The Development of a National Wood Products Model

CHRIS BOROUGH AND HAMISH CRAWFORD

Jaakko Pöyry Consulting
PO Box 3866 MANUKA ACT 2603, Australia
Phone +61 2 62952777, Fax +61 2 62952803
chris.borough@poyry.com.au
hamish.crawford@poyry.com.au

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

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 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

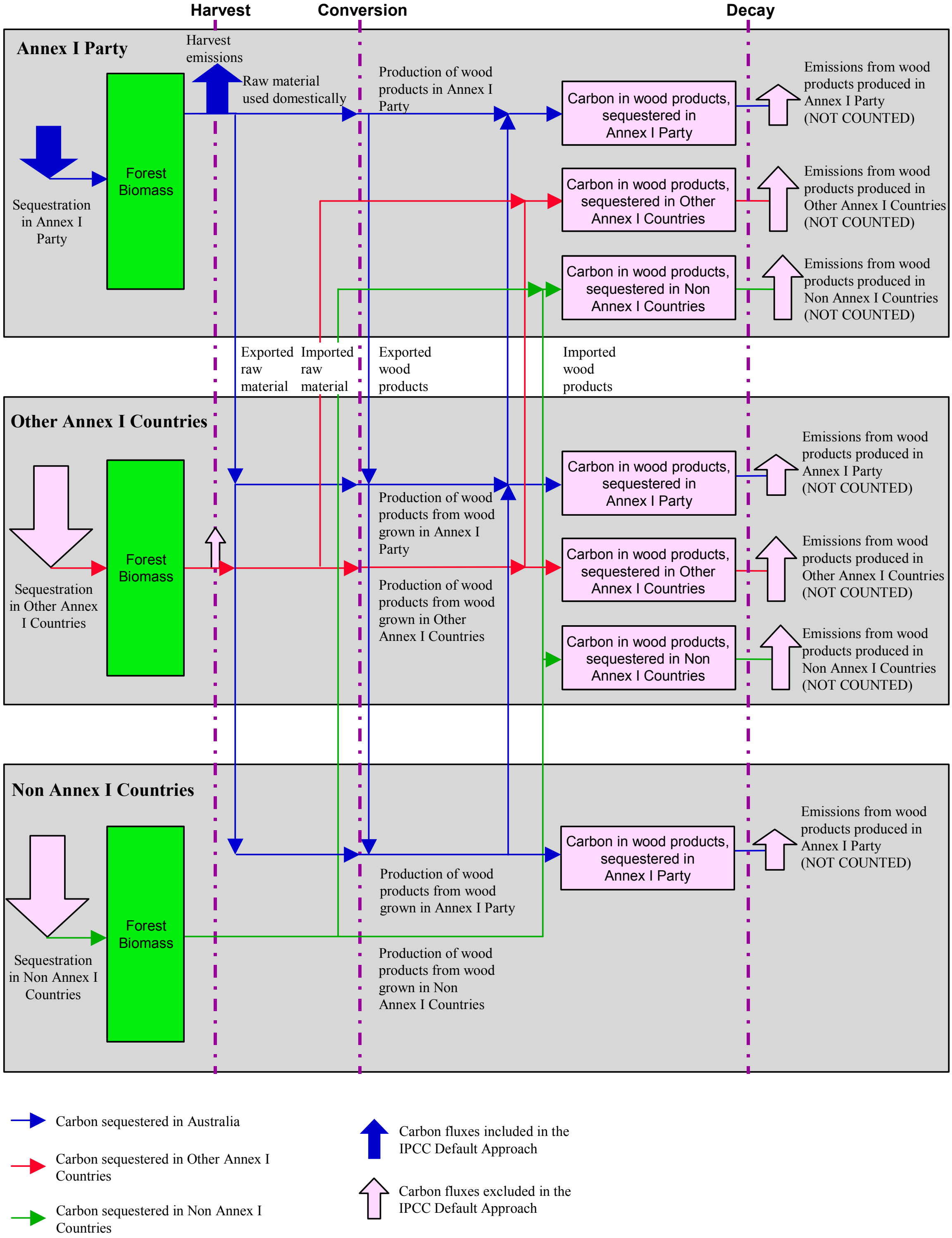


Figure 2: Flow of carbon through wood products pools under the Production Approach

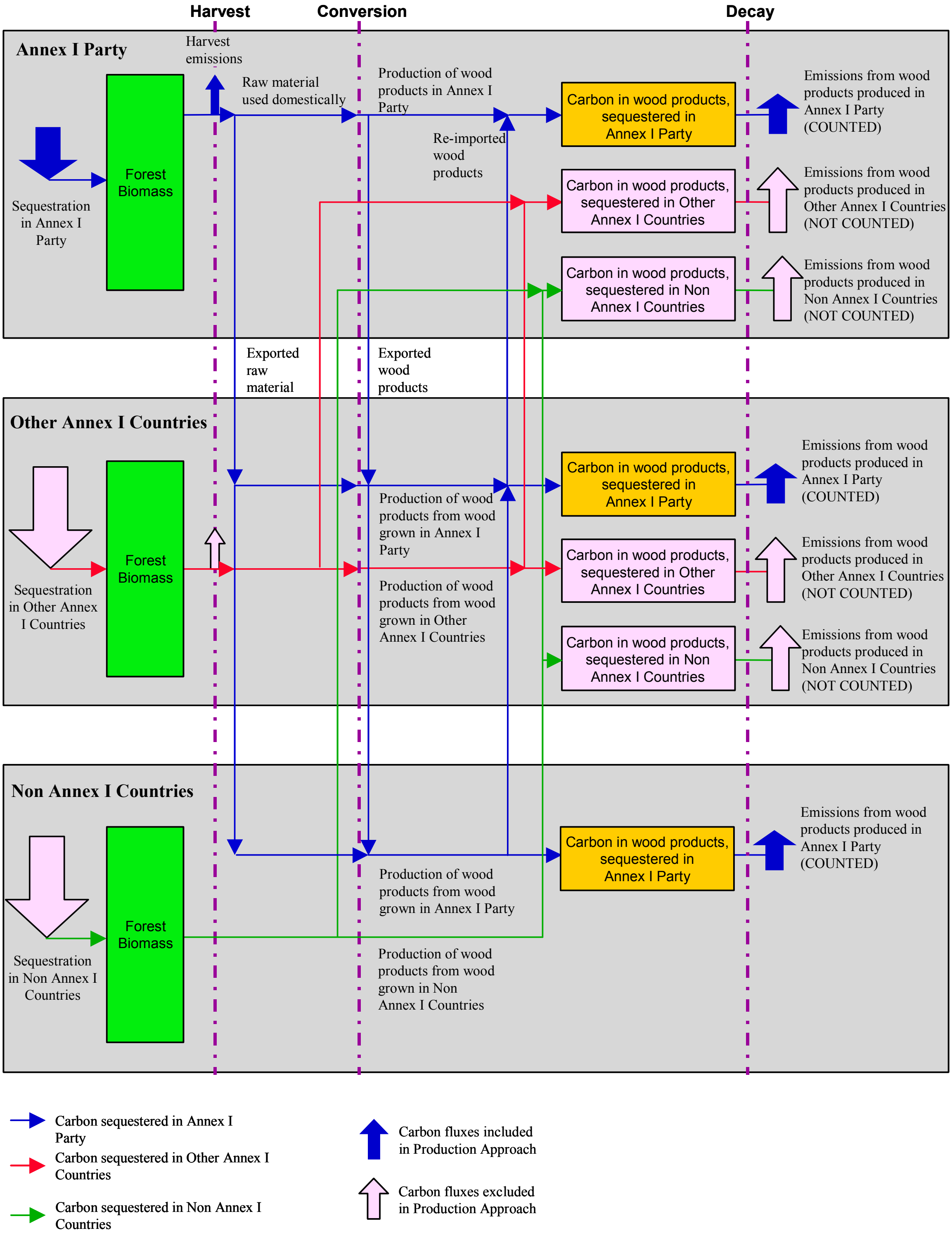
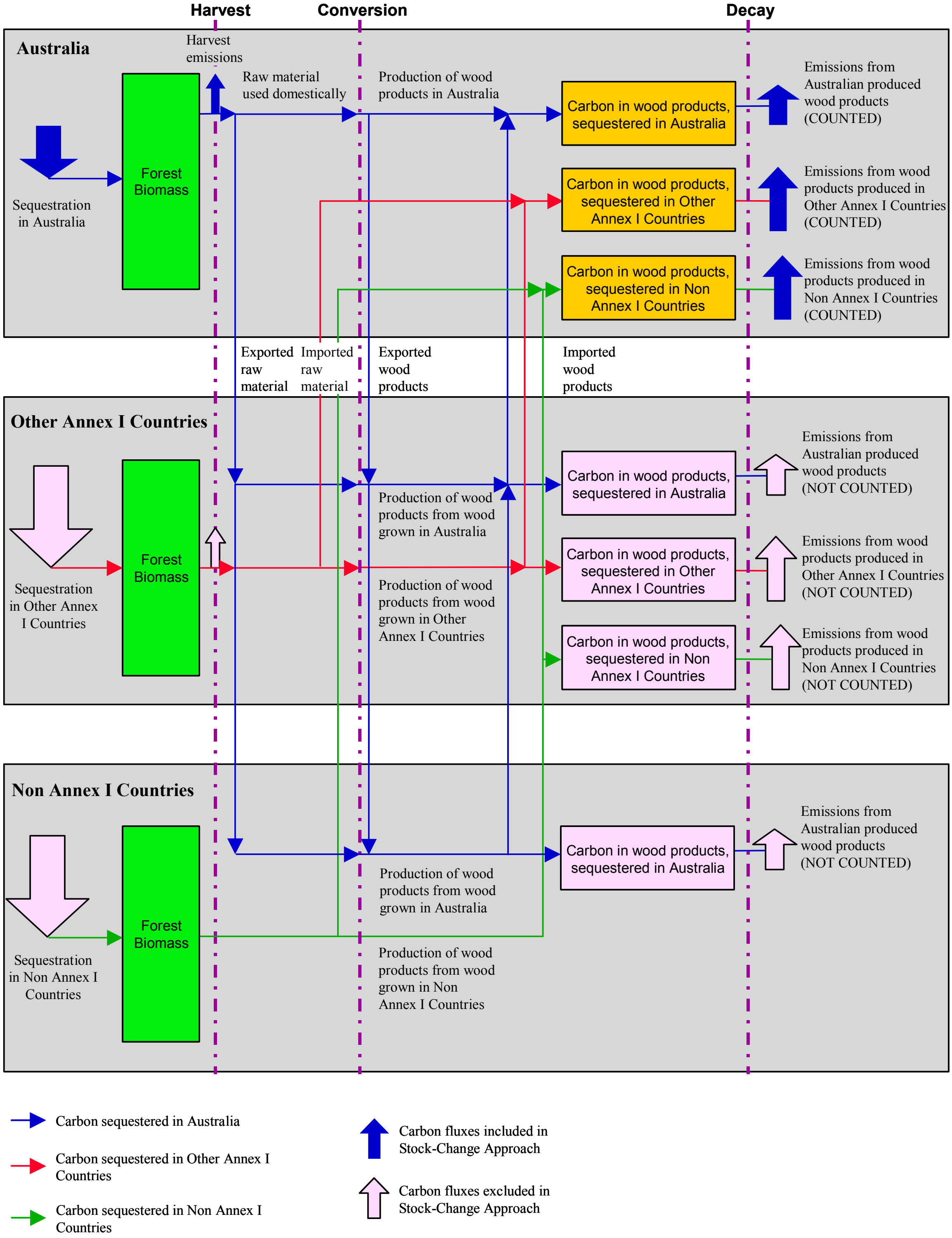


Figure 3: Flow of carbon through wood products pools under the Stock-Change Approach



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 m^3

	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 (M*t* carbon)	Stock-Change Approach (M*t* 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:

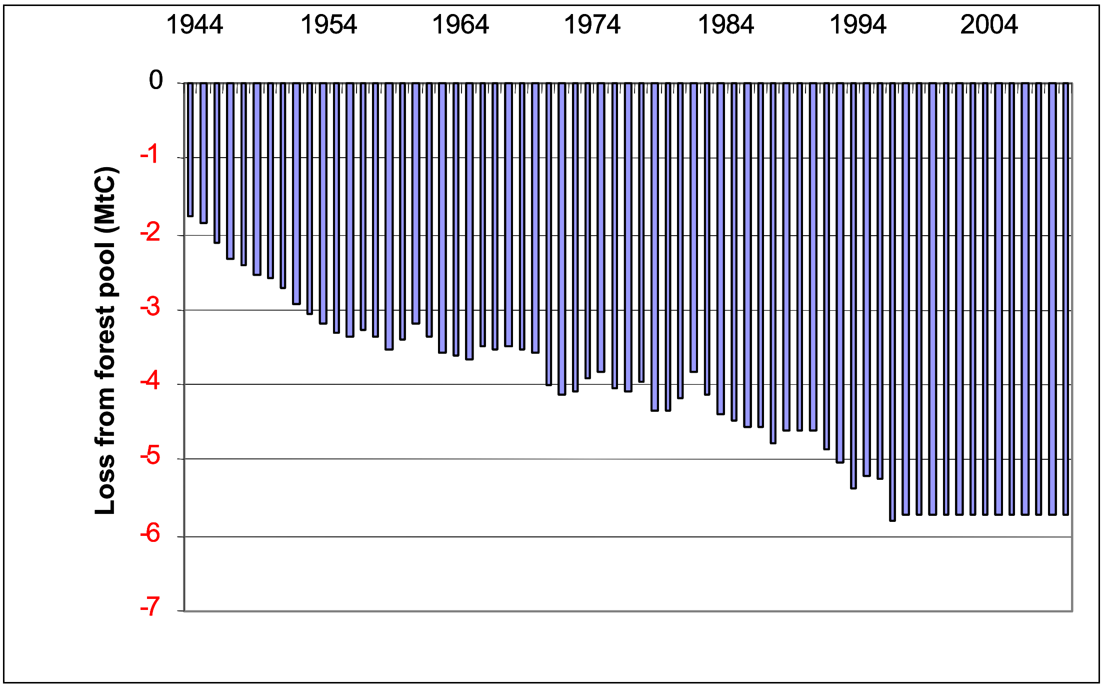
- An estimate of raw materials input, whether of sawlogs, woodchips ex-sawmill, or pulp logs.
- An estimate of the products of processing, e.g. "x"% sawdust, shavings or sander dust for on site energy generation or compost, "y"% woodchips for other manufacturing processes, "z"% of sawn timber products, 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

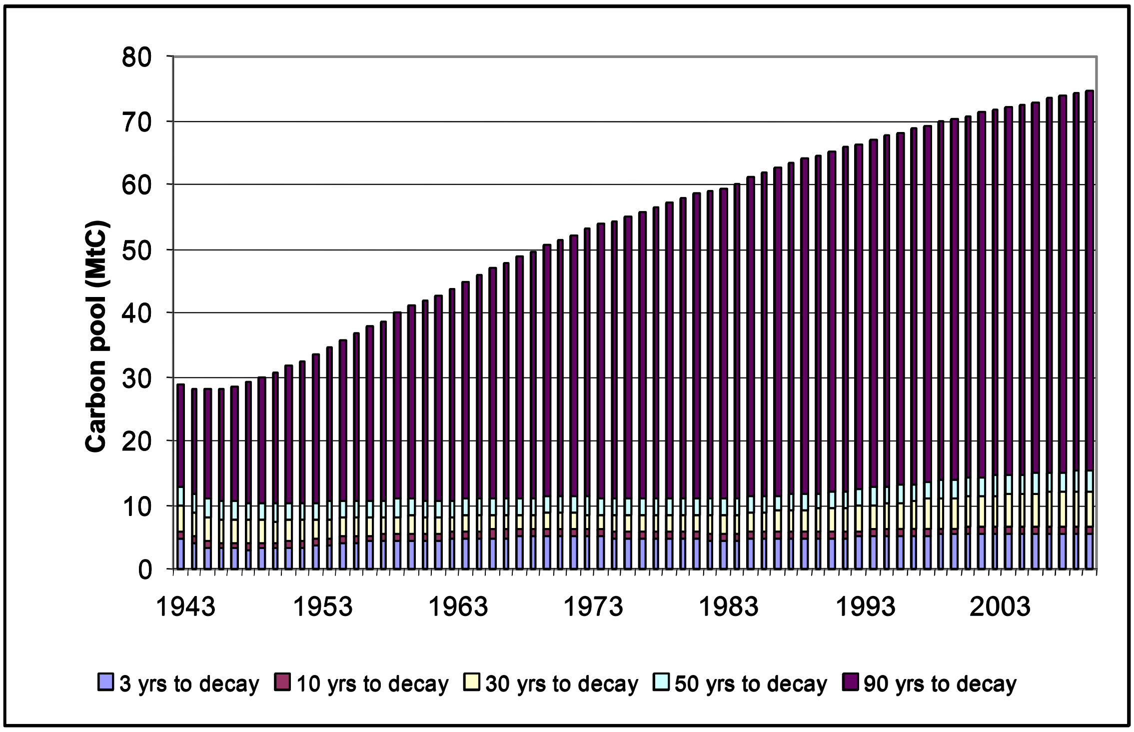
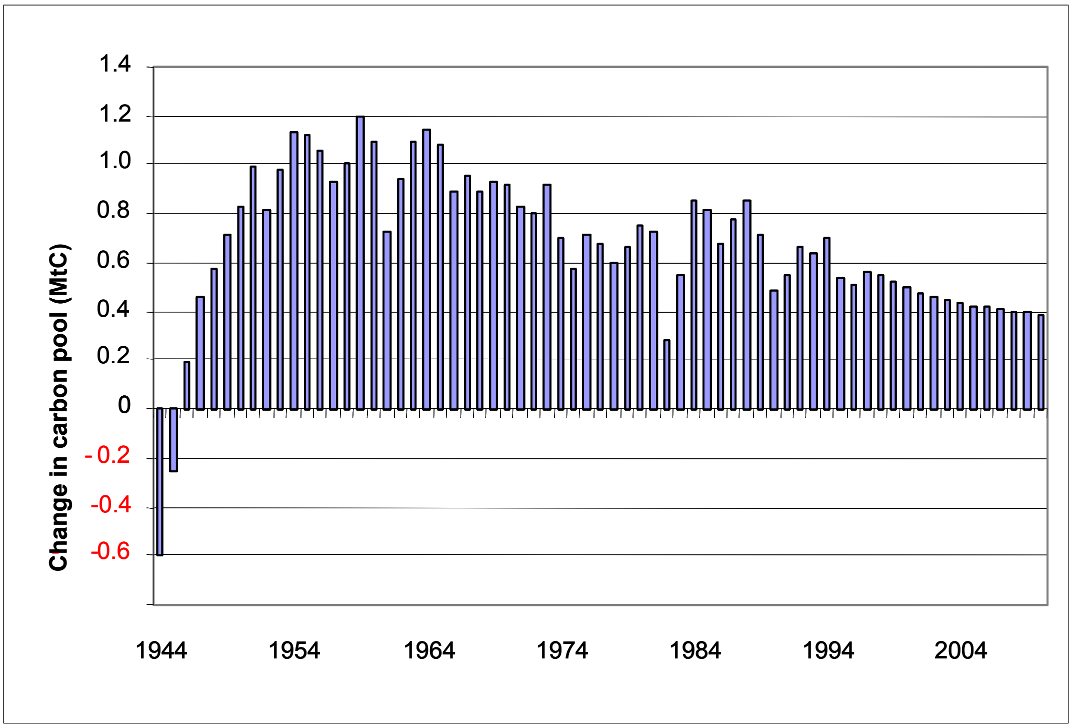


Figure 6 show the change in carbon stocks under the stock-change approach. It is important to recognise that the current version of the Carbon Model assumes production remains constant from 1998. Therefore, annual additions to the pool are also constant. Given that the amount of carbon lost annually 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

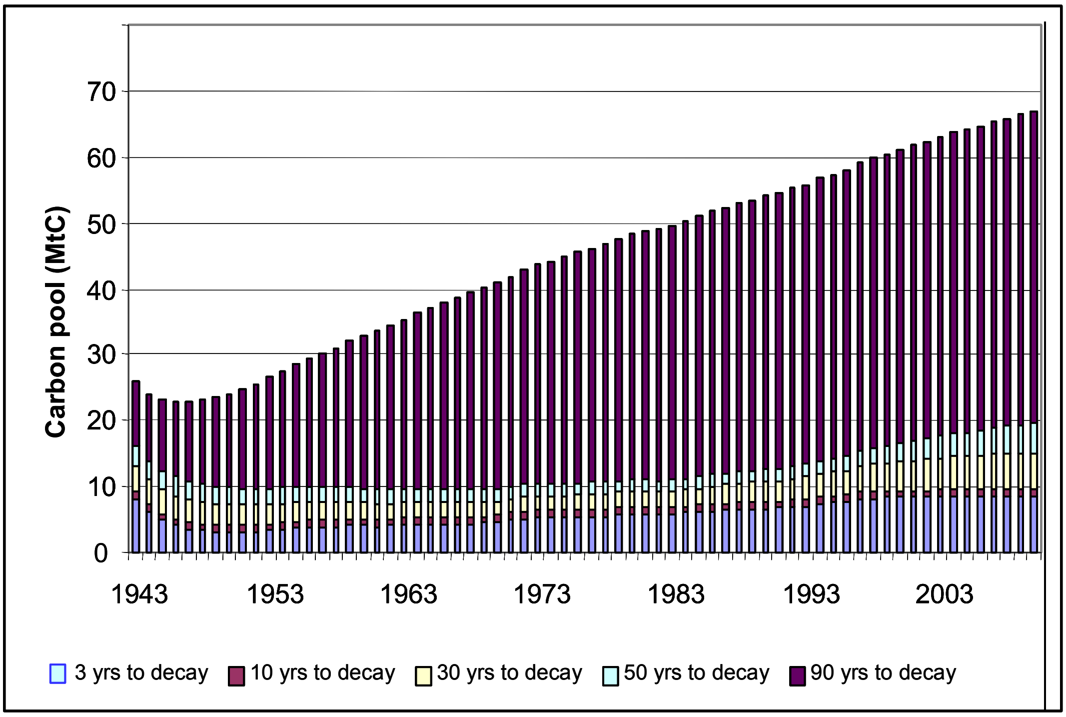
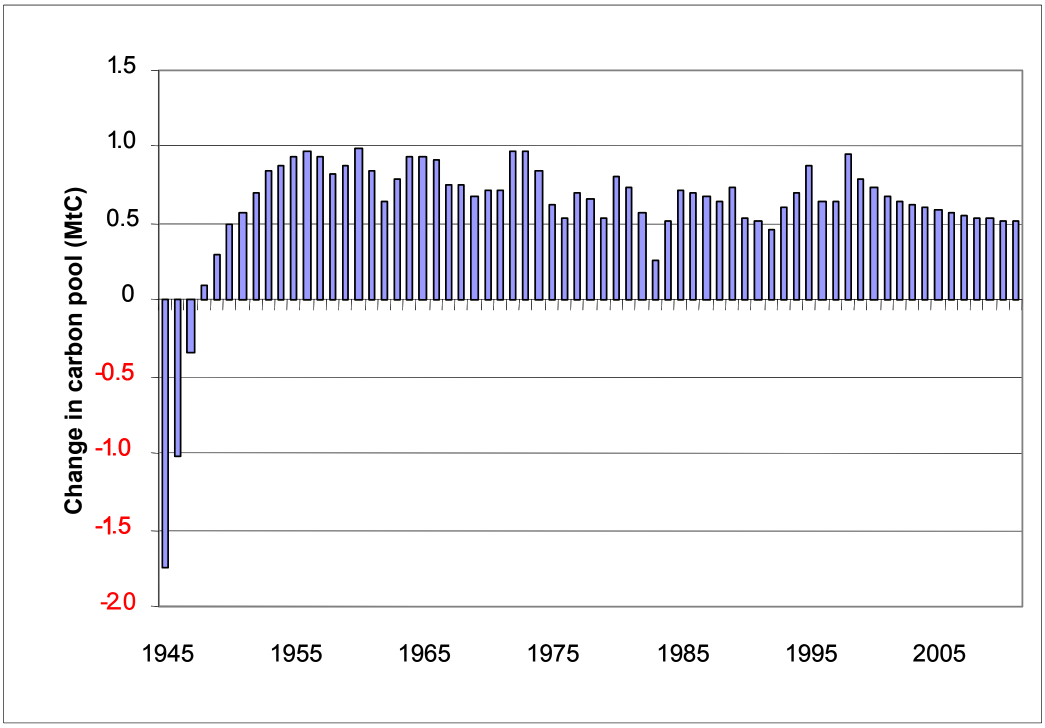


Figure 8 shows the change in carbon stocks under the production approach. The decline shown in the rate of increase in the carbon pool indicates that the amount of carbon lost through decay exceeds the increase in the carbon pool arising from production.

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

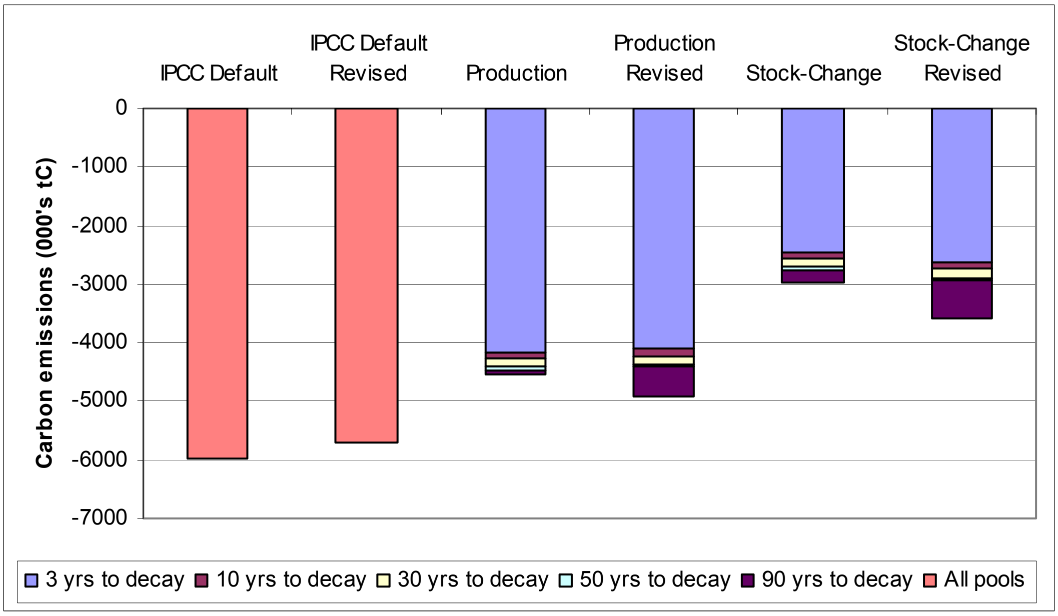


Table 3 summarises emissions.

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.

REFERENCES

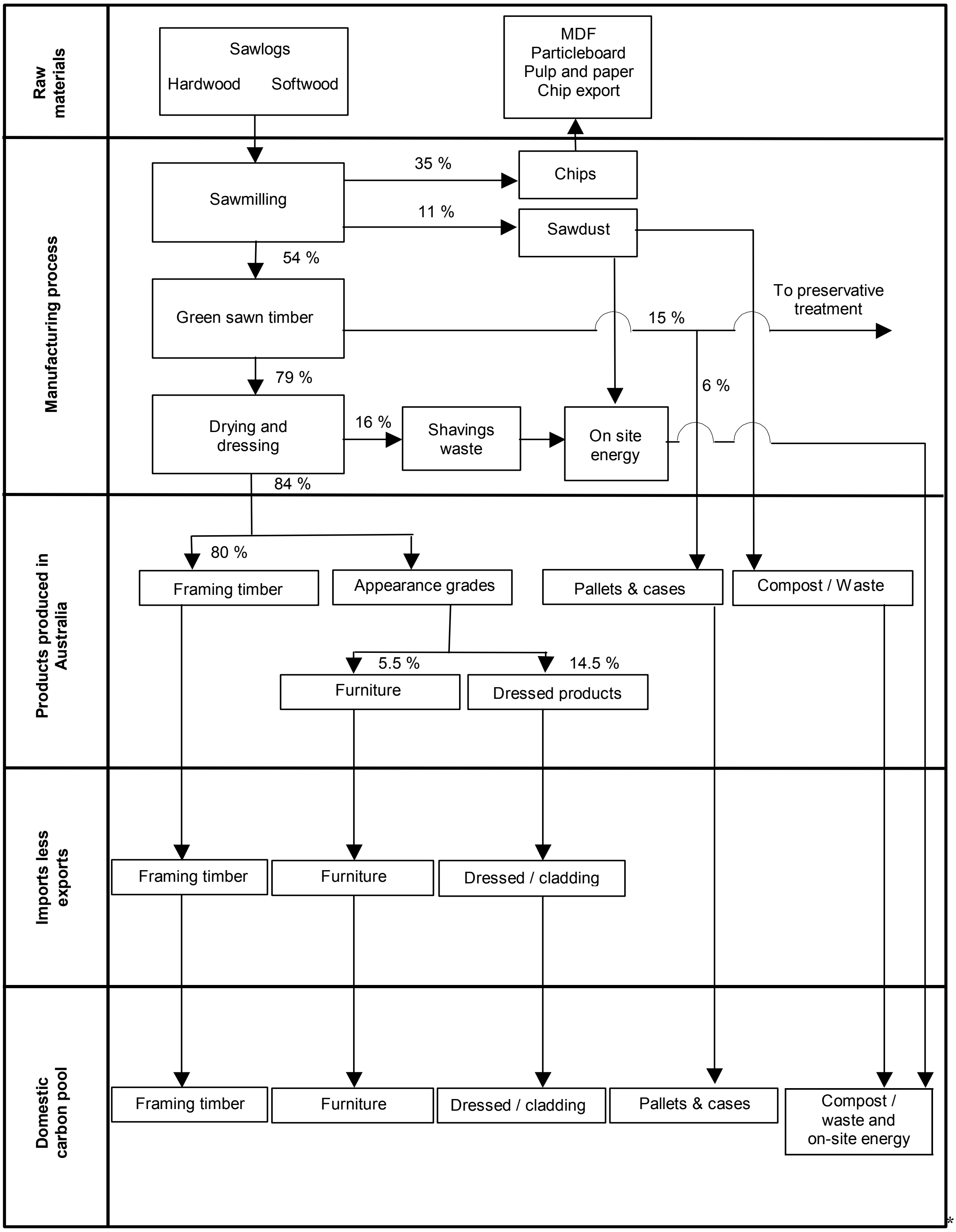
BROWN, S., LIM, B., SCHLAMADINGER, B. 1998. Evaluating approaches for estimating net emissions of carbon dioxide from forest harvesting and wood products. IPCC Meeting Report, Dakar, Senegal, 5-7 May 1998.

JAAKKO PÖYRY CONSULTING 1999. Usage and lifecycle of wood products. National Carbon Accounting System, Technical Report No. 8. Australian Greenhouse Office, Canberra.

JAAKKO PÖYRY CONSULTING 2000. Analysis of Wood Product Accounting Options for the National Carbon Accounting System, Technical Report No. 24. Australian Greenhouse Office, Canberra.

APPENDIX

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



* Percentages shown for softwood sawmilling, refer to model for hardwood and cypress pine

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

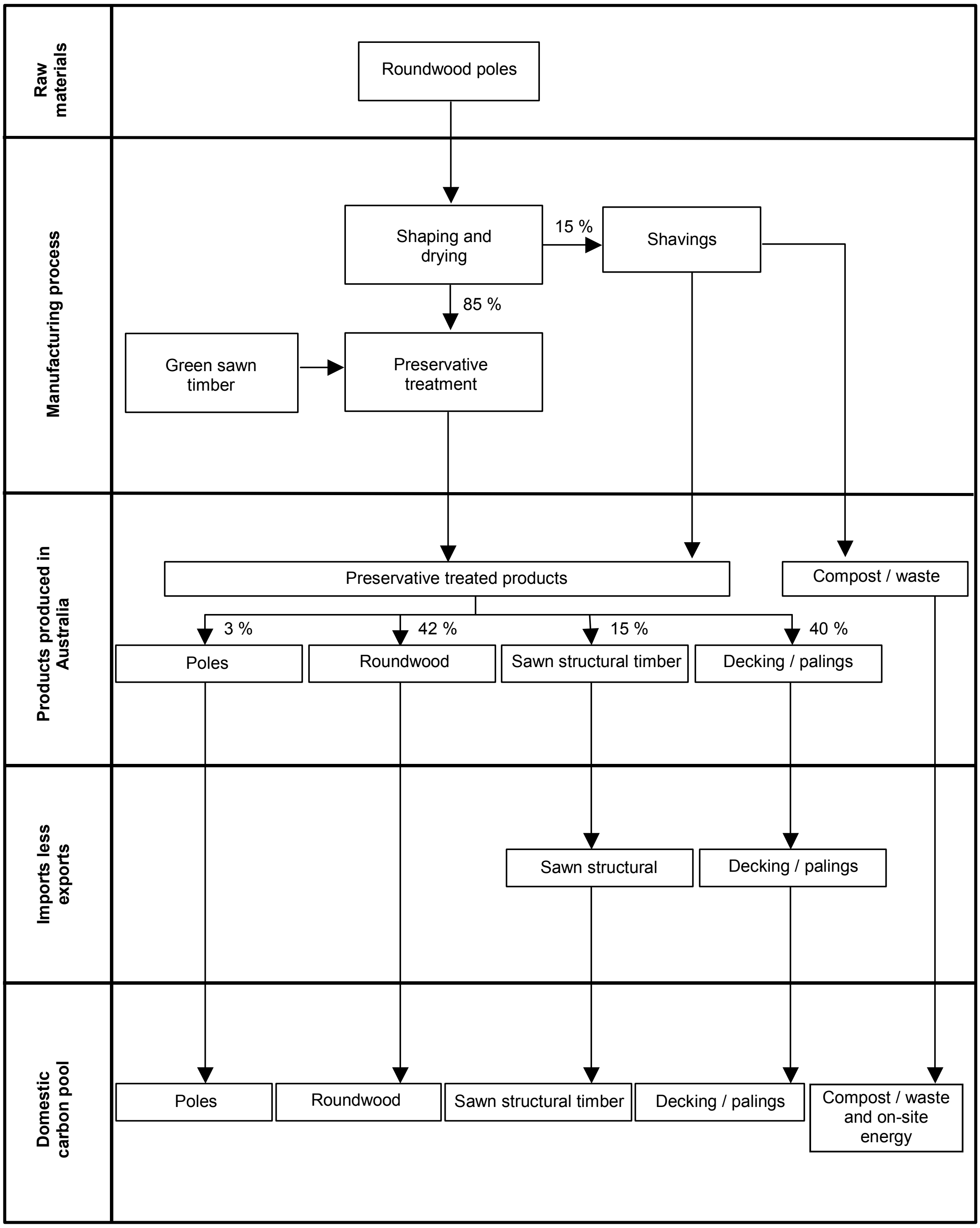


Figure 12: National Carbon Accounting Model for Wood Products - Wood Flows in Plywood Production

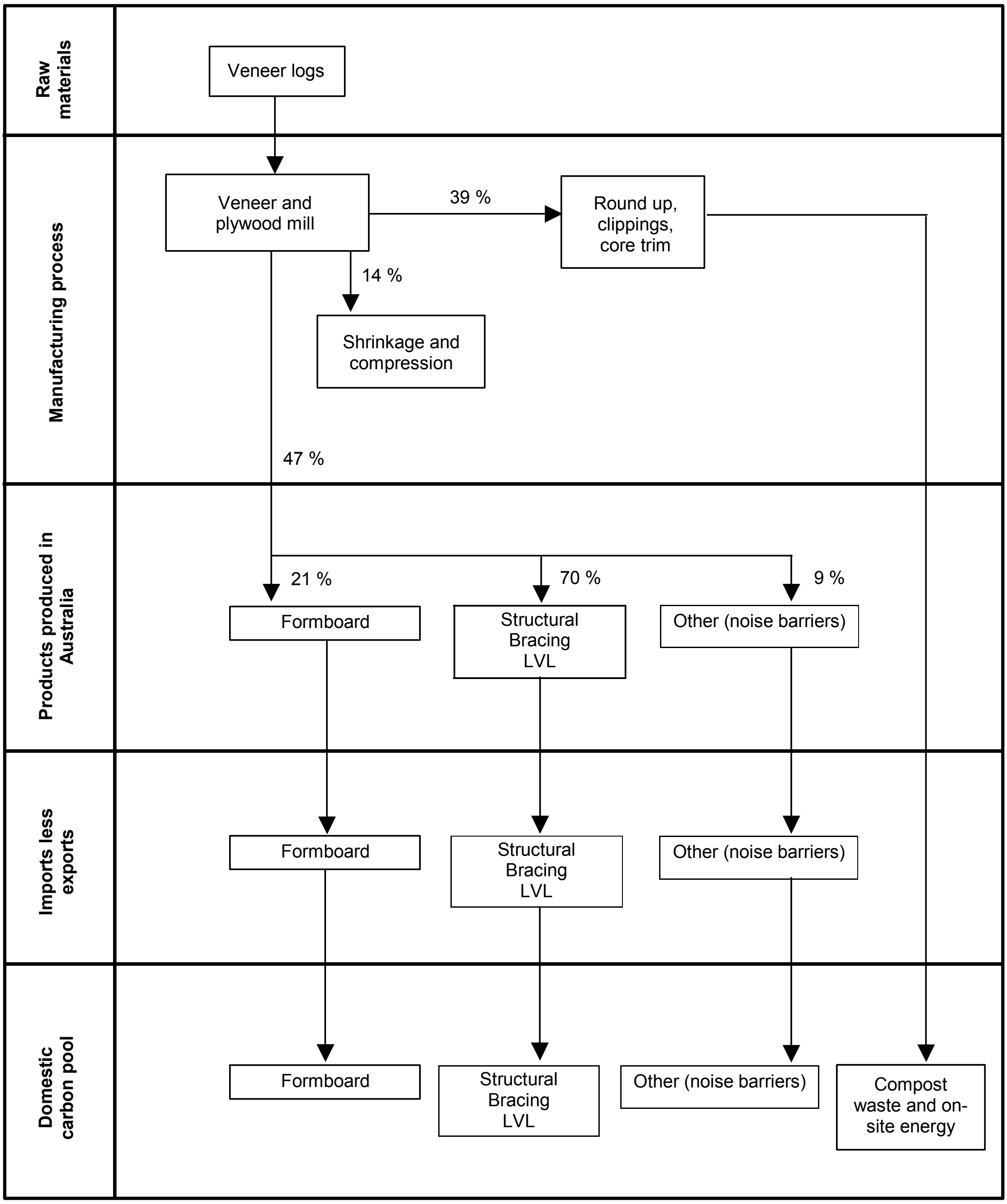
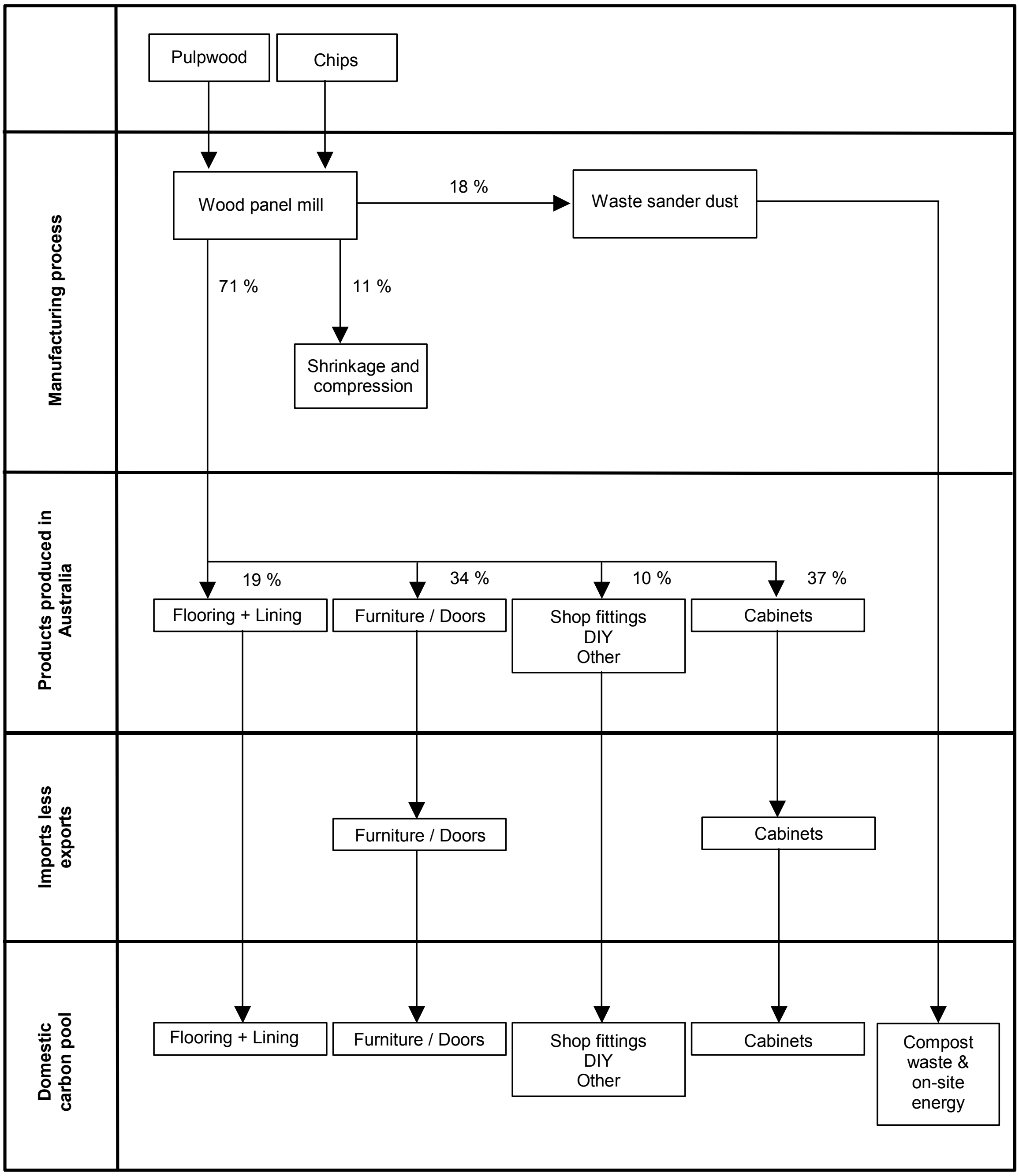


Figure 13: National Carbon Accounting Model for Wood Products - Wood flows in MDF and particleboard manufacture *



* 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.

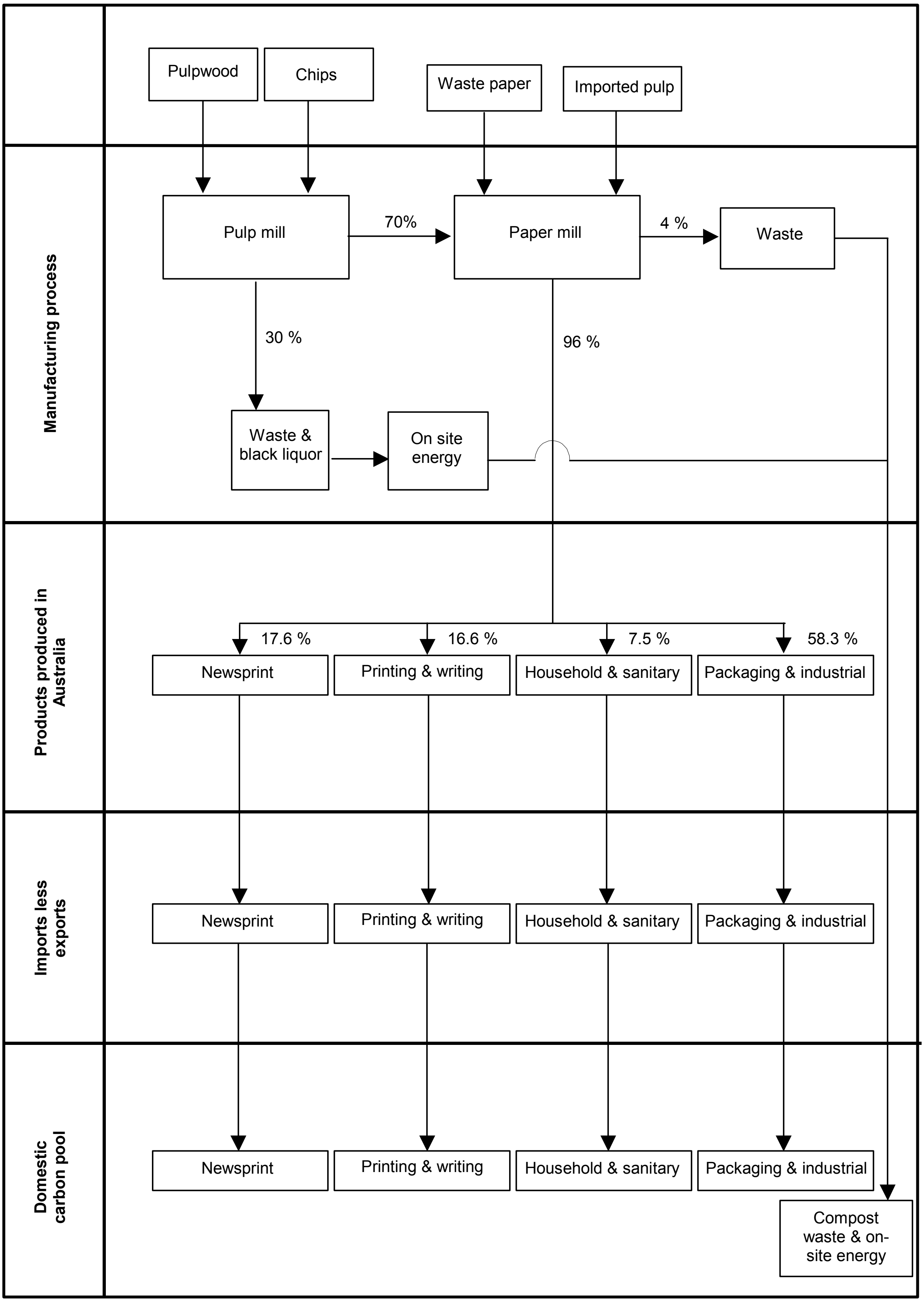
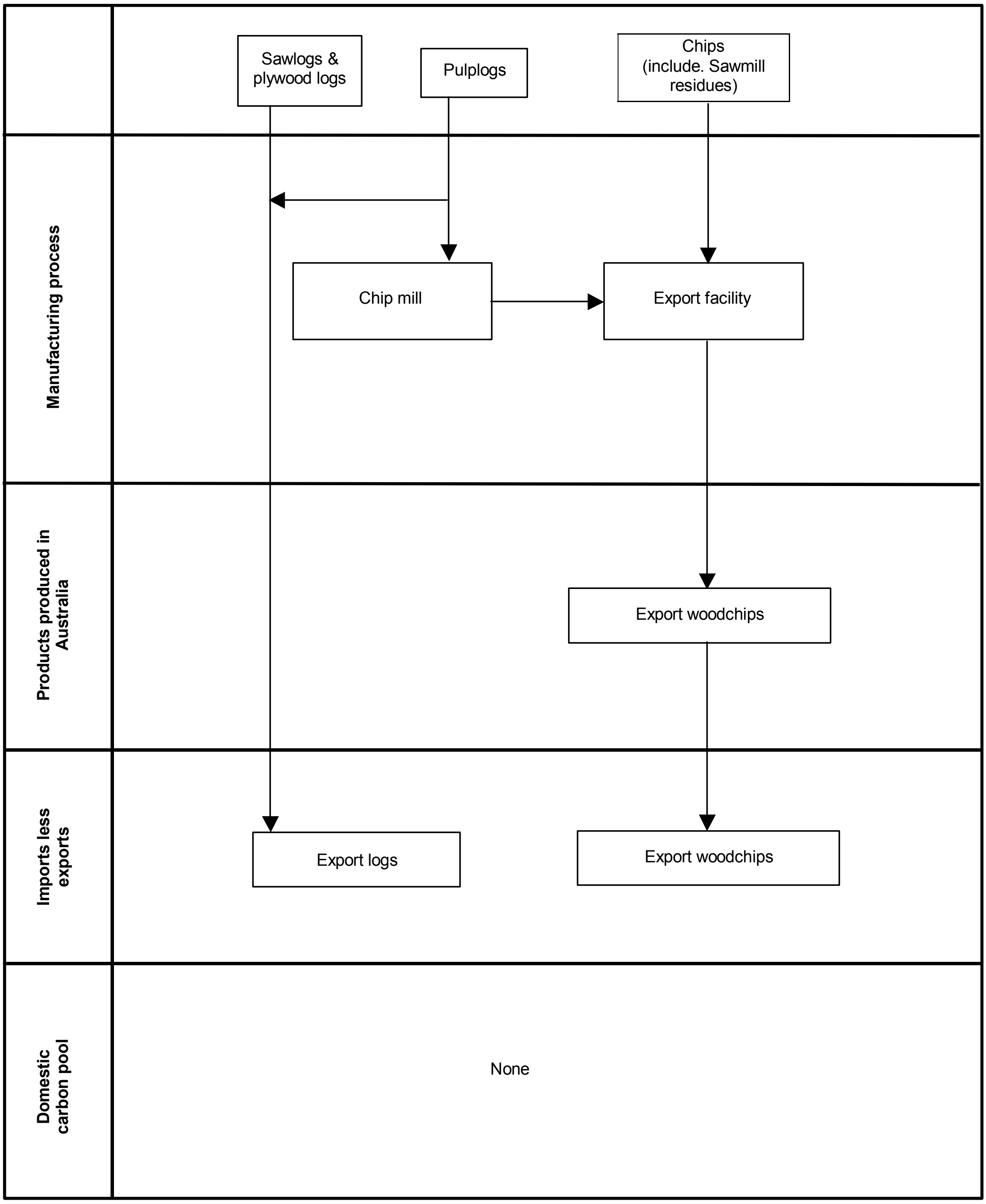


Figure 15: National Carbon Accounting Model for Wood Products - Wood flows in export woodchips and logs.



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

PAUL MCFARLANE, JUSTIN FORD-ROBERTSON

Forest Research,
Sala Street, Private Bag 3020, Rotorua, New Zealand
Phone +64 7 343 5899, Fax +64 7 343 5899, jfr@forestresearch.co.nz

PowerPoint presentation: www.joanneum.at/iea-bioenergy-task38/workshop/canberradata/ford-robinson.ppt

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.

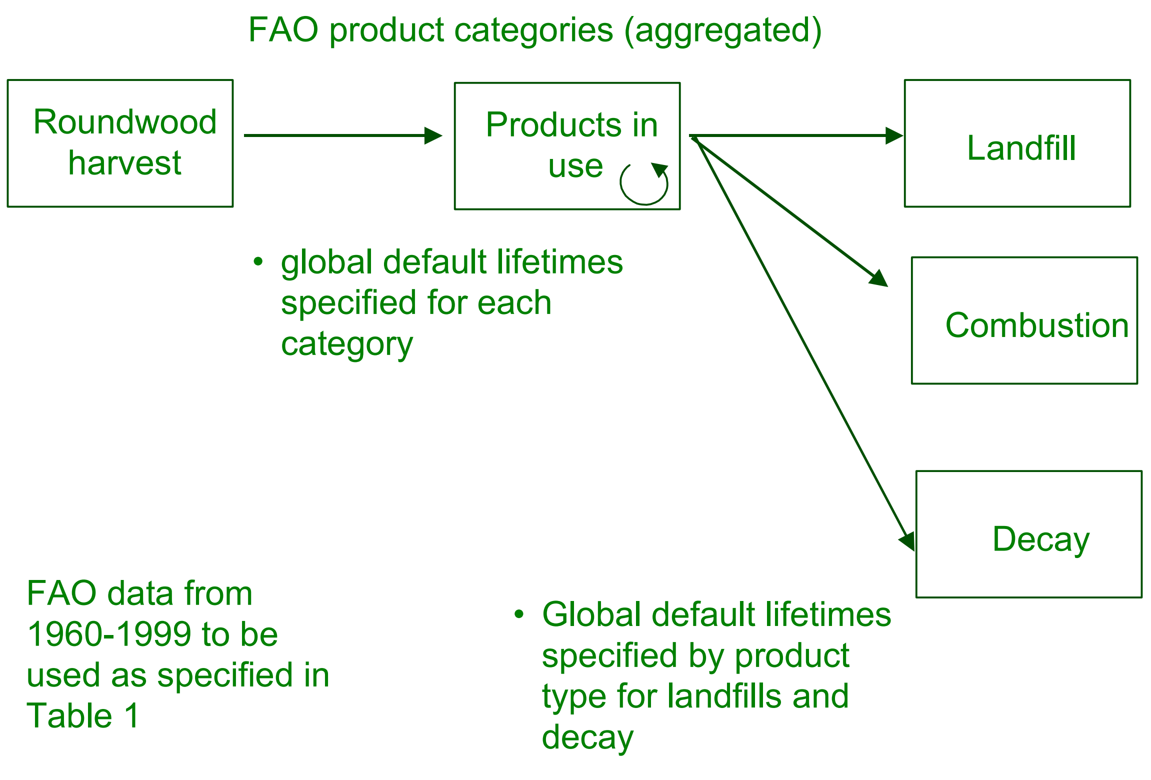
It was suggested it would be difficult to trace the origin of wood products, e.g., from different countries or forests. One solution proposed is to include the management of harvest wood products carbon stock as an additional activity under Article 3.4.

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

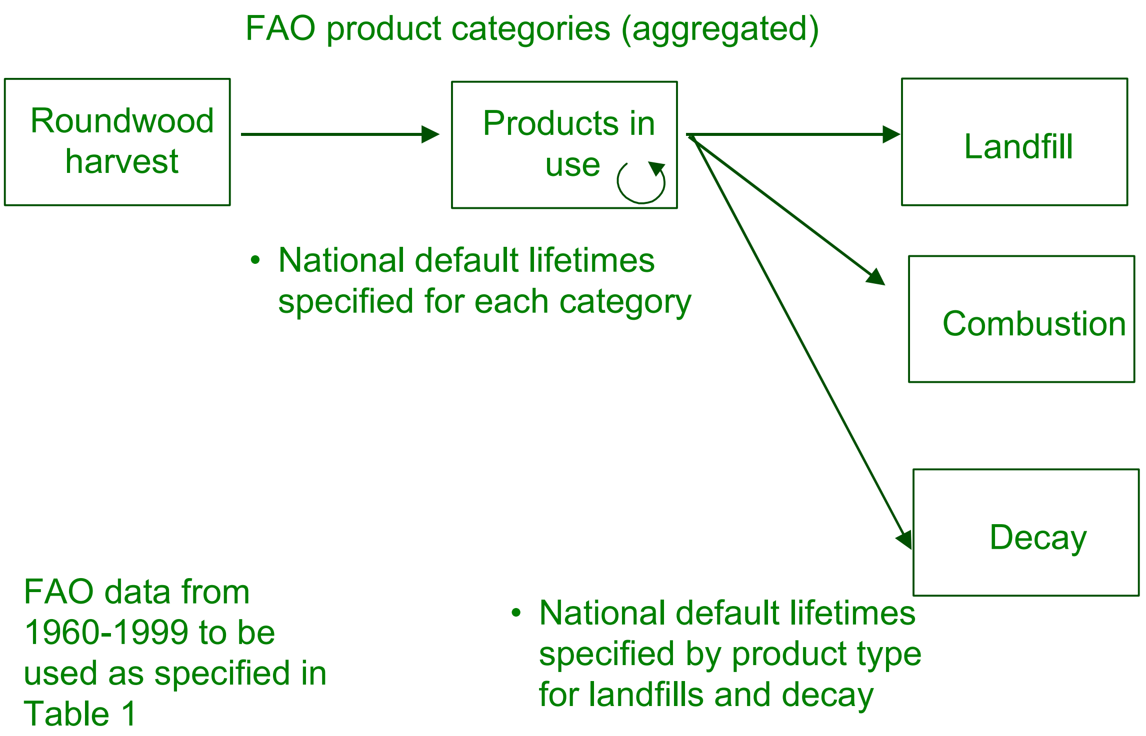
Countries may use their own data to improve inflows and outflows, e.g., roundwood removals, product manufacture, and landfill decay rates. Where suitable data are available, a direct inventory method, which is based on an empirical estimate of the product pool, is preferred. Such a method may result 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

KIM PINGOUD

VTT Energy
P.O. Box 160602044 VTT, Finland
Phone +358 9 4561, Fax +358 9 456 6538,kim.pingoud@vtt.fi

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

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.

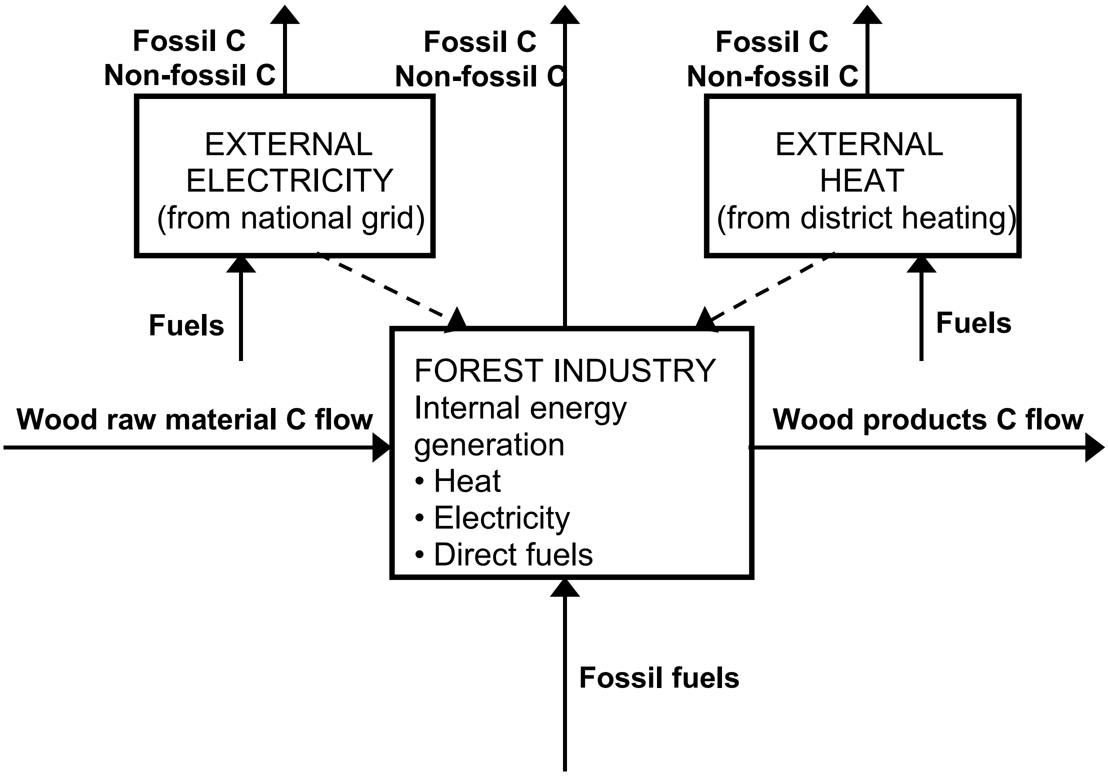
METHODS

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	Heat	Electricity	C in raw material /
	1000 m^3/a	MWh/m^3	MWh/m^3	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.

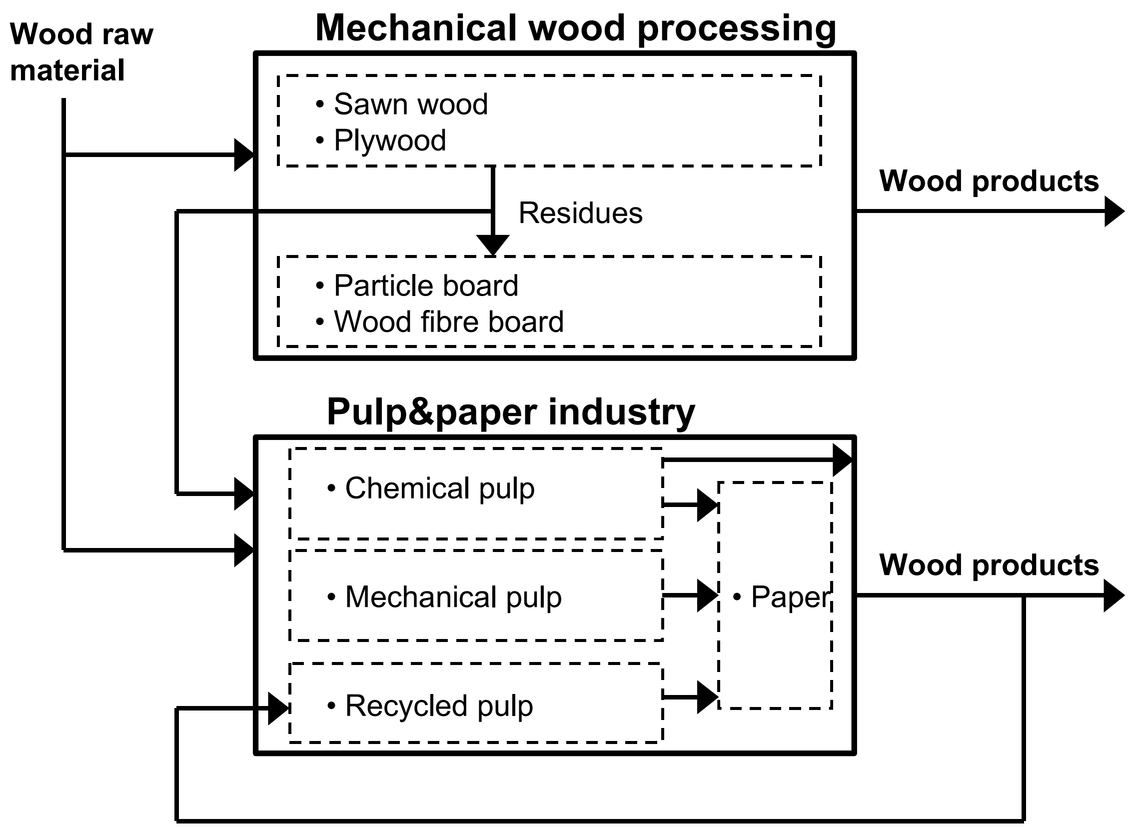


Table 2. Estimated average energy supply in the main production branches of Finnish mechanical wood processing in 1995 (A. Lehtilä, personal communication).

	Sawn wood	Plywood	Particle board	Wood fibre board
Internal energy generation				
Assumed efficiency of heat production = 80 %				
Fuels:				
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).

		MECHANICAL PULP					CHEMICAL PULP			RECYCLED PULP	
Main paper grades	t paper / t 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 1000 t/a	Direct fuels MWh/t	Heat MWh/t	Electricity 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 MWh/t	Black liquor MWh/t
MECHANICAL PULP	GWP, NB	0.45	0
	GWP, B	0.45	0
	TMP, NB	0.49	0
	TMP, B	0.49	0
CHEMICAL PULP	SCP	0.46	0.69
	HSUP, B	1.00	4.47
	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	
C emissions (kgC / MWh)	
Fossil C emissions	96
Non-fossil C emissions (wood)	7
Primary energy (MWh / MWh)	
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.

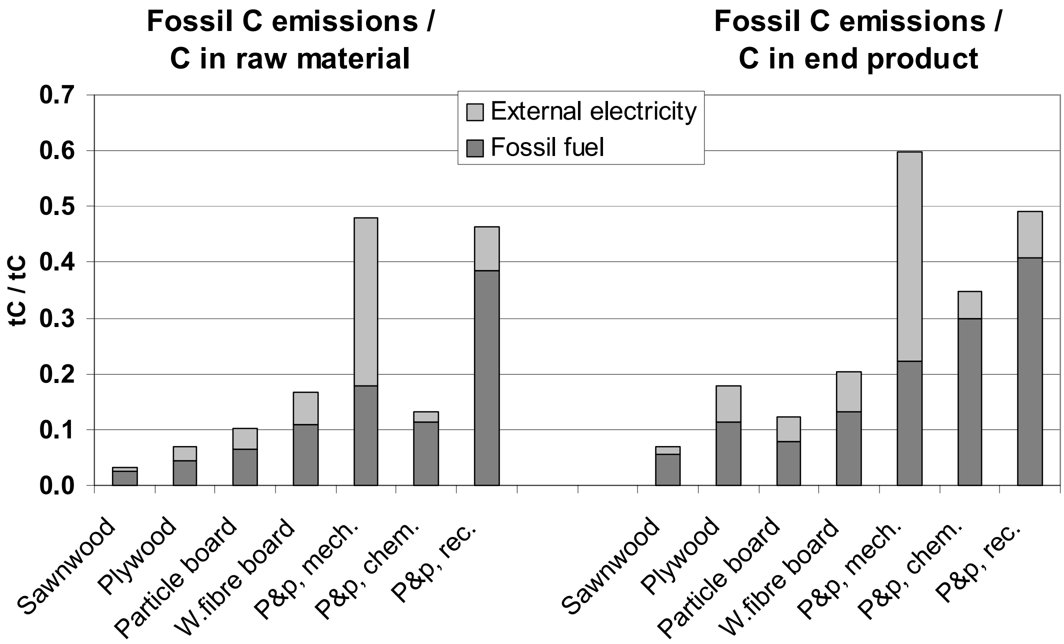
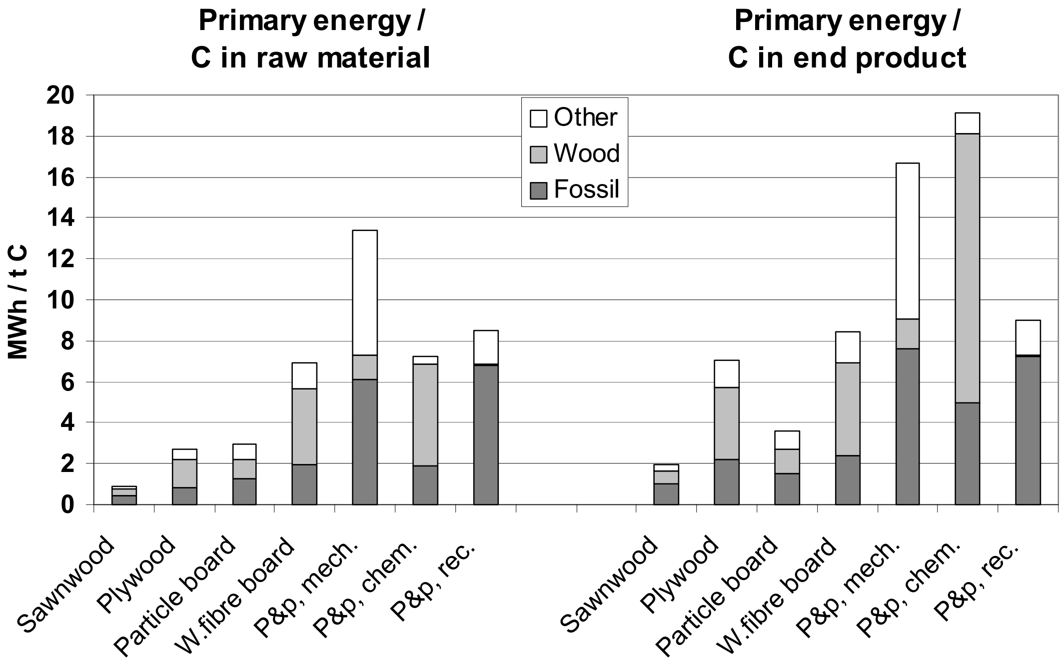


Figure 4: Primary energy consumption of manufacturing of HWP in Finland in 1995, expressed as primary energy divided by wood based C in raw material and wood based C in end product, respectively.



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 emissions
Harvesting	0.012	17 %
Roundwood transport	0.031	44 %
Sawn wood transport	0.028	40 %
Total	*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.

ACKNOWLEDGEMENTS

I am grateful to Antti Lehtilä, Ari Pussinen and Ilkka Savolainen for many valuable comments during the study. I also thank the Ministry of the Environment (Contract No. 2/742/98) and Tekes, the National Technology Agency of Finland (Contracts Nos. 40563/98 and 40856/00) for their funding.

REFERENCES

BROWN, S., LIM, B., AND SCHLAMADINGER, B., 1998. Evaluating approaches for estimating net emissions of carbon dioxide from forest harvesting and wood products. Meeting report. Dakar, Senegal, 5-7 May 1998. IPCC/OECD/IEA Programme on National Greenhouse Gas Inventories, 51 p.

CARLSON, E., AND HEIKKINEN, P., 1998. Energy consumption by the Finnish pulp and paper industry and comparison of electricity prices in certain European countries (report in Finnish, abstract in English). The Finnish pulp and paper research institute, Sustainable Paper Report 21. 81 p.

FINNISH FOREST RESEARCH INSTITUTE, 1996. Yearbook of Forest Statistics 1996, Official Statistics of Finland, Agriculture and forestry 1996:3, 352 p.

HWP WORKSHOP, 2001. Harvested Wood Products Workshop, Rotorua, New Zealand, 12-16 February. Chairman's Summary.
http://www.forestresearch.co.nz/site.cfm/hwpworkshop

IPCC, 1996. Intergovermental Panel for Climate Change. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 1. Reporting Instructions.

LEHTILÄ, A., 1995. New energy technologies and emission reduction potential in Finland (in Finnish, abstract in English). Technical Research Centre of Finland. *VTT Research Notes 1697*. Espoo. 73 p. + app. 8 p.

LEHTILÄ, A., AND TUHKANEN, S., 1999. Integrated cost-effectiveness analysis of greenhouse gas emission abatement. The case of Finland. *VTT Publications 374*, Espoo, 145 p. + app. 15 p.

LISKI, J., PUSSINEN, A., PINGOUD, K., MÄKIPÄÄ, R., AND KARJALAINEN, T., 2001. Which rotation length is favourable to mitigation of climate change? Manuscript submitted for publication in *Canadian Journal of Forest Research.*

MALINEN, R., WARTIOVAARA, I., AND VÄLTTILÄ, O., 1993. Scenario analysis of the development of Finnish pulp industry up to year 2010 (report in Finnish, abstract in English). SYTYKE, The Environmental Research and Development Programme for the Finnish Forest Industry – Project 22, *Publications of the Water and Environment Administration, Series A 123*, Helsinki, 170 p.

MYRÉEN, B. AND ANHAVA, J., 1992. The state of the Finnish forest industry in 1995 (report in Finnish, abstract in English). SYTYKE, The Environmental Research and Development Programme for the Finnish Forest Industry – Project 6, *Publications of the Water and Environment Association - Series A 117*, 173 p.

MINISTRY OF THE ENVIRONMENT, 1999. Finland's national greenhouse gas inventory to the UN's Framework Convention on Climate Change. Years: 1990, 1995-1997. Helsinki.

SAVOLAINEN, I., PINGOUD, K., AND LEHTILÄ, A. 1999. Life cycle greenhouse gas emissions for products manufactured at a European wood-processing company. Proceedings of the IEA Bioenergy Task 25 workshop "Bioenergy for mitigation of CO_2 emissions: the power, transportation, and industrial sectors", 27-30 September 1999, Gatlinburg, Tennessee, USA. (Eds. Robertson, K.A., and Schlamadinger, B.) Joanneum Research, Graz, January 2000, pp. 91-98.

STATISTICS FINLAND, 1996. Energy and Environment, *SVT Environment 1996:2*. 135 p.

STATISTICS FINLAND, 1997. Energy Statistics 1996, *SVT Energy 1997:1*. 130 p.

UNFCCC, 1992. United Nations Framework Convention on Climate Change. http://www.unfccc.de/resource/conv/index.html

UNFCCC, 1998. Kyoto Protocol to the United Nations Framework Convention on Climate Change (with addendum). Document FCCC/CP/1997/7/Add.1. http://www.unfccc.

How Sinks in Wood Products Affect the Cost of Kyoto Protocol and World Trade of Forest Products: Results from a Global Economy-wide Model[1]

JOHANNA POHJOLA

Finnish Forest Research Institution
Unioninkatu 40 A, 00170 Helsinki, Finland
Phone +358 9 85705 738, Fax 358 9 85705 717, johanna.pohjola@metla.fi

PowerPoint presentation: www.joanneum.at/iea-bioenergy-task38/workshop/canberradata/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 CO_2 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 the 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.

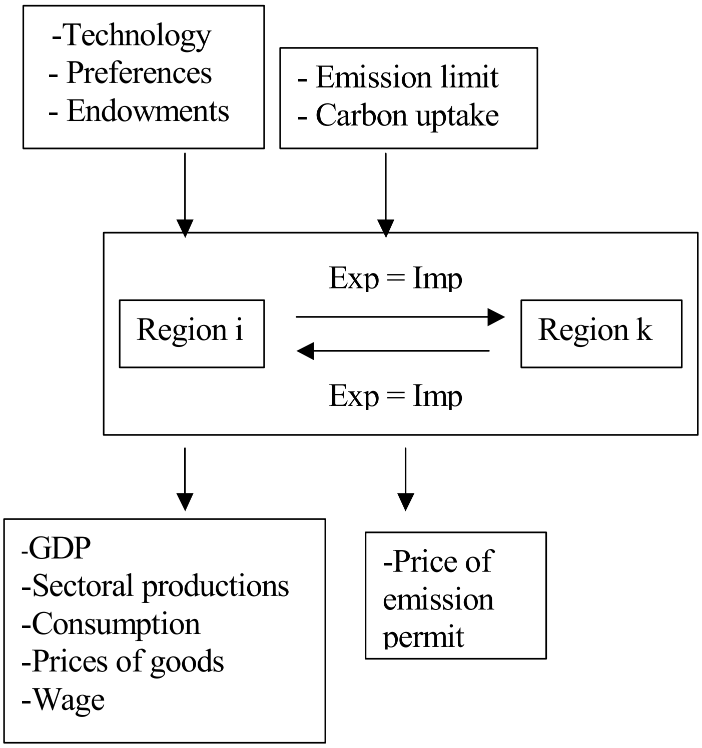
MODEL DESCRIPTION

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.

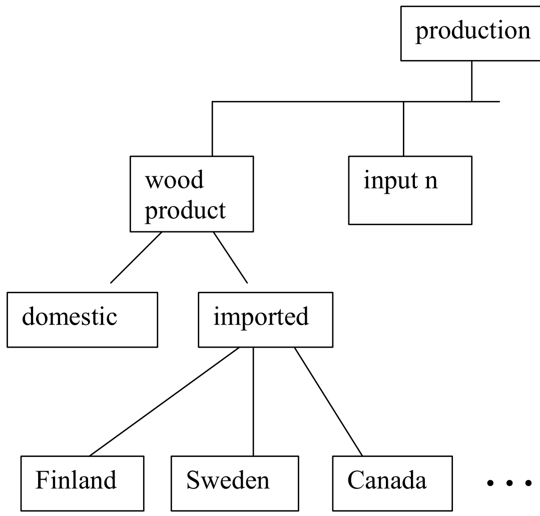
Households

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 CO_2 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 sequestrating 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 anayse 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 that 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.

REFERENCES

BACKLUND ET AL., 1995: K. Backlund, B. Kriström, K.-G. Löfgren and E. Polbring, Global Warming and Dynamic Cost-Benefit Analysis under Uncertainty. An Economic Analysis of Forest Carbon Sequestration. Umeå Economic Studies No.395. University of Umeå.

BROWN ET AL., 1998: S. Brown, B.Lim and B. Schlamadinger, Evaluating Approaches for Estimating Net Emissions of Carbon Dioxide from Forest Harvesting and Wood Products. IPCC/OECD/IEA Programme on National Greenhouse Gas Inventories. Meeting Report. Dakar, Senagal, 1998. http://www.ipcc-nggip.iges.or.jp/public/mtdocs/dakar.htm

GIELEN ET AL., 1999: D.J. Gielen, A.J.M.Bos, M.A.P.C.De Feber and T. Gerlagh, Biomass for Energy or Materials? - A Western European systems engineering perspective. *Proceedings of* the

Workshop Bioenergy for mitigation of CO_2 emissions. IEA Bioenergy Task 25 Workshop, Gatlinburg, USA. http://www.joanneum.ac.at/iea-bioenergy-task38/workshop/gatlinburg.pdf

HOEL, M. 1996. Should a Carbon Tax Be Differentiated across Sectors? Journal of Public Economics 59, 17-32.

KARJALAINEN ET AL., 1994: T. Karjalainen, S. Kellomäki and A. Pussinen, Role of wood-based products in absorbing atmospheric carbon. Silva Fennica 28, 67-80.

POHJOLA, J. 1999. Economywide Effects of Reducing CO_2 Emissions: A Comparision Between Net and Gross Emissions. Journal of Forest Economics 5:1, 139-168.

REILLY ET AL., 1999. J.Reilly, R.Prinn, J.Harnisch, J.Fitzmaurice, H. Jacoby, D.Kicklighter, J.Melillo, P.Stone, A.Sokolov and C.Wang, Multi-gas assessment of the Kyoto Protocol. Nature 401, 549-555.

TAHVONEN, O. 1995. Net National Emissions, CO_2 Taxation and the Role of Forestry. Resource and Energy Economics 17, 307-315.

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

ROBERT MATTHEWS[1] AND REBECCA HEATON[2]

[1]Mensuration Branch, Forest Research, Alice Holt Research Station, Wrecclesham, Farnham, Surrey, GU10 4LH, UNITED KINGDOM. Phone +44 1420 526235, Fax +44 1420 23450, robert.matthews@forestry.gsi.gov.uk

[2]Cardiff University Field Centre, Newbridge on Wye, Llandrindod Wells, Powys, LD1 6NB, UNITED KINGDOM. Phone +44 1597 860308, Fax +44 1597 860381, heatonrj@cardiff.ac.uk

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

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 ±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:

$$e_{i,t} = e_{i,1990} \qquad [1]$$

where $e_{i,t}$ is the CO_2 emission (in units of tonnes carbon) from fossil fuel consumption in the ith 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.

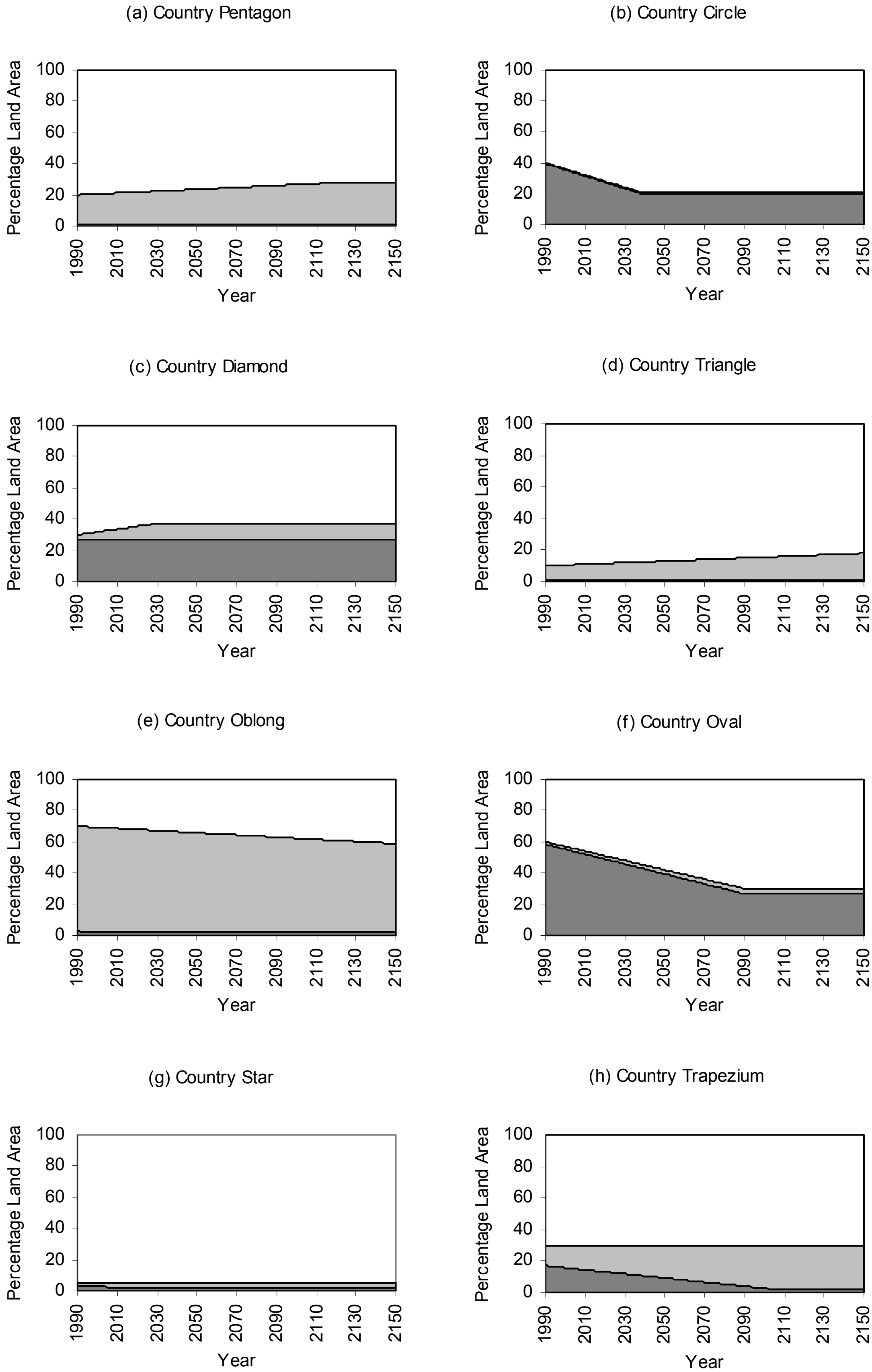
All afforestation was assumed to take place through creation of commercially productive forests on non-forest land, while all deforestation was assumed to take place through loss of old-growth forests to non-forest.

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:

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

where H_t is the carbon net sink/source due to HWP for the hypothetical world (tC 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:

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

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

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 overal 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 Ri 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 Ri 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 $S_{i,.}$ 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

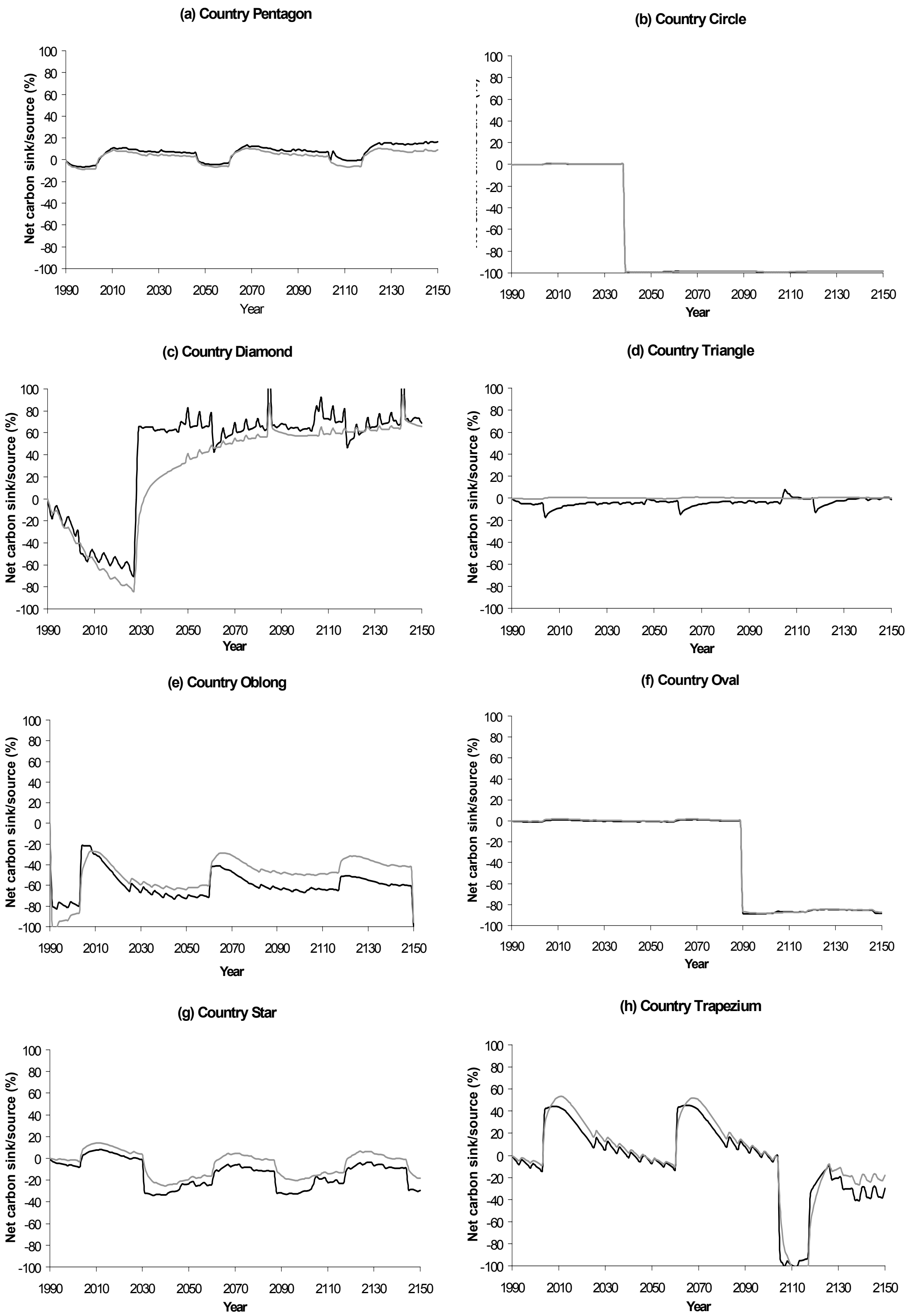
Figure 2a-h shows examples of projections of percentage changes in the carbon net sink/source for the eight model countries over the period from 1990 to 2150, calculated as follows:

- 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 ±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)

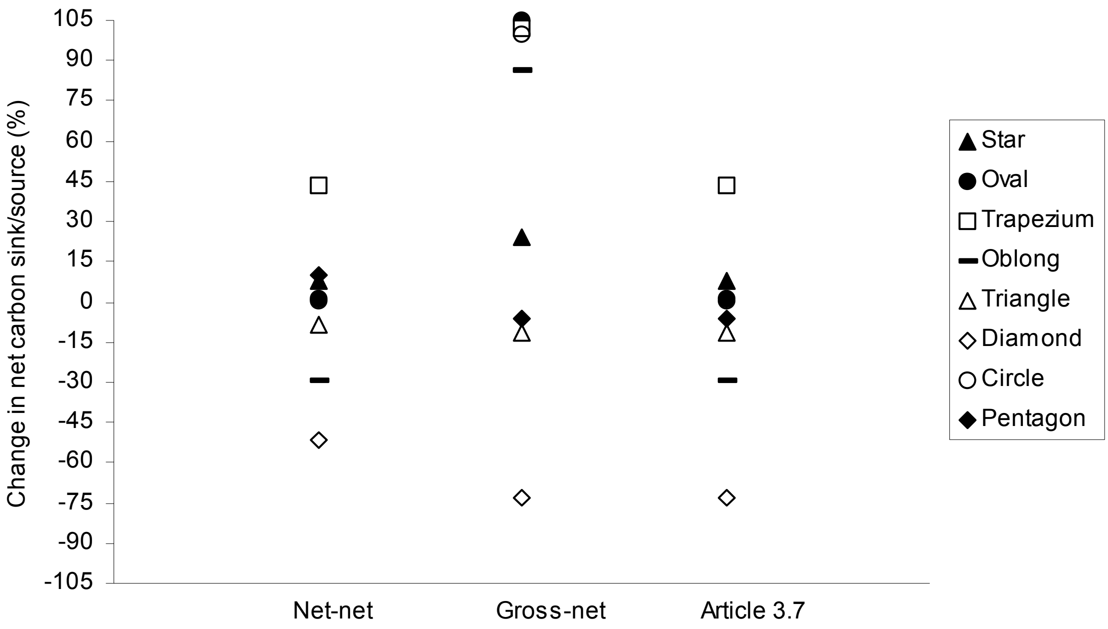


Figure 3(b)

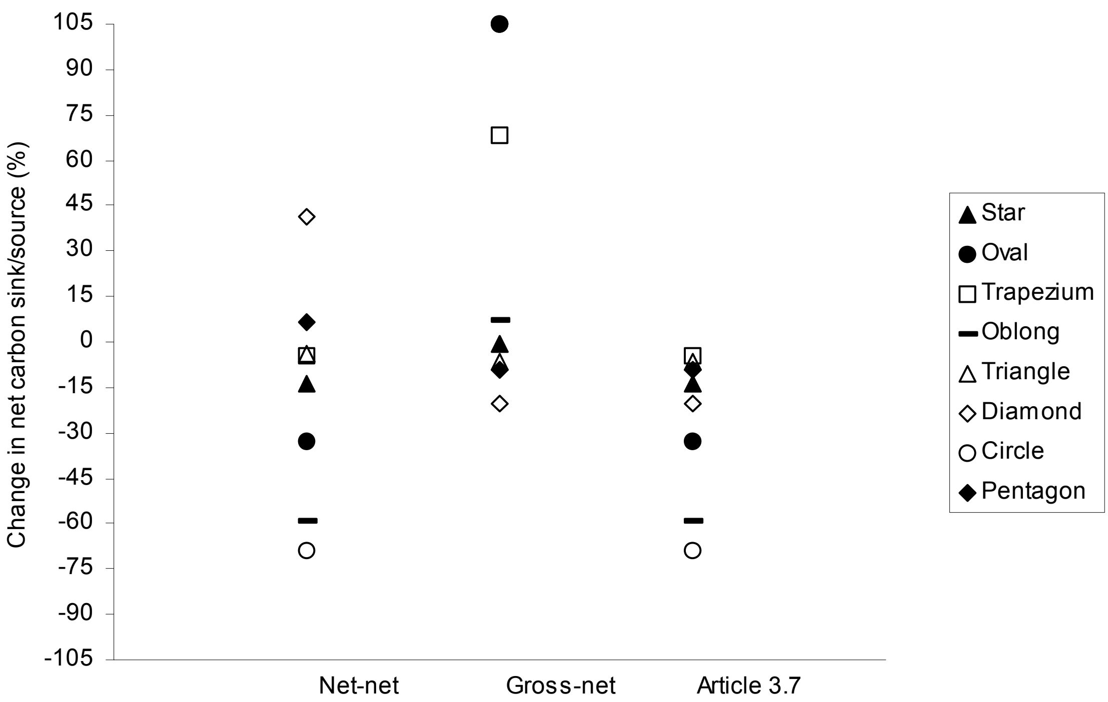


Figure 4. Influence of HWP accounting method on change in reported percentage change in net carbon sink/source for accounting periods of 2008-2012 (a) and 1990-2150 (b). Percentage changes greater than 100% or less than –100% are shown between the ranges 100% to 105% and -105% to -100% respectively.

Figure 4 (a)

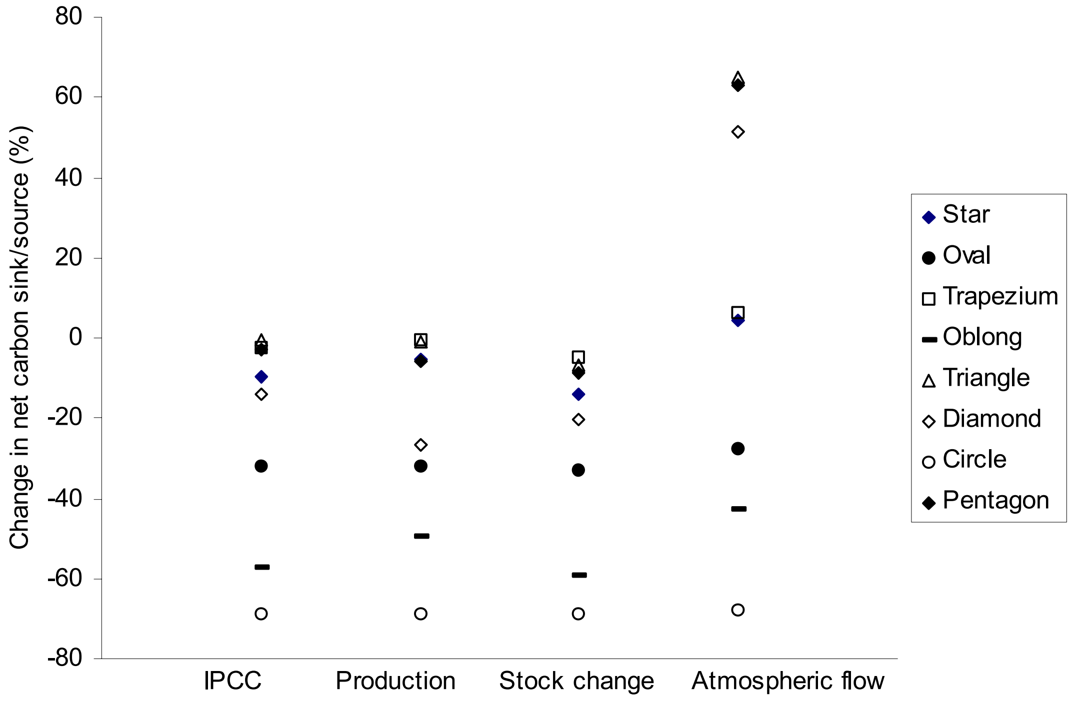
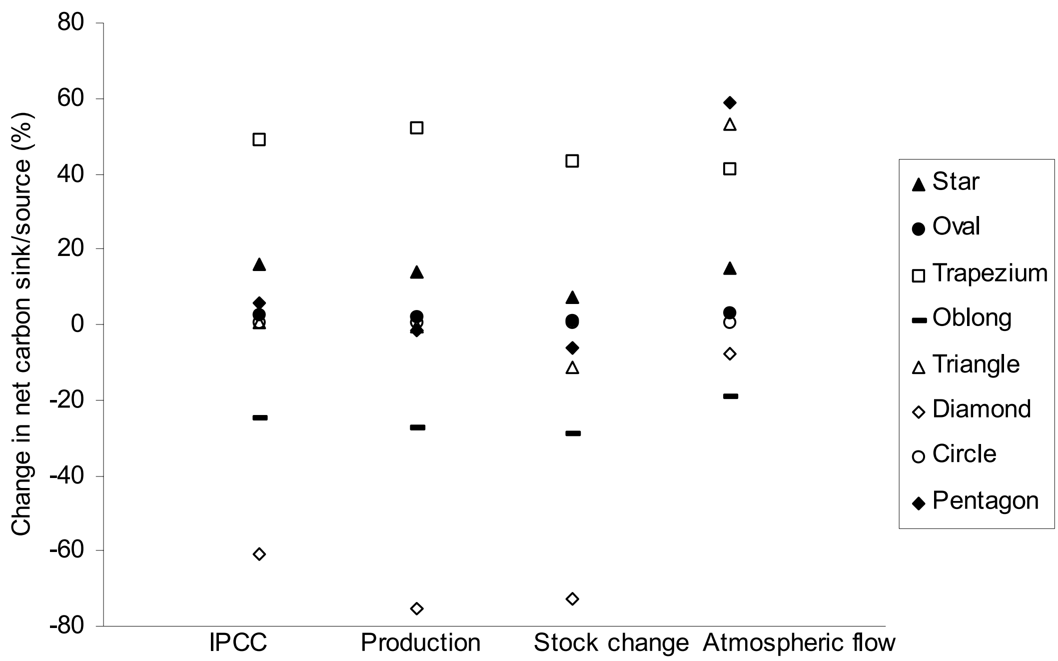


Figure 4(b)



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 understate 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(a)

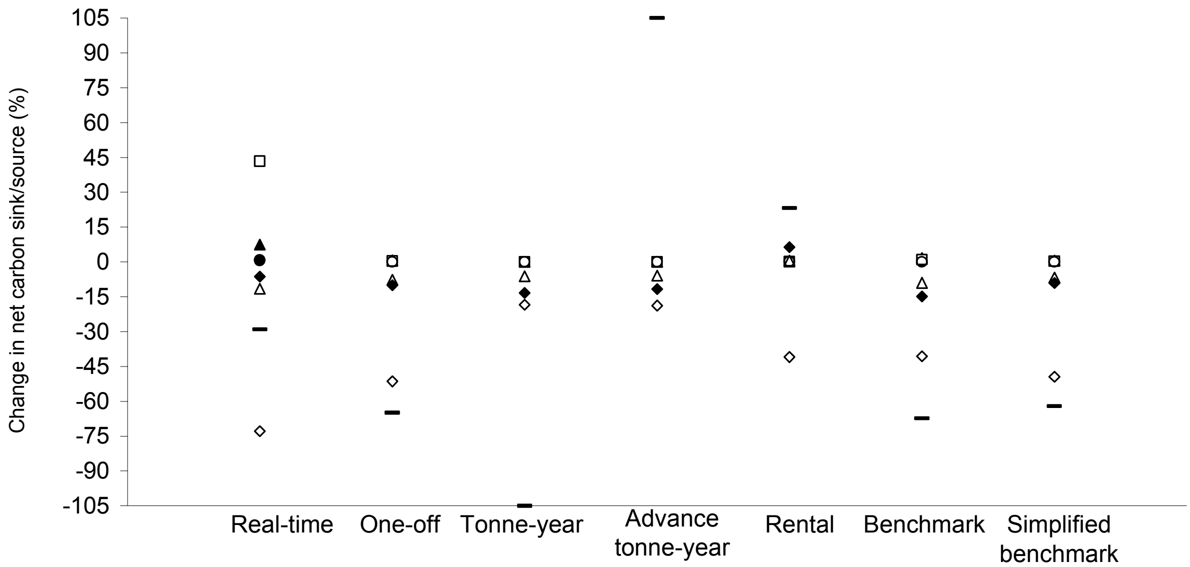


Figure 5(b)

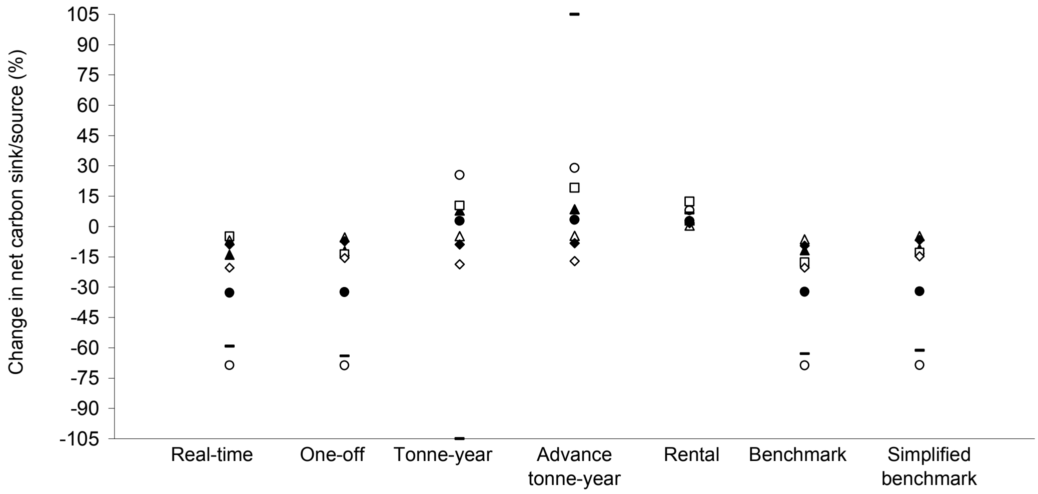


Figure 5(c)

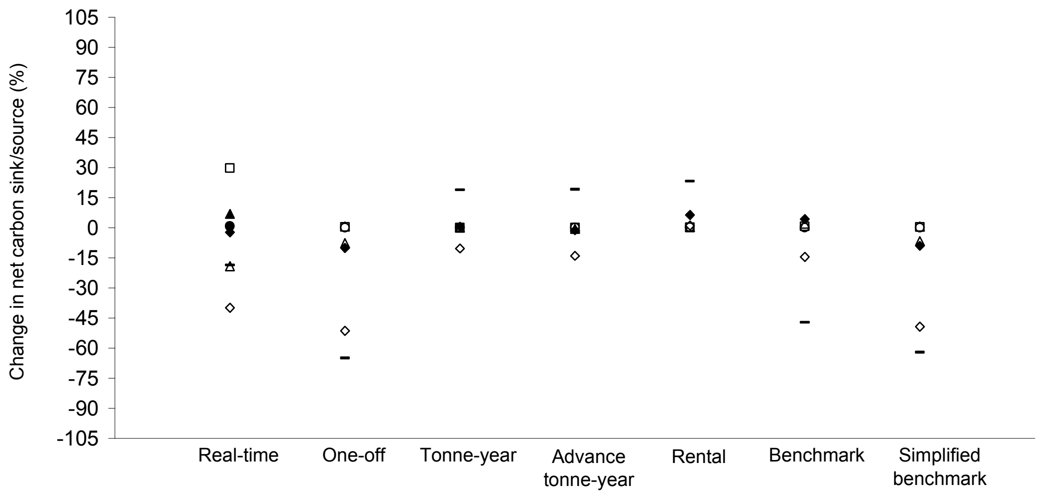


Figure 5(d)

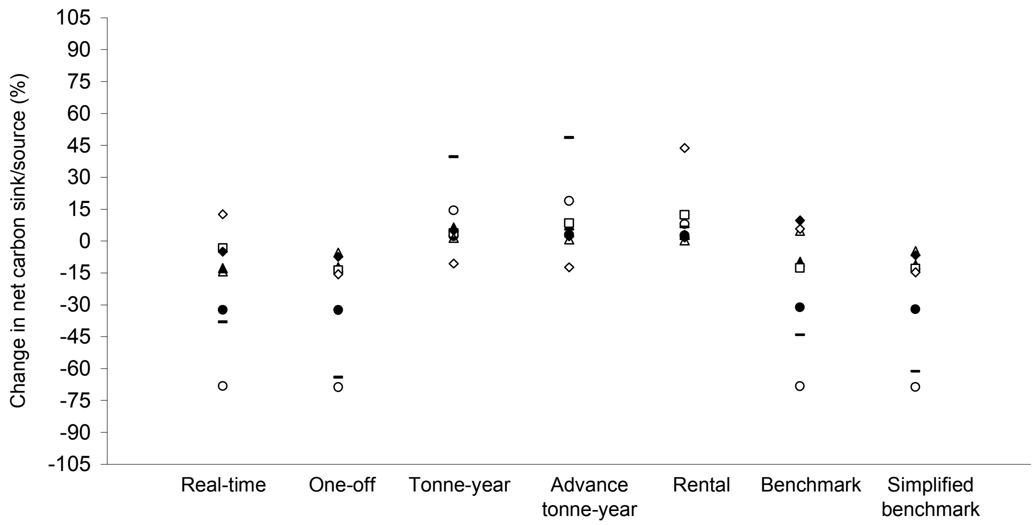


Figure 5(e)

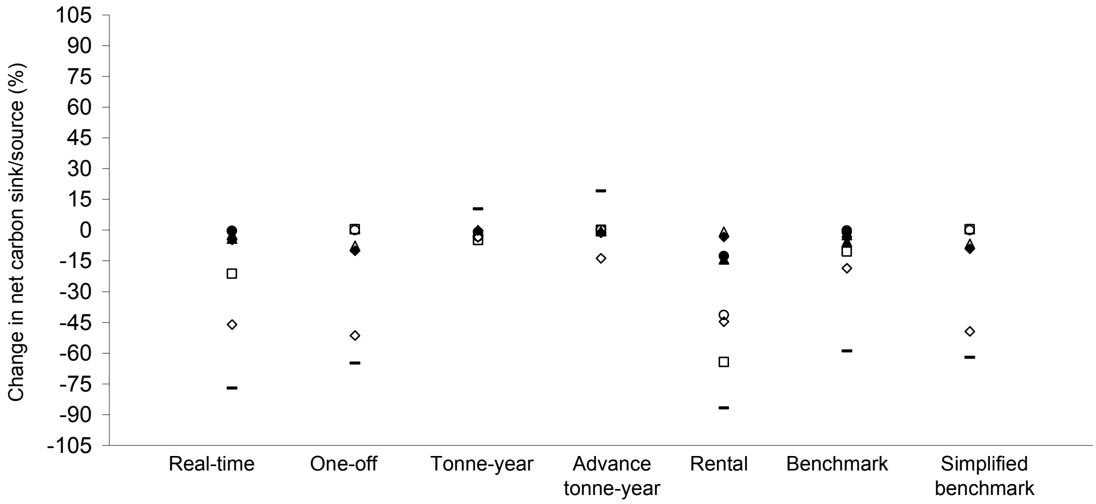
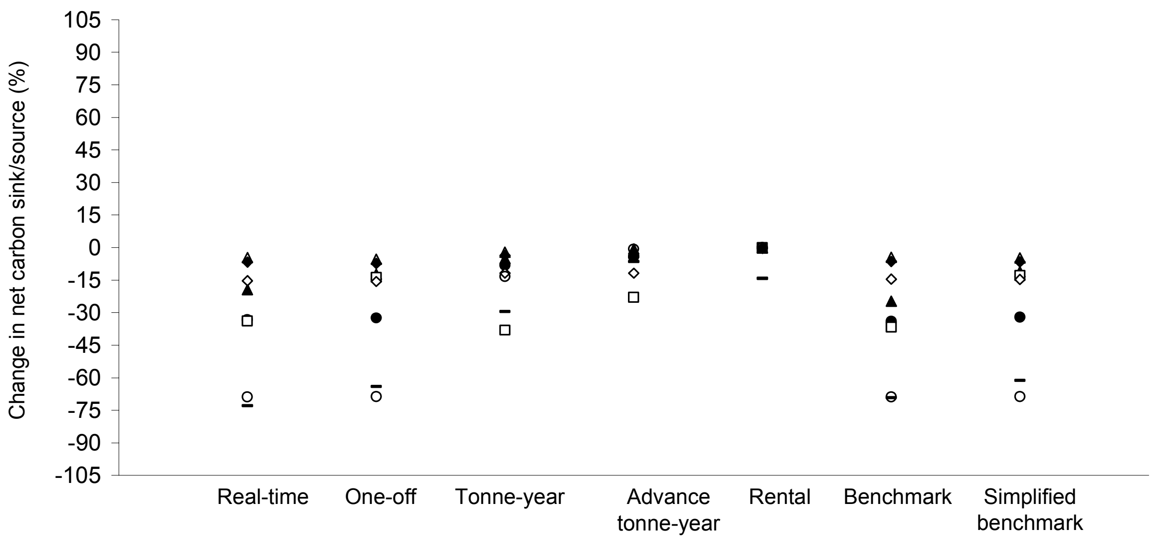
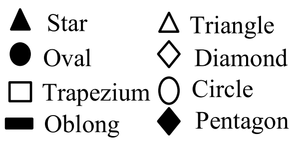


Figure 5(f)



Legend for Figures 5(a) – 4(f):



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 ±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 understate 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

This study was part funded by the UK Department of Environment, Transport and Regions and the British Forestry Commission. The authors thank Miriam Baldwin (Forest Research) for processing and graphical presentation of model results. RJH acknowledges the Llysdinam Charitable Trust for facilities provided.

REFERENCES

ALEXANDER, M. 1997. Estimation of national carbon stocks and fluxes of wood based products. Thesis in part fulfilment of degree of MSc, University of Surrey. 1997.

CHOMITZ, K. 1998. The permanence and duration issue in carbon offsets based on sequestration, Development Research Group, World Bank, Draft. 1998.

EDWARDS, P.N., CHRISTIE, J.M. 1981. Yield models for forest management. Forestry Commission Booklet 48. HMSO: London. 1981.

FEARNSIDE, P.M., LASHOFF, D.A. and P.H. MOURA-COSTA. 2001. Accounting for time in mitigating global warming. *Mitigation and Adaptation Strategies for Global Change* in press.

FRUIT, K., MARLAND, G. 2000. Carbon sequestration methodologies. Draft. 2000.

IPCC 2000. Special Report on Land Use, Land-Use Change, and Forestry. Watson R.T., Noble I. R., Bolin B., Ravindranath N.H., Verado D.J. and Dokken D.J. Cambridge University Press. Pp. 377.

JACKSON, M. 1999. Carbon sharefarming: owning a measured sequestration commodity. Paper presented to the AiC Worldwide 2nd Annual Emissions Trading Forum, Sydney, Australia, August 1999. http://www.thecarbonstore.com

KIRSCHBAUM, M.U.F., SCHLAMADINGER, B., CANNELL, M.G.R., HAMBURG, S.P., KARJALAINEN, T., KURZ, W.A., PRISLEY, S., SCHULZE, E.-D. and T.P. SINGH. 2001. A generalised approach of accounting for carbon stock changes under the Kyoto Protocol. Draft.

MACLAREN, J.P. 2000. Carbon accounting methodologies – a comparison of real-time, tonne-year and one-off stock change approaches. Draft.

MATTHEWS, R.W. 1992. Forests and arable energy crops in Britain: can they help stop global warming? In: Richards, G.E. (ed.) Wood fuel for thought. Proceedings of a conference held by the Energy Technology Support Unit, Bristol, England, 23-25 October 1991. ETSU: Harwell. 1992.

MATTHEWS, R.W. 1994. Towards a methodology for the evaluation of the carbon budget of forests. In Kanninen, M. (ed.) Carbon balance of the world's forested ecosystems: towards a global assessment. Proceedings of a workshop held by the Intergovernmental Panel on Climate Change AFOS, Joensuu, Finland, 11-15 May 1992, 105-114. Painatuskeskus: Helsinki. 1994.

MATTHEWS, R.W. 1996. The influence of carbon budget methodology on assessments of the impacts of forest management on the carbon balance. In: Apps, M.J. and D.T. Price (eds.) Forest Ecosystems, Forest Management and the Global Carbon Cycle, NATO ASI Series I 40: 233-243. 1996.

MOURA-COSTA, P., WILSON, C. 2000. An equivalence factor between CO_2 avoided emissions and sequestration – description and applications in forestry. *Mitigation and Adaptation Strategies for Global Change 5*: 51-60.

PINGOUD, K., PERÄLÄ, A. and A. PUSSINEN. 2000. Inventorying and modelling of carbon dynamics in wood products. In: Robertson, K.A. and B. Schlamadinger. (eds.) Bioenergy for Mitigation of CO_2 emissions: the power, transportation and industrial sectors. Proceedings of the IEA Bioenergy Task 25 Workshop, 125-140.

THOMPSON, D.A., MATTHEWS, R.W. 1989. The storage of carbon in trees and timber. Research Information Note 160. Forestry Commission: Edinburgh. 1989.

TIPPER, R., de Jong, B.H. 1998. Quantification and regulation of carbon offsets from forestry: comparison of alternative methodologies, with special reference to Chiapas, Mexico. *Commonwealth Forestry Review 77*: 219-228.

UNFCCC, 1992. United Nations Framework Convention on Climate Change. Convention on climate change. http://www.unfccc.de/resource/conv/index.html

UNFCCC, 1998. Kyoto Protocol to the United Nations Framework Convention on Climate Change (with addendum). Document FCCC/CP/1997/7/Add.1.
http://www.unfccc.de/ resource/docs/convkp/kpeng.pdf

WINJUM, J.K., BROWN, S. and B. SCHLAMADINGER. 1998. Forest Harvests and Wood Products - Sources and Sinks of Atmospheric Carbon-Dioxide. *Forest Scienc*e *44*: 272-284