that the FCP must be approved by all countries and parties directly involved with the project, and acceptable in terms of goals such as biodiversity, promotion of technology transfer and aesthetics. ‘Additionality’ implies that all carbon benefits must be “additional to any that would otherwise occur”. The requirement for additionality is only specified for JI and CDM projects (Articles 6 and 12). However, establishing additionality of a project is also useful in context with Article 3, to ensure that the project is consistent with the goals of the UNFCCC¹⁵ and the Kyoto Protocol. In practical terms, additionality is most easily demonstrated by comparing the carbon stock of the baseline scenario [Section 3], with the expected carbon yields accumulated due to the FCP [Section 2]. If the net carbon stock of the project exceeds that of the baseline, then project carbon benefits are said to be ‘additional’.

As described in Section 1.4, all sources of leakage minimized, then quantified and subtracted from the total expected carbon stock of the FCP. The final aspect of Kyoto compatibility is to assess the ‘capacity’ of the project to fulfil expectations. This can be evaluated by appraising the skills of the FCP management team, technology and equipment, as well as considering the ecological, political and economic environment in which the project is undertaken.

¹⁵ The overall aim of the UNFCCC is the “...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system...” (UNFCCC 1992).

4.1.2 Economic assessment of the project

Using the preliminary estimates of carbon yield [Section 2], a FCP owner should conduct an economic analysis of each of the proposed forest carbon management alternatives. Economic analysis should attempt to factor in a range of possible forest products and forest uses. A number of computer models can be used to conduct economic analysis of the project (Stone *et al.* 1996). Alternatively, a simple cost-benefit analysis, and plotting the NPV of each of the alternative management regimes against the BAU scenario would suffice.

4.1.3 Impact on other forest values

Prior to implementation of a forest carbon sequestration project, a FCP owner should carefully consider other forest objectives, such as recreation, aesthetics, aboriginal land rights and water supply. This is necessary to comply with other objectives of the Kyoto Protocol, as well as achieve public support for the project and therefore ensure temporal continuity (Brown *et al.* 1997).

4.2 Project Registration

Having decided upon which forest management regime to implement, and determined that the project is indeed Kyoto credible and economically viable, a FCP owner can now proceed to 'register' their FCP with a central carbon registry [Section 9.5.3]. Although most countries have yet to establish a national carbon registry, it is likely that a registry will be crucial to the development of an efficient national carbon accounting system. Some countries are also beginning to trial national registries on a voluntary basis¹⁶.

The central carbon registry is managed by a national agency that maintains records of Kyoto-credible forest carbon. FCP owners wishing to obtain official national recognition of Kyoto-credible forest carbon would be required to register and report to the central carbon registry using a national standardized format. Registration will encourage uniformity in carbon inventory methodologies, eliminate confusion regarding interpretation of data, facilitate exchange of information between operational and national level carbon inventory and increase data accuracy, transparency and verifiability. Most importantly, registration provides encouragement for a united, coordinated effort towards greenhouse gas abatement, thereby helping to avoid leakage due to market effects where demand is simply shifted to emitters (AGO 1999b).

The use of web-technology would greatly increase efficiency of data transfer between operational and national level carbon inventory (AGO 1999b). A web-based registry could also provide FCP owners with advice on how to conduct forest inventory, as well as providing default carbon yield curves for region and species.

Once a FCP has been officially registered, the FCP owner can proceed to implement the project.

PHASE TWO: PROJECT IMPLEMENTATION – INVENTORY AND MANAGEMENT

5. DESIGN SAMPLING SYSTEM

5.1 Consider sampling and accounting objectives

In designing a forest carbon sampling system, it is necessary to define either the *specified* level of precision to be achieved by the forest inventory, or the *maximum* level of precision that can be achieved, given fixed inventory costs (MacDicken 1997). Different levels of precision may be

¹⁶ In 1997, the Voluntary Challenge and Registry [VCR] was established in Canada. http://www.vcr-mvr.ca/home_e.cfm. In October 2000, the Pacific Rim Regional Association of RC&D's launched the 'Carbon Technology Transfer Center' for registration and trade of carbon: http://www.pacrimrcd.com/Aggregator/carbon_technology_transfer_center.htm. The Environmental Resources Trust (ERT) has setup a GHG Registry for quantifying, registering, and tracking GHG emissions and/or reductions <http://www.ecoregistry.org/>.

required for each forest carbon pool [i.e.: aboveground biomass, belowground biomass, soils, litter, etc] (AGO 1998). Thus, sample size allocated for each forest carbon pool should reflect the required precision.

5.2 alternative accounting methods

It is assumed that the ‘stock change’ method will be used to account for changes in forest carbon for projects eligible under Articles 3.3 and 3.4¹⁷. This method is discussed below. There are, however, a number of alternatives to the stock change method that have been proposed to account for forest carbon sequestered in JI and CDM projects. Three methods are discussed briefly below.

5.2.1 Stock change method

The stock change method of accounting involves calculating the difference between forest carbon storage at two different points in time. The total change in carbon stock is calculated by subtracting the carbon stock at the start of the commitment period, from that at the end of the commitment period. Figure 1 shows an example of how to calculate ‘Kyoto credible’ carbon for ARD activities over the first commitment period.

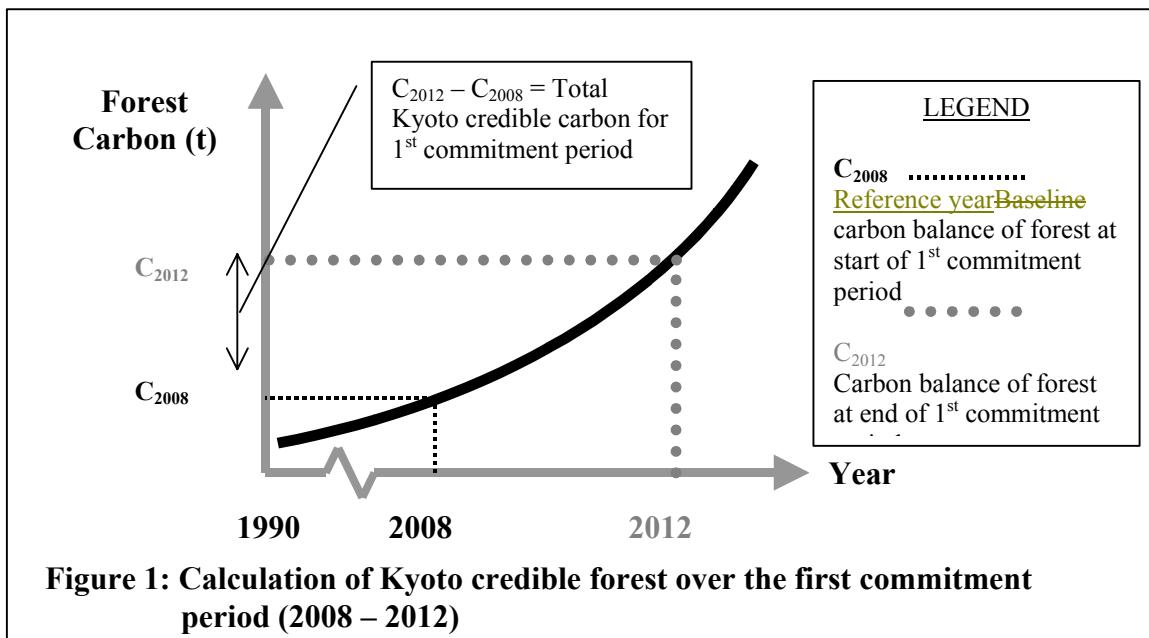


Figure 1: Calculation of Kyoto credible forest over the first commitment period (2008 – 2012)

A disadvantage of the stock change approach is that it may provide disincentive for long-term sustainable forest management practices. This is because the stock change method detects short-term fluctuations in carbon storage. Practices such as juvenile spacing, thinning, and planting of slow-growing species may result in short-term carbon emissions [or slower rates of carbon sequestration]. In the long term, however, these practices result in greater forest carbon storage. In order to address this issue, the ‘average forest carbon storage’ accounting method has been proposed.

¹⁷ The stock change method of carbon accounting (over the commitment period) is the methodology specified to be used to account for carbon storage under Article 3.3: “...measured as verifiable changes in carbon stocks in each commitment period..” (UNFCCC 1997). It is unclear at this stage whether the stock change method is required for Article 3.4. The IPCC *Special Report on LULUCF* (2000) identified at least four ways that additional activities could be temporally accounted for: Using 1990 as a baseline; Stock change over the first and subsequent commitment periods (provided activities were implemented after 1990); Using a BAU baseline; and stock change over the second and subsequent commitment periods (IPCC 2000). For the purposes of this document, it is assumed that the stock change method will be adopted for Article 3.4.

5.2.2 Average carbon storage accounting method

Under the ‘average carbon storage’ accounting methodology, the amount of Kyoto-credible carbon is calculated as the average forest carbon storage over successive rotations (Moura Costa & Wilson 1999). By calculating the average forest carbon storage, the long-term trend in forest carbon storage is captured, as opposed to the fluctuations [Figure 2].

Figure 2 depicts the carbon storage of a forest that has been thinned once, then harvested. The solid black line indicates the change in carbon stocks to be reported, using the stock change method. The dashed black line shows change in carbon stocks using the average carbon storage method. This implies that carbon losses due to harvesting [or thinning or spacing] are not debited [providing the forest was immediately replanted] (Moura Costa 2000).

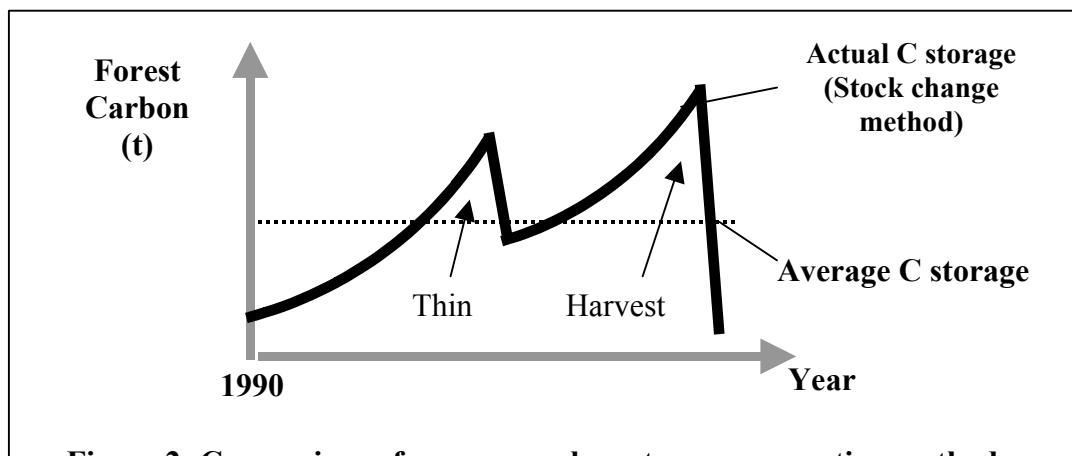


Figure 2: Comparison of average carbon storage accounting method with stock change method.

5.2.3 The ton-year method

The ton-year method has been proposed to address the issue of permanence of forest carbon storage. The method gives a FCP credit for each year of storage, relative to the rate of carbon decay in the atmosphere. It has been determined that storage of one ton of carbon for one year is equivalent to preventing the emission of 0.0182 tons of carbon, regardless of whether it is released again at the end of this year (Moura Costa & Wilson 1999). Therefore, one year of forest carbon storage could generate 0.0182 carbon credits. According to the CO₂ decay curve, storing one ton of forest carbon for 55 years could generate one carbon credit.

6. CONDUCT FOREST CARBON INVENTORY

Forest carbon inventory can potentially be conducted using three main methodologies: Field measurement, modeling and remote sensing techniques, or some combination of the three.

6.1 Estimation using allometric equations

For small FCP owners, it may be most practical and cost effective to use simple allometric equations to estimate forest biomass. Using this approach carbon estimates can be derived from current forest inventory data and data redundancy and high inventory costs can be avoided. The following sections describe how forest carbon can be estimated using field measurements.

6.1.1 Carbon storage in Aboveground Biomass

Tree carbon estimates can be derived from volume. Tree volume is estimated based on height and diameter at breast height, and by applying the appropriate allometric equation¹⁸. Volume estimates are then multiplied by a species-specific expansion ratio to estimate the total aboveground biomass. The expansion ratio accounts for the volume of the branches, leaves, twigs and other aboveground non-merchantable tree components¹⁹. For greater accuracy, expansion ratios should be specific to the region and species. Where these expansion ratios are not available, they can be developed by plotting a regression of non-merchantable biomass against merchantable volume and statistically determining the appropriate regression equation. This requires the use of destructive sampling techniques. As a last resort, country specific default expansion ratios can be obtained from the *1996 Revised IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 1996).

To calculate aboveground biomass on a dry weight basis, the total aboveground biomass is then multiplied by the appropriate biomass conversion ratio. This is a ratio to exclude the weight due to moisture in the tree. Biomass conversion ratios again should be species and regionally specific. However, default values are generally available in literature.

To convert biomass to carbon, the proportion of carbon contained in the biomass must then be multiplied by the dry weight of biomass. In general, the carbon content varies very little between species, and the IPCC default carbon content is 0.5 (IPCC 1996). However, species specific carbon contents for most forest species are generally available in literature. This estimate can then be scaled up to produce estimates of aboveground biomass carbon uptake on a per hectare or stand-level basis, by averaging the total carbon storage from a number of statistically significant plots across the stand, and multiplying by the stand area.

To express the total aboveground biomass carbon as CO₂ equivalents, stand level aboveground biomass carbon is simply multiplied by the stoichiometric ratio of CO₂, which is $^{44}_{12}$.

For multi-species stands, stratification may reduce sampling error. In this case, carbon storage for each species can be sampled independently, and summed to give total stand-level carbon storage.

6.1.2 Carbon storage in other carbon pools

Sources of carbon emissions must be reported from the belowground biomass, litter, dead wood and soil unless the FCP owner can prove that the pools are *not* net sources of carbon emissions. If the carbon pool is a sink, the FCP owner has the option of including the pool in their forest carbon inventory. Therefore, it is useful for a FCP owner to have a general knowledge of the processes involved in measurement of other carbon pools. A description of the carbon measurement procedures for each of these carbon pools can be found in MacDicken (1997).

6.2 Estimation using models

Where the stand size becomes too large or the forest too complex in structure, measurement of forest carbon on an individual tree basis may no longer be practical. In this case, the FCP owner may prefer to use a software-based model to estimate forest carbon²⁰.

To calculate current year carbon storage, the model will utilize simple forest inventory data input. These data are then substituted into a series of equations inherent within the model. Usually, a model

¹⁸. An example of an allometric equation specific to coastal Douglas fir in British Columbia, Canada is:

$$V = [4.796550265 \times 10^{-5}] * [D^{1.813820}] * [H^{1.042420}]$$

Where: V = Total merchantable volume of the tree [m³], D = Diameter at breast height [cm], and H = Tree height [m]. In cases where allometric equations are not available, these can be developed using regression analysis of measurements taken from destructive sampling techniques.

¹⁹. Many of the expansion ratios available may also account for below ground biomass. If this is the case, aboveground biomass and belowground biomass should simply be accounted for together.

²⁰. A summary of a range of software-based forest carbon models is available at the following address: <http://www.joanneum.ac.at/iea-bioenergy-task38/model/fmodel.htm>

will determine the carbon balance in the above and belowground biomass, however models can often also determine the amount of carbon in soils, litter and dead wood (Vine et al. 1999).

6.3 Integration of remote sensing techniques

Remote sensing can be used in forest carbon inventory for three purposes: Direct measurement of carbon, stratification and/or to provide estimates of forest area. Direct measurements of forest carbon can be obtained via SAR [Synthetic Aperture Radar] scanners. SAR scanners are capable of examining the patterns and strength of spectral reflectance of vegetation (Baker & Luckman 2001). Data from the scanner can then be input into a computer model, which can then produce estimates of Net Ecosystem Productivity [NEP] and forest carbon storage. A range of these computer models are available: InTEC, Integrated Terrestrial Ecosystem Carbon Cycle Model (Canadian Centre for Remote Sensing CCRS 2000); BEPS, Boreal Ecosystem Productivity Simulator (Liu 1997) and Forest-BGC (Running & Coughlan 1998, Running & Gower 1991);

Remote sensing can also prove useful for stratification of land use and/or forest type prior to field sampling. By examining the crown formation characteristics of forests from aerial photographs or spectral reflectance from satellite images, it is possible to identify forest and non-forest areas, and classify forest according to forest type or species (Avery & Burkhardt 1983). Stratification can enhance efficiency of forest inventory by reducing variation between grouped sample plots. Another way remote sensing can significantly enhance the accuracy of a forest carbon inventory, is to provide more precise estimates of forest area. This is beneficial since inaccuracy in forest area estimates has been identified as being one of the major sources of error in forest inventory estimates (NGGIC 1998).

One problem with the use of remote sensing at the operational level, is that the cost can prove prohibitive for a single forest owner. This problem can be overcome by cooperating with other land holders nearby, organizing to have remote sensing conducted at the same time on a larger area of land. Costs are then shared amongst a number of individuals.

7 DETAILED MODELING OF FUTURE CARBON YIELD

Once the FCP has been implemented and forest inventory has been conducted, more detailed estimates of carbon yield can be produced, using the carbon yield prediction models as described in Section 2. The FCP owner will have gained some experience and insight into the limitations associated with the project. This experience should give FCP owner a more realistic idea of the assumptions, constraints and growth trends for input into the carbon and timber yield projection models. More reliable estimates of future carbon yield are especially important if the FCP owner intends to conduct forward trades of forest carbon [Section 11.1].

8 MONITORING, VERIFICATION AND CERTIFICATION

The Kyoto protocol specifies that carbon estimates should be... “ reported in a transparent and verifiable manner...” (UNFCCC 1997); therefore a well-designed system for monitoring, verification and certification is essential. Monitoring can be defined as the “periodic inspection or measurement of project carbon against reported or estimated values” (State Forests NSW 2000). Verification can be defined as the act of checking the validity of the claims of a project (Moura Costa et. al. 2000). Certification occurs when the verification agency officially confirms that the FCP conforms with specified verification criteria.

8.1 Monitoring

A forest carbon monitoring system involves an analysis of reported values to estimates obtained from the re-measurement of a certain proportion of forest inventory plots. If reported and re-measured estimates differ significantly, this suggests incorrect inventory design or technique, or invalid assumptions. To reduce the costs of monitoring, a combination of ground-based and remote sensing techniques can be adopted. Monitoring and verification costs for small landholders could be

minimized through groups of forest owners forming a ‘carbon pool’ of plantations, thereby sharing costs among a number of individuals.

8.2 Verification and Certification

There are three components that are required for a successful verification/certification system (Moura Costa et al. 2000); a published standard, an accreditation body and verification/certification agencies that are accredited to use the standard.

A forest carbon verification standard is defined as a set of generally accepted principles, procedures and methodologies for recording the level of forest carbon sequestration and emissions (Meridian Institute 2000). This would allow forest owners to conduct their own forest carbon inventory suitable to their own forest type, geography and technological capabilities. In order to ensure that the standard is unbiased and suitable to all parties, the international standard would be developed by an independent standard setting authority, comprised of representatives from all parties to the UNFCCC. More detailed national guidelines may also be developed for each country. The guidelines should provide standards for each the field measurement, remote sensing and modeling components of the inventory system.

In addition to an independent standard setting authority, an accreditation body is also required. The accreditation body would attest to the integrity and competence of the verification/certification agency, and oversee the performance of the verification agencies to ensure that the published verification standards were being used appropriately. At present, there is no established accreditation body for this purpose. However the Meridian Institute is currently proposing to establish an international standard setting, accreditation and certification system (Meridian Institute 2000). Under a National Carbon Network [NCN] scheme [Section 9.5.5], it is likely that government for each of the parties to the Kyoto Protocol will play a major role as an accreditation body.

Upon official certification by the accreditation body, the verification/certification agency would then be licensed to undertake the actual verification procedure. In order to verify the existence of Kyoto credible forest carbon, three main aspects of the project should be examined. First, the project baseline should be assessed in terms of validity of assumptions. Next, the verifier should confirm that the actual project activities have occurred. Finally, the forest carbon inventory system itself is verified. The verifier would then compare their own estimates of forest carbon data to those reported by the project owners. Based on this comparison, uncertainty of forest carbon data could be calculated.

Certification occurs if the verification agency can attest that the carbon accounting data is true as represented, and meets the carbon verification standard (Meridian Institute 2000). This will normally involve the fully accredited verification agency issuing a certificate, giving formal recognition of a specified quantity of forest carbon storage. Certification of forest carbon storage has the benefit of encouraging investor and buyer confidence, and also avoids the possibility of trading of poor quality, non-verifiable carbon credits (Obersteiner et al. 2000).

9 REPORTING OF FOREST CARBON DATA

Reporting of forest carbon estimates should be accompanied by an assessment of uncertainty, assumptions and excluded carbon pools. For verification purposes, it is also prudent to supply adequate documentation and explanation of project activities and inventory methodology. In addition, this section defines a formal methodology for reporting of carbon data to a ‘National Carbon Network’ (NCN) to facilitate efficiency in data collection; and to provide a means of scaling up of operational level carbon inventory to interface with national level GHG reporting.

9.1 Reporting of Uncertainty

There are two main types of uncertainty associated with forest carbon data: measurement uncertainty, and counterfactual uncertainty (Moura Costa et al. 2000). Measurement uncertainty is due to limited data availability, and limited resources available to capture this data. There are four

types of measurement uncertainty: Uncertainty due to averaging and use of approximated values [such as a root to shoot ratio]; Uncertainty associated with the science of forest carbon sequestration; the uncertainty associated with attempting to measure parameters that cannot be directly measured [eg: Using diameter and height to approximate biomass] (Vine et al. 1999). The final type of measurement error arises due to mistakes, systematic biases and accidental errors occurring during the actual forest inventory (Brack & Wood 1998). Measurement uncertainty, is readily quantifiable and should be stated when reporting forest carbon estimates.

Counterfactual uncertainty generally refers to the inability to predict ‘what might have been’ (Tetlock and Belkin 1996). Counterfactual uncertainty arises due to assumptions that are made in estimating baselines, future forest management regimes and occurrence of risk events. Counterfactual uncertainty is difficult to quantify, and is best dealt with conducting extensive risk management assessment, and using a reputable software package to produce reliable estimates of future carbon yield [Section 2].

Uncertainty can be reported in either of two ways (Vine et al. 1999): Statistically, as the standard error of the mean, or confidence limits around the mean; or qualitatively, where a precision of level of high, medium or low, for example, is assigned to the estimate.

9.2 Documentation of Project Activities

To facilitate verification and certification, each stage of the forest carbon inventory and accounting system should be documented. An ‘audit trail’ allows an independent third party to verify that the forest carbon inventory is carried out according to a specified standard, and that the claimed amount of carbon storage is a good approximation of actual carbon storage. Given the uncertain and dynamic nature of the Kyoto protocol, extensive documentation will also be useful in ensuring that early FCP emission reductions are officially recognized, ahead of finalization of climate change negotiations (CO2e.com 2000).

9.3 Reporting of assumptions and excluded carbon pools

If a forest carbon pool is not accounted for, “transparent and verifiable proof” must be provided to prove that the unaccounted pool is not a source (SBSTA 2000). It follows that a report on unaccounted pools must accompany all inventory estimates. A list of all assumptions made during the inventory, modeling and calculation stages should also be prepared.

9.4 Post-Reporting Feedback

Review and feedback mechanisms are useful to facilitate flexibility and improvement of a forest carbon accounting system. To facilitate public input and feedback, annual carbon progress reports could be released, both internally and publicly. Sampling systems should be reviewed by experienced forest inventory specialists and statisticians, and verification reports should be noted and adjustments made accordingly. Formulation of a special review board, to assess, recommend and implement the required changes would be advisable for larger FCP owners

9.5 The Concept of the National Carbon Network

The National Carbon Network [NCN] presented in this section is a proposed model to facilitate efficiency in data collection; and to provide a means of scaling up of operational level carbon inventory to interface with national level GHG reporting. The proposed NCN model is divided into six main sectors:

1. Public relations and consultancy
2. Inventory
3. Recording, reporting and tracking of forest carbon [National Carbon Registry]
4. Risk management
5. Accreditation of verification agencies
6. Supervision of emissions trade/brokerage services

Each of these sectors is inter-related as shown in Figure A1 in the Appendix. The role and basic operations of each sector are described in the following sections.

9.5.1 Public relations and consultancy services

The primary means of communication between the NCN and individual forest growers, would be via a web-based national carbon registry [Section 9.5.3]. Forest growers could also communicate with the NCN via a series of regional representatives [Section 9.5.1.4]. The public services sector could be divided into four departments: project evaluation; management advice; legislative services, and public relations. Each of these departments is outlined below.

9.5.1.1 Project evaluation

In order to assess the Kyoto compatibility and economic feasibility of a forest carbon project [Section 4.1], the NCN could provide an evaluation service to forest growers. Using a number of specified guidelines, the NCN could advise forest owners as to whether their proposed project is Kyoto-eligible.

The NCN could provide either basic, web-based evaluations, or conduct in-depth project evaluations. Basic project evaluations could occur via the public-services module in the web-based registry [Section 9.6.3]. Alternatively, the forest grower could elect to have an in-depth project evaluation carried out in person by one of the regional NCN representatives. This would involve a site visit by the regional representative, who would conduct soil and site productivity test, and conduct a personal interview regarding management intentions of the owner, commitment and expected outcomes of the project.

9.5.1.2 Inventory and Management advice

FCP owners are likely to benefit significantly from a well-written manual, providing detailed information on how to conduct forest inventory, and advice on how best to manage a forest carbon project (BRS 2000). The NCN could publish an inventory and management manual via the public services module in the web-based registry. It is essential that the manual be easy to read, and provide detailed illustrations on how to conduct forest inventory. In addition, the regional NCN representative would be available for individual consultations and guidance regarding inventory and management advice.

9.5.1.3 Legislative services

The legislation regarding ownership of carbon is, at this stage, highly uncertain. Prior to commencing trade of forest carbon, it is essential to legally establish separate ownership of the trees, land and carbon (Blair 1999). This will allow trade of forest carbon as a separate commodity, regardless of whether the ownership of the trees or land changes hands. Pending the finalization of appropriate legislation, a forest grower would be prudent to seek legislative advice regarding the formulation of legally binding contracts, to establish carbon rights. The NCN could offer this service, by providing a legally binding on-line carbon rights contract. The contract could also be accompanied by simple explanations of the implications of the carbon rights contract. NCN regional legislative representatives would also be available for personal consultation in legislative services.

9.5.1.4 Public relations

It is crucial to maintain well-established lines of communication between the forest grower and the NCN to overcome distrust of a government agency; to facilitate interest in establishing a forest carbon project, and to inform forest growers about how to manage and maintain a forest carbon project (BRS 2000). The public relations program of the NCN could comprise a number of initiatives, such as:

- A web-based promotional and informational package
- A series of regional seminars and conferences
- A network of regional contact persons, preferably employment of individuals who are local, approachable and well established in the community.

- Informational booklets and pamphlets distributed to secondary and tertiary education institutions.

9.5.2 Inventory

The challenge of any national forest carbon inventory program, is to provide a means of scaling up operational, stand-level forest inventory to interface with the national level GHG inventory, allowing participation of both small and large scale forest growers. In an attempt to meet these requirements, the national forest inventory proposed under the NCN provides a system of incentives to encourage small forest growers to submit detailed inventory information to supplement broad scale forest inventory. This system, described below, would be conducted on two levels: broad scale forest inventory, and detailed operational level forest inventory.

9.5.2.1 Broad scale forest inventory

Broad-scale forest inventory would be conducted by the NCN on all forest land within the country. This would be done using a combination of remote sensing and ground sampling techniques. Benefits of the NCN conducting a broad scale forest carbon inventory are numerous: The per unit cost of inventory is minimized. Carbon data could be obtained for Kyoto forests where the FCP owner is unable to conduct inventory themselves. Utilization of remote sensing data enables carbon data to be reported in a manner that is both timely and consistent (Natural Resources Canada 2001). Inventory data could be used for a range of purposes. However, a major limitation of conducting such broad-scale forest inventory, is that areas of less than approximately 20 metres cannot be measured or mapped accurately (Weir pers. Comm. 2000). Therefore, there is also a need to conduct a more detailed, operational level forest inventory.

9.5.2.2 Operational level forest inventory – The carbon ‘refund scheme’

In order to increase the precision of the national forest inventory and enable mapping and measurement of small areas of forest, more detailed, ground-based forest sampling techniques must be implemented. Via a ‘carbon refund scheme’, individual forest owners are encouraged to cooperate with the NCN and conduct their own detailed forest inventory. This refund scheme could work as follows: In order to claim rights to the carbon ownership of their forest, the forest owner would be required to electronically register their forest on a national web-based carbon registry [Section 9.6.3]²¹. By officially registering their forest, a forest owner would effectively enter into an agreement with the NCN. Under this agreement, the forest owner would be required to make a ‘payment’ to the NCN for conducting the broad scale forest carbon inventory [in much the same way that one might pay taxes to the government]. This ‘payment’ would obligate the forest carbon owner to forfeit a proportion of their forest carbon ownership to the NCN. If the forest owner decided to conduct their own forest carbon inventory to supplement the broad forest inventory carried out by the NCN, they would be entitled to a ‘carbon refund’ of a certain proportion of their carbon ownership. The more detailed forest inventory information submitted by the forest grower, the greater amount of carbon that would be refunded by the NCN. In this way, the number of carbon credits obtained by the forest owner would be in proportion to the precision of the forest carbon inventory. Thus, additional costs of inventory are offset by the increase in carbon that is eligible for trade. The concept of a ‘variable precision carbon accounting system’ is derived from the carbon accounting standard developed by the State Forests of NSW (2000).

9.5.3 Maintain a national carbon registry

As described in Section 4.2, forest owners would be required to register their forest on the web-based national carbon registry. A national carbon registry is also needed to meet the requirements of Articles 6 and 12²². The national carbon registry would essentially be a user-friendly, multi-purpose,

²¹ If a FCP owner decided not to register their forest, they would not be eligible to claim carbon offsets. The NCN would obtain rights to claim ownership of the forest carbon. The NCN could then decide whether to conduct their own detailed forest carbon inventory, or simply use data from the broad scale forest inventory [Section 9.5.2.1].

²² A decision was made at COP 4 to facilitate the development of web-based national carbon registries. This decision specified that: “Each party in Annex B shall establish and maintain a national registry to ensure the accurate accounting of the issuance... holding, transfer, acquisition, cancellation and retirement of

web-based computer program. The carbon registry could be divided into a number of separate modules, each to perform a separate role. Some ideas for modules in the national carbon registry might be:

- Land Tenure module: Linked with national tenure records, register ownership
- Inventory module: Contains all historical and current forest inventory data
- Public accounts module: Tracks ownership of carbon for each forest owner, tracks emissions record for each forest owner
- Public Services module: Contains general information, references, links and contact details [Section 9.5.1.4]
- Carbon accounting module: Spreadsheet-based statistical module, to combine all forest inventory data to calculate forest carbon on an operational, regional and national level
- Risk management module: Contains a record of carbon contributions of each forest grower towards a carbon risk management buffer. Primarily maintained by independent risk management agencies [Section 9.5.4]
- Verification/Certification module: Documents verification and certification of the forest by an independent verification/certification agency [Section 9.5.5].
- Emissions trading module: Details of purchase and sale of forest carbon credits, interfacing with the public accounts module. Primarily run by the independent clearing house.
- GIS component: All data within the national carbon registry would be spatially referenced and linked to a GIS system (AGoA 2000).

9.5.4 Risk Management

As described in Section 9.5.2.2, the ‘carbon refund scheme’ requires the forest owner to forfeit a certain proportion of carbon ownership to the NCN as ‘payment’ for forest inventory. A proportion of this carbon is automatically contributed to a national carbon risk management pool. The NCN could act as a risk manager for the forest owner, by using a proportion of these retained carbon credits to form a ‘risk mitigation buffer’ against disturbance events (State Forests NSW 1998). Thus, in the event that the forest was destroyed by fire or insect attack, the losses would be covered by the reserve pool of carbon credits. The buffer of carbon credits would also balance the temporary carbon loss occurring during the harvest/regeneration cycle across the entire carbon pool.

To perform this role, the NCN could oversee the license and performance of a number of risk management agencies. Each of the risk management agencies would compete for the right to manage the carbon pool of forest growers. In the same way that tax payers are required to fill out a tax-return, forest owners could fill out a ‘carbon-return’. Level of risk could be assessed in terms of potential for natural disturbances, anthropogenic interventions and socio-political and economic risk (Moura Costa et al. 2000). Under this risk assessment, each forest carbon project could be assigned a ‘permanence rating’, or likelihood of achieving permanent carbon storage. Based on this permanence rating, the carbon pool manager could then negotiate the amount of carbon ownership forfeited to the national carbon pool [and thus, the level of risk protection required]. In this way, the amount of carbon that is eligible for trade is in proportion to level of risk associated with the project.

The NCN could also provide advice on other means of reducing risk associated with forest carbon projects, such as portfolio diversification or strengthening of insect and fire protection activities. The NCN may also function as a simple insurance agency, whereby a forest grower may choose to make financial payments to insure against risk, rather than setting aside a proportion of their carbon credits towards a carbon pool.

9.5.5 Accreditation of verification agencies

As described in Section 8.2, there is a need for an international accreditation body, to attest to the competence of independent verification agencies. The NCN could perform this role, as well as

(one-ton equivalents of CO₂)” (FCCC/SB 2000). A copy of these guidelines is available at the following address: <http://www.unfccc.int/resource/docs/2000/sb/crp22.pdf>

overseeing the performance of verification agencies by allowing them access to appropriate records the national carbon registry. The agent could then check their own estimates of forest parameters against the forest inventory data recorded by the NCN and the forest owner in the carbon registry. The agent would then be required to write up a verification report, stating the precision of forest carbon inventory estimates. The verification agent would then file the report in the verification module of the national carbon registry. Upon receiving the verification report, the NCN could then certify the amount of forest carbon that is tradable, according to the precision of the inventory.

9.5.6 Oversee Emissions trade/Brokerage services

An ‘emissions clearing house’ is essentially a mechanism for trading of CO₂ equivalents. An emissions clearing house should be run by an entity that is independent of the NCN kept separate from the NCN. Otherwise, there is potential for fraudulent activities such as inflated forest carbon inventory estimates to create additional carbon credits (Beil 1999). The NCN could act as the central governing body of the emissions clearing house, described further in Section 11.3

PHASE THREE: EMISSIONS TRADE

Having measured, monitored and reported the amount of ‘Kyoto eligible’ forest carbon, a FCP owner may wish to participate in an emissions trading market. To do so, the FCP owner must determine the amount of forest carbon that they should make available for trade, and then proceed to enter the emissions trading market.

10 DETERMINE NUMBER OF CARBON CREDITS

Emissions trading will involve buying and selling of one-ton equivalent of CO₂ known as ‘carbon credits’. Described below is the process by which a FCP owner can determine the amount of carbon that is eligible for trade as carbon credits, or ‘Trade Eligible Carbon’, TEC.

10.1 Determine Amount of Trade Eligible Carbon

There are four steps involved in calculating the amount of TEC. First, the FCP owner must determine the net amount of forest carbon for the first accounting period. This can be done using the stock change methodology, as explained in Section 5.2.1. The second step required to calculate TEC, is subtract stock of carbon to account for counterfactual²³ and measurement uncertainty of carbon estimates. This conservative approach will instill market confidence by ensuring that all carbon credits represent real and verifiable carbon storage. The third step in calculating the amount of TEC, is to subtract a buffer stock of carbon to account for risk of unexpected carbon loss²⁴. To quantify risk, it is suggested that a FCP owner should undertake a qualitative risk assessment. The forest owner should retain a pool of forest carbon in reserve in proportion to the severity and frequency of risk events over the project lifetime. Another way of dealing with risk is to insure forest plantations. Then, in the event of a risk event occurring, the forest owner would be compensated for lost carbon credits and timber value. Another risk management strategy suited particularly to small forest owners, is the formulation of carbon ‘pools’, whereby a number of forest owners agree to spread the risk of carbon loss due to disturbance amongst a number of individuals. Responsibility for carbon credit acquittal in the event of carbon loss would then become the shared responsibility of each of the carbon pool members. A similar principle can be applied to a single forest owner, whereby risk is spread across a “diverse portfolio of carbon sequestration projects” (Brown *et al.* 1997). Finally, a FCP owner should account for their own emission reduction quota before selling their carbon to another party. At present, it is uncertain as to how a country might proportion their

²³ Since counterfactual uncertainty is difficult to quantify, the FCP owner should undertake a risk assessment and estimate the uncertainty associated with yield forecasts to calculate the probable error of counterfactual assumptions.

²⁴ Note that in the event that a NCN has been established and the FCP owner contributes to a national risk management buffer via the ‘carbon refund scheme’ [Section 9.5.4], subtraction of carbon due to risk will not be required. Until a NCN has been established, a FCP owner would be prudent to voluntarily contribute to their own risk management buffer.

allocated emission reduction quotas. In the event that individual sectors and companies are allocated an assigned amount of emissions, it would be wise for a FCP owner to meet their own emission reduction quota before selling their carbon.

11 EMISSIONS TRADE

The Kyoto Protocol allows carbon to be traded internationally via three mechanisms: Joint Implementation [JI], the Clean Development Mechanism [CDM] and International Emissions Trading [IET]. JI allows Emission Reduction Units [ERU's] to be traded between Annex I countries [via linkage to a specific project, to the approval of both parties]. The CDM allows transferal of Certified Emission Reductions [CER's] to an Annex I country from a non-Annex I country. International Emissions Trading [IET] has been included as a mechanism under Article 17 of the Kyoto protocol, and allows carbon to be traded at market value between Annex I countries.

Essentially, emissions trade enables a party to purchase or sell the right to emit a specified amount of GHG's from another party (CO2e.com 2000). It is proposed that by allowing trade of emissions, parties will be able to meet their allocated emission quotas at least cost²⁵. Emissions trade is particularly suitable to FCP's, since the substantial initial establishment costs of a FCP can be financed through profit from the forward sale of forest carbon. The Sections below define the units of emissions trade, how these trading units will be allocated, and proposes a trading mechanism within the NCN.

11.1 Defining the trading unit and trading mechanism

The primary unit of international emissions trade is likely to be one-ton CO₂ equivalent, or carbon credit. In selling of a carbon credit, a FCP owner promises to sequester a one ton equivalent of CO₂ in a specified year, and that this carbon should remain stored in the forest for a specified amount of time. A carbon credit cannot be used to meet Kyoto targets until the carbon is actually sequestered (State Forests NSW 2000). Depending upon the time of sale and storage of the forest carbon, there are three different types of trading mechanisms (CO2e.com 2000): A 'forward sale' of carbon credits occurs when a buyer agrees to purchase a carbon credit from the seller at a specified date in the future. A 'futures contract' is similar to a forward sale, but is tradable in its own right, and is facilitated by a 'futures exchange' trading platform (CO2e.com 2000). Finally, carbon credits can be sold as 'options', which entitles a buyer the right, but not the obligation to purchase carbon credits in the future.

11.2 Allocation of permits

Although a formal international emissions trading market is yet to be established, it is expected that companies will be allocated a set number of 'emission allowances', the total of which will reflect the Kyoto target of the particular country. There are two main options for the initial allocation of emission allowances (AGO 1999b): administrative allocation, and auctioning. Administrative allocation (sometimes referred to as the 'grandfathering' approach) would involve distribution of emission permits to companies by the government. The number of emission permits allocated to each company might depend on level of historical emissions and/or the extent to which the industry would be adversely affected by greenhouse gas abatement (AGO 1999b). The administrative allocation of permits should also contain provisions for recognition of early emission abatement action. The alternative approach to administrative allocation, is auctioning. This would involve a system whereby a company would gain emission permits by purchasing them on an open market.

11.3 Emissions trading within the National carbon network

As described in Section 9.5.6, the NCN could act as the central governing body of the emissions clearing house. In order to gain a license to provide emissions trade/carbon brokerage services, a party would need to apply to the NCN. The applicant would need to provide adequate documentation to ensure they had a well-designed system in place that is capable of tracking all

²⁵ It has also been found that by allowing full trade of emissions, global GDP is expected to decline by 0.2% in 2010. This is compared to the expected decline of 0.5% in 2010 without emissions trading (Reuters News Services 2001).

transactions in an efficient manner. The NCN would then oversee the performance of the clearing house, to ensure all transactions were accountable and legal. To assist the clearing house in providing an efficient, fully verifiable means of trading carbon, the NCN would provide the clearing house with direct access to the public accounts module of the carbon registry. The national clearing house would calculate the number of carbon credits for each forest grower wishing to participate in the market, and assign each carbon credit with its own unique serial number, linked with the public accounts module of the national carbon registry. In this way, the national clearing house would keep track of carbon credits bought and sold via a simple double-entry accounting system (Lamb 1998). It is anticipated that individuals could actually trade 'on-line' via an electronic clearing house, which would also interface with the national carbon registry [Section 9.5.3]. This would enable prospective buyers instant access to information about the origin and nature of carbon credits on the market.

11.4 Existing Exchanges and trading systems

A large number of trades in forest carbon have occurred already. Initially, trades were largely project-specific [eg: In July, 1999, Tokyo Electric Power company agreed to purchase the carbon sequestered from planting 1000 hectares of forest from the State Forests of NSW]. As the emissions trading market progresses, however a greater number of trades will be facilitated by the ever-increasing number of emissions trading platforms. For example, GERT, A Greenhouse Gas Emissions Trading Pilot <http://www.gert.org/>; and Climate Partners <http://www.climatepartners.com/index.cfm> in Canada. In Australia, the Queensland emissions trading platform, <http://www.qetf.org/>, and The Carbon Trader <http://www.thecarbontrader.com/bottom.htm> have been established. In the US, CO2e.com <http://www.co2e.com/strategies/default.asp>; and Trexler and Associates <http://www.climateservices.com/> are large emissions trading platforms. To date, most exchanges occurring through trading platforms involve the buying and selling of options (CO2e.com 2000). Most of these trading platforms encourage on-line trading, whereby a buyer or seller is required to register on the global trading platform. Once registered, the user can gain access to pricing information, and can proceed to place a bid to purchase carbon, or offer carbon for sale. An example of one of the worlds first on-line emissions clearing houses is CO2e.com, founded by Cantor Fitzgerald in association with Price Waterhouse Coopers. As an indicator of the success of on-line trading of carbon, between 60 to 100 trades had already occurred within weeks of launching the site, trading approximately 160 million tonnes of carbon (CO2e.com 2000).

CONCLUSIONS

The 'Kyoto Protocol', signed by the parties to the United Nations Framework Convention on Climate Change (UNFCCC) in 1997, allows countries to use carbon sequestered in forests as a means to meet internationally binding Greenhouse Gas reduction quotas. An international forest carbon accounting framework for measuring, reporting and trading of forest carbon is therefore required. This framework must provide incentive for sustainable forest management practices without compromising the integrity of the protocol, as well as providing a means of 'scaling up' carbon inventory.

An eleven step forest carbon accounting framework, designed to meet the reporting requirements of the Kyoto Protocol, is described in this paper. The process by which an operational-level forest carbon project owner can assess their need for a forest carbon project was discussed, and a range of forest management schemes were suggested. The report described how and why baselines should be measured, and discussed how field measurements, software packages and/or remote sensing can be used to conduct forest carbon inventory. The need for a monitoring, verification and certification system was highlighted. A National Carbon Network was proposed to act as a central carbon manager, to conduct a variety of forest carbon accounting and management roles, and facilitate efficiency in forest inventory and risk management. In order to commence trade of forest carbon, it was advised that risk, uncertainty and emission reduction targets should be taken into account when determining the amount of Trade Eligible Carbon. The unit of emissions trade was defined, and the variety of trading mechanisms and platforms were listed.

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Appendix

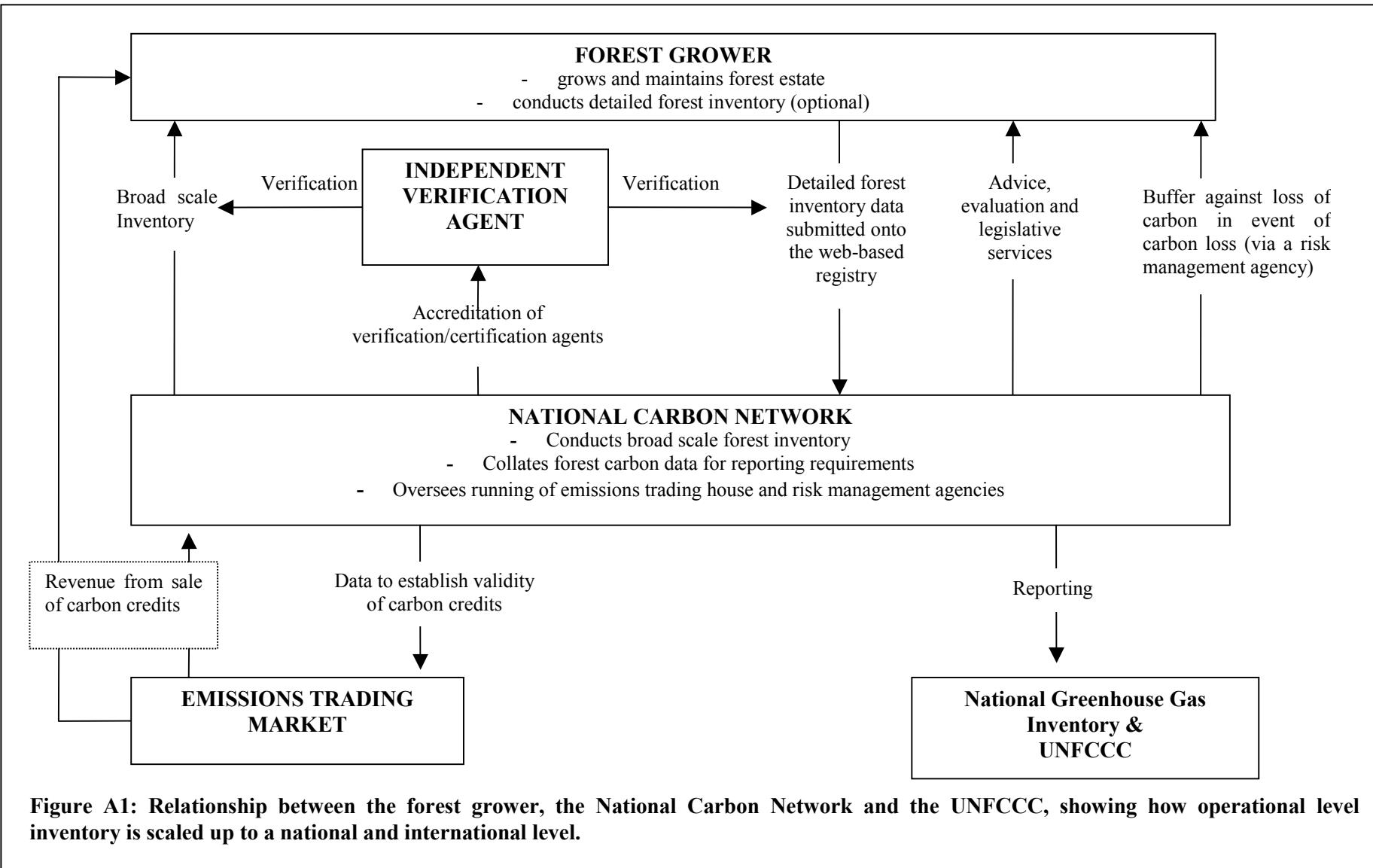


Figure A1: Relationship between the forest grower, the National Carbon Network and the UNFCCC, showing how operational level inventory is scaled up to a national and international level.

Subnational Entity Accounting for Carbon Sinks and Storage under the Kyoto Flexibility Mechanisms Based on Guaranteed Duration of Storage

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ABSTRACT

Legally binding commitment to retention of sequestered carbon provides an appropriate and useful basis for recognition of offsets to greenhouse gas emissions under the Kyoto flexibility mechanisms, and where there is only short-term commitment to retention, credits should be reduced proportionally for periods shorter than 100 years. 100 years has been identified, including by the IPCC Special Report on Land Use, Land Use Change and Forestry, as the period over which sequestration of an amount of carbon will offset an emission of the same amount, expressed in CO₂ equivalent terms. The agreed method for measurement of emissions and sequestration to meet national commitments in the first Kyoto commitment period is by verifiable change in stocks during the period 2008 – 2012. However, significantly different approaches are appropriate for national governments compared to domestic and multinational commercial enterprises. There are significant problems with the “verifiable change in stocks” approach at a subnational level. An approach based on Global Warming Potential equivalency, which seems prescribed by the wording of Article 5.3, and on the guaranteed duration of storage of sequestered carbon, is proposed. The approach aims to address concerns regarding permanence of sequestration, minimise the risks in credit ownership, give confidence in the durability of credits, support ecologically sustainable development and facilitate sequestration futures trading. It may also allow a qualitative cap on the use of sinks under the flexibility mechanisms rather than a quantitative cap. An approach to the use of sinks under the Clean Development Mechanism based on country-sectoral baselines is also proposed.

Keywords: Carbon sinks, carbon storage, carbon dioxide equivalent offset, CO₂eo, guaranteed duration of storage.

Introduction

This paper proposes a basis for accounting for carbon sinks and storage, under the Kyoto flexibility mechanisms, that addresses concerns regarding the permanence of sequestration in vegetation and soils, while maintaining consistency with the letter and spirit of the Protocol and the Framework Convention on Climate Change. This necessarily means assisting progress towards ecologically sustainable development and biodiversity conservation.

Much current discussion on accounting approaches for sinks is focused on accounting at the Party level, that is, at the level of nation states in the context of a binding international agreement. This paper addresses some desirable differences between Kyoto Protocol national accounting and carbon credit and debit accounting by subnational or multinational profit focused entities.

A principal concern is to ensure that when financial incentives to sequester carbon eventuate, they operate through a framework that can ensure that Ecologically Sustainable Development, Sustainable Forest Management and biodiversity conservation are furthered.

Two central tenets of this paper are that:

- Sequestration of carbon from the atmosphere is valuable in relation to the duration of storage, and that
- Guaranteed duration of storage of eligible sequestered carbon forms the appropriate basis for issuing credit against greenhouse emissions.

This responds to the stipulation by Lashof and O'Hare (Lashof and O'Hare 1998) that appropriate policies must be designed to minimise the risk of granting emission credits for biotic carbon sequestration that proves to be temporary.

Ownership, trade and accounting system based on guaranteed duration of storage are also more likely to be able to manage the risk of default on obligations to buy permits upon re-emission of the sequestered carbon in the future (over decadal timeframes). This is principally because sustainability becomes the subject of Third Party Verification, which will be required for trade.

When carbon pool managers have to demonstrate sustainability over the very long term, they must take into account both CO₂ fertilisation in the short term and climate change impacts on vegetation and soils (which may lead to re-emission of a proportion of carbon sequestered into vegetation and soils) in the long term. Their acceptance of this long-term responsibility as an auditable function may obviate the necessity of attempting to "strip out" the effects of CO₂ fertilisation. That is, any early advantage from fertilisation would be nullified over century timeframes by the impacts of climate change on biotic systems.

It is hoped that the rigorous approach proposed may allow for a qualitative rather than quantitative cap on the use of sinks under the Kyoto flexibility mechanisms, and avoid perverse outcomes which could include incentives for investment in short term and potentially unsustainable forests, the creation of unsustainable carbon-related commercial liabilities, and diminution of the climate and other possible benefits.

Some final comments in this paper relate to the effect of the accounting approach recommended here on accounting for carbon storage in harvested wood products, and to the further issue of minimising intrnational leakage of LULUCF project benefits under the CDM.

METHODS

Sequestration units

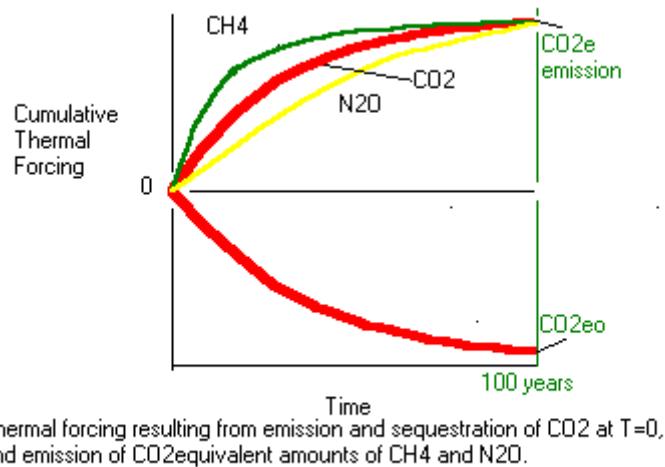
There is an obvious need for a unit to offset emissions, which are expressed in CO₂ equivalents, on a purely "apples with apples" basis. The need is recognised in the Kyoto Protocol in Article 5.3 which states: "The global warming potentials used to calculate the carbon dioxide equivalence of anthropogenic emissions by sources and removals by sinks of greenhouse gases shall be those accepted by the Intergovernmental Panel on Climate Change....." (UNFCCC, 1997). We must therefore examine the nature of global warming potentials and carbon dioxide equivalence in order to define a unit of sequestration that is consistent with accounting for emissions. We find that both mass and time are important.

Carbon dioxide equivalency is defined by the relationship between the cumulative thermal forcing resulting from the pulse injection of any greenhouse gas, with that resulting from the pulse injection of an equivalent mass of carbon dioxide, over a given timeframe. (HOUGHTON ET AL., 1994) Article 5.3 states that the global warming potentials used shall be those determined by the IPCC. These are based on a 100 year timeframe. It is on the basis of these global warming potentials that we say that methane has a global warming potential of 21 and nitrous oxide, 320.

100 years was identified by the IPCC Special Report on Land Use, Land Use Change and Forestry (WATSON ET AL , 2000), (P88) as the period over which sequestration of an amount of carbon will offset an emission of the same amount, expressed in CO₂ equivalent terms).

This is sketched in Figure 1, which illustrates the contributions to cumulative thermal forcing of equal CO₂e emissions of carbon dioxide, methane and nitrous oxide. The reduction in thermal forcing caused by the withdrawal of an equivalent amount of CO₂ from the atmosphere is also shown. As can be seen, to offset the effects of an emission of a CO₂ equivalent amount of any greenhouse gas, the same amount of CO₂ must be withdrawn from the atmosphere, and held for 100 years. This unit can be appropriately termed a carbon dioxide equivalent offset, or CO₂eo.

Figure 1: Cumulative thermal forcing of equal CO₂e emissions of carbon dioxide, methane and nitrous oxide.



It has been asserted that carbon held out of the atmosphere for a required equivalence time could be released back into the atmosphere without penalty or the necessity of recording an emission. (Moura-Costa and Wilson 1999) However CO₂ persists and continues to exert thermal forcing well beyond the 100-year timeframe used to compare the thermal forcing effects of the various greenhouse gases. This is even more the case in respect of the longer-lived greenhouse gases such as HFCs and nitrous oxide, which may also be offset by sequestration of atmospheric carbon. Further, biotic storage of carbon will in most cases be offsetting emissions of fossil carbon that has been in geological storage for millions of years.

Therefore, it is suggested that 100 years of storage be seen as the period required to earn a full offset a CO₂e emission, and that within the limits of this policy instrument, proportional credit be awarded for shorter periods of guaranteed sequestration. Release of the carbon back to the atmosphere at any point in time should result in the reversal of all credit gained.

The role of carbon pooling

Carbon stocks sequestered in vegetation and soils are vulnerable to fire, changed management practices, and the effects of climate change. This vulnerability can be best managed through pooling individual sequestration projects, combined with the retention of an appropriate buffer of credit to meet obligations to cover any decrease in the size of the managed pool.

Also, carbon pooling allows for the evening of carbon flows by, for example, covering emissions from periodic harvest with sequestration in other projects. Ideally a carbon pool where harvest is a feature of management would eventually have, like a “normal forest”, an even distribution of age classes up to the age of harvest.

It is proposed that carbon sequestration should be counted only up to the point at which the average carbon density over multiple rotations of a harvested forest is reached. Carbon pooling where a normal forest structure is approximated allows for this level of credit to be claimed at the pool level, notwithstanding that individual forest stands may at a point in time be below their sustainable level.

This sustainable increase in landscape carbon density is the maximum which could be safely claimed without the contingent liability of permit purchase to cover shortfalls at the pool level.

The future price of emission permits, and therefore of carbon credits, is unknown, but likely to rise steeply in response to tighter emission reduction targets in future commitment periods (in pursuit of the objective of stabilising greenhouse gas concentrations). Self-insurance at the pool level through retention of a buffer of credits is seen as a more practical risk management strategy than conventional insurance, because of the timeframes and uncertainties involved. A 20% buffer below measured and verified storage in a saturated pool might be reasonable. The buffer could be built up over time such that the relative security of early years' sequestration is recognised.

Following from the above, pooling of sequestration projects, measurement and verification at the sub-pool level, and pool managers assuming responsibility for maintaining the pools integrity, are seen as practical ways of ensuring the environmental and economic integrity of credits against emissions.

Legal arrangements

The risk of accidental or deliberate release of carbon stocks stored in forests is inherently greater than that of carbon stored in geological deposits stored in the Earth's crust. This is particularly the case bearing in mind the serious impacts of climate change likely to occur on both biodiverse forests and timber production monocultures.

Any legal system to enable trade of credits against emissions must effectively manage this risk to provide any real equivalence between biotic offsets (carbon credits) and emissions. It must also be based on complete and balanced accounting of sources and sinks.

Legislation and contracts should therefore be based on the guaranteed duration of storage rather than the fact of absorption.

It is therefore suggested that legislative and contractual arrangements must give appropriate cognisance to all relevant carbon pools and that:

- Legislation should enable commitment to retention of sequestered carbon in the form of covenants or easements on titles where the obligation is (essentially) to maintain an average change in landscape carbon density over a given timeframe, through the carrying out of an agreed management plan.
- Where there is only short term commitment, credit allowed should be reduced proportionally for periods shorter than 100 years
- Carbon pooling is a necessity for risk management and normalising carbon flows, and that therefore,
- Carbon pool managers must have enforceable rights to ensure that an agreed management plan is carried out over the timeframe of a sequestration project.

A proposed convention regarding carbon pool managers responsibilities is that their responsibility to ensure ongoing carbon storage would only last for the 100 years proposed as the period over which a credit is earned, with subsequent responsibility for any re-emission reverting to the owner/s of the forest and land at the time.

This would enable contractual arrangements between land/forest owners and carbon pool managers to have a finite period, rather than perpetuity, which is a fairly vague legal concept.

Effects of the proposed system on accounting for harvested wood products

The 1998 Dakar Workshop on "Evaluating Approaches for Estimating Net Emissions of Carbon Dioxide from Forest Harvesting and Wood Products", (IPCC, 1999) sponsored by the IEA, IPCC

and OECD defined three different logically consistent and scientifically defensible approaches. These are the “Stock Change”, “Production”, and “Atmospheric Flow” approaches.

These are examined in turn in relation to the accounting approach outlined above, assuming that their effects at a national level would be mirrored in their effects on subnational entities. That is, producing and consuming country obligations and rights would be the same as for the project or pool level producer and consumer.

Stock Change approach

Under this approach changes in carbon stocks are accounted for by the producer, while changes in the wood products pool are accounted for by the consumer. Adoption of a time based accounting approach as outlined above would mean giving credit for carbon storage to both the producer and consumer. As with the approach as proposed at the Dakar workshop, reduction of carbon stocks in the hands of the producer (or representing pool) through sale would result in emissions being recorded. However, to the extent that ongoing sequestration in wood products could be underwritten by guarantees, credit could then be claimed by the consumer, again in proportion to the 100-year time horizon.

The approach generally has the benefit of giving credits and debits to the parties who actually own and control the relevant pools.

Production approach

Under the production approach changes to both the forest and wood products pools are accounted for by the producer. Adoption of the approach outlined in the paper would give an additional benefit to the producer in proportion to the actual or deemed additional storage time of carbon in the wood products. However, it would provide this benefit for storage in a carbon pool that is under the control of another party.

Atmospheric Flow approach

Under this approach credit is given for sequestration and debit for re-emission when, where, and in whose hands they actually occur. The approach has the probably undesirable effect of driving production of wood while providing a disincentive for its use. As this approach focuses on the moments of sequestration and emission, it is generally incompatible with an approach which gives credit in proportion to the duration of carbon storage.

Clean Development Mechanisms (CDM) issues

Projects under the Clean Development Mechanism are unique in earning credit in nations without quantified emission limitation and reduction objectives. This raises the possibility of nations benefiting from carbon credit income from “sinks projects” while rates of deforestation nationwide accelerate.

In order to remove the possibility of such undue credit being earned, it is proposed that countries seeking to host project-based activity under the CDM should be required to negotiate a national LULUCF baseline, and that the sum of project credits within the country would be limited to the quantum due to improvements on the baseline case. The proposed rule could also be seen to represent movement towards non-Annex B nations taking on national commitments under the Protocol, a precondition of the United States’ participation.

It is hoped that a combination of the guaranteed duration of storage approach to accounting for sequestration and emissions in the LULUCF sector and this proposed rule for CDM implementation can overcome some substantial objections to inclusion of sinks projects under the CDM at all.

Conclusion

It is recommended that sequestration credits for domestic and international trade should:

- be underpinned by comprehensive and long term management plans attached to the titles of the land and vegetation through covenants binding all subsequent owners for the full term,
- be the subject of clear contractual arrangements between all parties to a project, defining roles and responsibilities, and share of project inputs and outputs,
- be issued preferentially to carbon pool managers where the carbon pool under management is sufficiently large and diversified to allow for risk management and appropriate internal hedging.
- receive credit in proportion to the guaranteed duration of storage (up to 100 years) of the sequestered carbon, discounted against 100 years,
- claim only up to the average biomass and soil carbon pool increase which can be sustained over extended timeframes e.g. for 100 years,
- claim only net project benefits in any year, with all associated emissions deducted.
- be risk managed through pooling and maintenance of a hedge of credits, and/or through insurance, to cover loss by fire, pests, climate change etc.

This approach will minimise the risks in credit ownership and trade, give confidence in their durability, and enable trading of future sequestration. It also requires compliance with sustainability principles as an auditable function of carbon pools.

In respect of LULUCF projects under the CDM, the following rule is proposed:

Credit for CDM projects in the LULUCF sector in a country shall be limited to the credit due at a national level in improving on an agreed national LULUCF emissions baseline.

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Appendix

Workshop program

List of participants

IEA Bioenergy

Task 25/38 - Greenhouse Gas Balances of Biomass and Bioenergy Systems

Information for Participants
for the international workshop

Carbon accounting and emissions trading related to bioenergy, wood products and carbon sequestration.

26-30 March 2001

Canberra, Australia

Jointly organised by



State Forests New South Wales
PO Box 100, Beecroft
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AUSTRIA

Task 38 Website: www.joanneum.ac.at/iea-bioenergy-task38

Background

IEA Bioenergy is an international, collaborative research programme on Bioenergy (www.ieabioenergy.com). The primary goal of IEA Bioenergy Task 38 (“Greenhouse Gas Balances of Biomass and Bioenergy Systems”) is to investigate all processes involved in the use of bioenergy and land-use systems, on a full fuel-cycle basis, with the aim of assessing overall greenhouse gas balances. Participating countries are Austria, Australia, Canada, Croatia, Denmark, Finland, The Netherlands, New Zealand, Sweden, United Kingdom, and the USA. This Task follows on from the previous IEA Bioenergy Task 25.

This workshop in Canberra, Australian Capital Territory, Australia, is the final Task 25 workshop and the first workshop of Task 38. It is part of a series of such events within the Task, taking place on a regular basis. For more detailed information on the Task, its output, and on previous workshops, see www.joanneum.ac.at/iea-bioenergy-task38.

Workshop Venue

The Workshop is being held at the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Theatrette, Building 1

CSIRO Forestry and Forest Products (<http://www.ffp.csiro.au/>)

Banks Street, Yarralumla, ACT, Australia.

Travel from the hotel to the workshop venue will be either walking or group taxis.

Excursion: Australian Field Tour

The two-day field trip (26-27th March) in the NSW Southern Highlands will depart from Canberra 7:30 am and travel firstly to the Tumut district. We will visit a Eucalypt/effluent irrigation project and a new pulp mill, and overnight in Tumut. The second day we will travel back to Canberra via Cooma, looking at pine plantation operations, the Snowy Mountains Hydro-electric Scheme and Kosciuszko National Park. Accommodation on Monday night will be booked for you and paid for as part of the registration fee. The registration fee also includes lunch and dinner on Monday 26th March, and breakfast, lunch and dinner on Tuesday 27th March.

Extra information for the field tour:

On average, Tumut’s maximum daily temperature in March is 27°C, getting down to 10°C at night. As we move up into the snowy region on the Tuesday it becomes a bit cooler so make sure you bring something warm. By way of contrast, Kiandra’s mean daily maximum temperature in March is 18°C. So.....be prepared for a wide range of weather conditions – it may be pretty warm on the lower slopes but conditions can change rapidly especially as we go up into the snowy region. As we’ll be out in the open for a lot of the tour, make sure you wear sturdy shoes and comfortable clothing. A hat, sunglasses, plenty of sunscreen, and a bottle of water are also recommended.

Task 25/38 Workshop Program

MONDAY, 26 MARCH AND TUESDAY, 27 MARCH, 2001

7³⁰ The two-day field trip (26-27th March) in the NSW Southern Highlands will depart from Canberra 7:30 am and travel firstly to the Tumut district. We will visit a Eucalypt/effluent irrigation project and a new pulp mill, and overnight in Tumut. The second day we will travel back to Canberra via Cooma, looking at pine plantation operations, the Snowy Mountains Hydro-electric Scheme and Kosciuszko National Park. Accommodation on Monday night will be booked for you and paid for as part of the registration fee. The registration fee also includes lunch and dinner on Monday 26th March, and breakfast, lunch and dinner on Tuesday 27th March. The bus returns to the Best Western Embassy Motel on Tuesday evening.

WEDNESDAY, 28 MARCH 2001

8³⁰ **Welcome and Introduction**

Bernhard Schlamadinger – Joanneum Research, Graz, Austria, on behalf of Task 25/38
Annette Cowie – State Forests New South Wales.

Session 1: Carbon accounting of forestry and land use

Chaired by: Justin Ford-Robertson, Forest Research, New Zealand

8⁵⁵ **Introduction of the Australian National Carbon Accounting System (NCAS)**
Gary Richards, Australian Greenhouse Office, Australia

9⁰⁰ **Development of a “toolbox” for carbon accounting in forests?**
John Raison, CSIRO, Australia

9³⁰ **The Application of risk and uncertainty analyses in projects of forest carbon sequestration**
Chris Brack, Australian National University, Australia.

10⁰⁰ **The development of Full CAM: an integrated carbon accounting model for forests and agricultural systems.**
Gary Richards, Australian Greenhouse Office, Australia.

10³⁰ Coffee Break

11⁰⁰ **NCAS: Modelling Carbon sequestration following afforestation or reforestation.**
Keryn Paul, CSIRO Forestry and Forest Products, Australia .

11³⁰ **Discussion**

12⁰⁰ Lunch

Session 2: Carbon accounting of wood products and biofuels

Chaired by: Leif Gustavsson, Lund University, Sweden

13³⁰ **The development of a national wood products model**
C. Borough, Jakko Poyry Pty Ltd, Australia.

14⁰⁰ **Overview of the New Zealand Harvested Wood Products Meeting**
Justin Ford-Robertson, Forest Research, New Zealand

14³⁰ **Fossil carbon emissions associated with carbon flows of wood products**
Kim Pingoud, VTT Energy, Finland

15⁰⁰ Coffee Break

16⁰⁰ **How sinks in wood products affect the cost of the Kyoto Protocol and world trade of wood products**
Johanna Pohjola, Finnish Forest Research Institute, Finland

16³⁰ *Effectiveness of carbon accounting methodologies for LULUCF and harvested wood products in supporting climate-conscious policy measures*
Rebecca Heaton, Cardiff University, Wales, United Kingdom

17³⁰ **Discussion**

18⁰⁰ End of Session

19⁰⁰ Workshop dinner

THURSDAY, 29 MARCH 2001

Session 3: Managed forests for wood products, carbon sequestration and/or bioenergy; their role in greenhouse gas policy (COP negotiations)

Chaired by: Annette Cowie, SFNSW, Australia

8³⁰ *Are managed forest and soils an effective strategy for climate change mitigation? – an example from Sweden*
Bo Hektor, Dept of Forest Management and Products (for Mats Olsson, Swedish University of Agricultural Sciences, Sweden)

9⁰⁰ *Carbon Pools in a Eucalyptus forest managed for production or conservation*
Daniel Payne, Australian National University, Australia

9³⁰ *Sustainable steel production – the role of forest biomass.*
J.Nunn, BHP Research, Australia

10⁰⁰ *Implications of possible Article 3.4/CDM outcomes for wood based industries and bioenergy*
Bernhard Schlamadinger, Joanneum Research, Austria

10³⁰ Coffee Break

11⁰⁰ *Implications of different COP decisions for bioenergy, wood market and land use patterns in Italy.*
Lorenzo Ciccarese, Italian Environment Protection Agency, Italy

11³⁰ *Inclusion of soil C sequestration in the global climate regime? COP6 and beyond.*
Lasse Ringus, UNEP Collaborating Centre on Energy and Environment, Denmark.

12⁰⁰ *The New Zealand Ecologic Foundation “sinks” proposal for COP6b*
Peter Read, Massey University, New Zealand

12³⁰ **Discussion**

13⁰⁰ Lunch

Session 4: Trading in carbon credits from bioenergy and sequestration projects

Chaired by: Steve Schuck, Bioenergy Australia, Australia

14¹⁵ *CRC for Greenhouse Gas Accounting*
John Raison, CSIRO, Australia

14³⁰ *Issues Related to Forestry Carbon Crediting*
Doug Bradley, Domtar Inc, Canada

15⁰⁰ *A system for measuring, reporting and trading forest carbon from an operational to an international scale*
Zoe Harkin, University of British Columbia, Canada

15 ³⁰	Coffee Break and poster presentations
16 ⁰⁰	<i>Subnational entity accounting for sinks and stores in the Kyoto flexibility mechanisms</i> <i>Mark Jackson, The Carbon Store, Australia</i>
16 ³⁰	<i>Opportunities for Joint Implementation (JI) projects in the bioenergy and land use change sectors in Croatia</i> <i>Bernhard Schlamadinger, Joanneum Research,</i>
16 ⁵⁰	Discussion
18 ⁰⁰	End of Workshop

Poster Presentations

- ***Atlas of Australian Bioenergy Resources***: Rod Keenan, Bureau of Rural Sciences, Australia
- ***A practical procedure of accounting for LUCF activities under the Kyoto Protocol***: Miko Kirschbaum, CSIRO, Australia
- ***Certification of Soil Carbon Inventory in US Farming Systems***: Neil Havermale, Red Hen Systems, USA.
- ***The impact of different carbon accounting methods on the economic performance of Pinus taeda plantations***: Isabel Loza-Balbuena, University of Canterbury, New Zealand.

FRIDAY, 30 MARCH 2001

IEA Bioenergy Task 38 Business Session (for representatives of participating countries only)

8³⁰ ***IEA Bioenergy Task 38 - Administrative Matters*** Chaired by: Bernhard Schlamadinger

1. Task participation; Work Programme 2001, next workshop(work on subprojects? - UK 2001, alternative; Italy 2002?)
 2. Task 38 website, general expansion; password protected site
 3. Funded Subprojects (max 4 per year)
 - Informal proposals/budgets/timing
 - *IUFRO book chapter on wood products and bioenergy*
 - *FAQ on bioenergy and carbon sequestration*
 - Case studies: GHG balances of actual bioenergy and C sequestration projects
 - Country/sector specific baselines – bioenergy and C sequestration projects (can this include “has bioenergy replaced other energy sources or increased total energy capacity”)
 - Database of key energy, emission, carbon data, models, unit converters, links to other databases
 - Other sub projects
 4. Other Task Activities
 - Country Reports
 - Project clearing house
 5. Industrial involvement
 6. Posters and transparencies – updated?
 7. New Task Folder
 8. Defining the role of National Team Leaders (NTLs)
 9. Soil C paper
 10. Miscellaneous items
 - Collaboration with other Tasks
 - Exchange of Scientists
 - Research grants for students
 - Other ideas from participating countries.
- 13³⁰ End of Session and Lunch
 14³⁰ Discussion in smaller groups as appropriate

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