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Evaluation and development of methods

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Abstract

Greenhouse gas (GHG) impact of wood and paper products, in the following referred as harvested wood products (HWP), is twofold: 1) HWP form a renewable pool of wood-based carbon, whose changes act as carbon sink or source, 2) manufacture and whole lifecycle of HWP cause fossil carbon emissions. These fossil emissions are often smaller than those of rival products from nonrenewable sources, and thus material and energy substitution by HWP can cause a relative decrease in GHG emissions. This report considers both above components, but it focuses on impact 1) and specifically on the approaches and methods for estimating the balance of wood-based carbon in HWP. In estimation and reporting GHG emissions under the United Nations Framework Convention on Climate Change (UNFCCC), countries do in principle report all their fossil carbon emissions (including those of HWP lifecycle), whereas reporting principles of carbon balance in HWP, impact 1), is still open. At present only changes in forest biomass are reported whereas HWP stock is not assumed to change. Climate political debate has raised alternative and competing accounting approaches, which in totally different way allocate HWP emissions or removals between countries. The report discusses and compares the alternative approaches and provides numerical examples illustrating the position of various countries in above emissions allocation. After inclusion of HWP reporting under the UNFCCC, the next possible step could be to include HWP accounting in the commitments of the Kyoto Protocol. In this case, substantial barriers for international trade of HWP and use of renewable bioenergy might be formed, dependent on the choice of the HWP accounting approach.

In this study a dynamic spreadsheet model of carbon balance in HWP was developed, which countries could use in their national emissions estimation and reporting under the UNFCCC. The model requires as basic input data the production and international trade rates of HWP, provided worldwide and since 1961 by the FAO database, which is easily accessible through the internet. The report presents a short description of the above model. In addition, a more robust method for estimation of national HWP stocks is presented, based on direct inventory of building stock. However, this method is not applicable in national reporting globally, basically due to lack of relevant statistics in most countries. The GHG impacts of type 2) are also shortly illustrated by Finnish case studies, two of which consider material substitution in Finnish new construction.

Preface

This report presents results of a study belonging to the Climtech Programme. The study, however, has connections to some other tasks. The report includes an evaluation of approaches and methods for estimating and reporting carbon balance in wood-based products. This material has been used in the consultancy, which Kim Pingoud carried out for the UNFCCC (United Nations Framework Convention on Climate Change) Secretariat. Further, the EXPHWP model developed in this study is proposed to serve as an optional tool for estimating and reporting national carbon balance in wood-based products. It will be presented in the coming IPCC report, which provides good practice guidance for national inventories of GHG emissions from *Land Use, Land-Use Change and Forestry* (LULUCF).

Most Chapters of this report were written by Kim Pingoud and edited by Ari Pussinen and Sampo Soimakallio. Anna-Leena Perälä is responsible for Chapters 7 and 10 and Sampo Soimakallio for Chapter 9. The authors wish to thank the National Technology Agency of Finland (TEKES), Finnish Forest Industries Association and Ministry of Agriculture and Forestry for funding the study. We are also greatful for the stimulating co-operation within the Climtech Programme.

Contents

Appendices

1. Introduction

1.1 Greenhouse gas lifecycle of wood-based products

Wood-based products form an integral part in the carbon cycle of managed forest ecosystems. They form (1) a physical pool of carbon, (2) a substitute for more energy-intensive materials and (3) raw material to generate energy (IPCC 2001). In sustainable forestry the removals are in balance with forest growth in the long term, and wood removed from forest by harvest can be viewed as a replacement for the natural mortality that would otherwise occur eventually.

A growing wood-products pool acts as carbon (C) sink. Harvested wood provides renewable raw material for use as fuel, fibre, and building materials. Fossil C emissions can be avoided by using wood-based fuels. Material substitution by wood can cause relative emission reductions, as manufacture of rival products is often more energy intensive. Additional avoidance of fossil C emissions can be obtained due to by-product wood fuels built up when manufacturing wood materials. Further, at the end of their lifecycle wood materials themselves can often be used for energy and fossil fuel substitution. Ideally, to maximise fossil fuel substitution and the use of renewable solar energy, all wood-based material should actually be recycled to energy at the end of its lifecycle.

This report deals with greenhouse gas (GHG) balance of the lifecycle of wood-based products, referred in the following to harvested wood products (HWP). In Part I of this report the subject is considered in generic way. The direct and indirect GHG impacts of HWP are illustrated using some case examples. In climate policy the GHG lifecycle view comprising all the direct and indirect impacts is relevant, for instance, to actions called *Policies and measures* taken or mandated by a government, often in conjunction with business and industry, to curb greenhouse gas (GHG) emissions below anticipated future levels. Part II concentrates on the *balance of wood-based C* in HWP and its estimation, reporting and accounting under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. In this context the indirect impacts on fossil C emissions are not considered. Part III presents methods developed in Finland and some Finnish case studies considering both estimation of C balance of HWP and material substitution by HWP.

1.2 HWP and the UNFCCC

The concept *estimation and reporting* refers in this report to methods used in the national GHG inventories under the UNFCCC. The *Revised 1996 IPCC Guidelines for*

National Greenhouse Gas Inventories (IPCC 1997a, b and c) provide the present basis for Parties' reporting. The term *accounting* refers to the emission accounting rules associated with the Kyoto Protocol to the UNFCCC. Accounting rules are a result of negotiation process, and the accounted emissions under the Kyoto Protocol differ, in general, for instance, from "full carbon accounting" or from national emissions reported under the UNFCCC.

The GHG reporting according to the *1996 Guidelines* is divided into different sectors: Energy, Industrial Processes, Agriculture, Land-Use Change and Forestry and Waste. Considering HWP, it can be noted that at present practically all *fossil* CO_2 and other GHG emissions associated with their lifecycle (e.g. harvesting, transport and manufacture) are reported under the Energy sector. CO_2 emissions from wood fuels are reported as auxiliary data, but excluded from the CO_2 emission totals to avoid double counting. (This is due to the fact that emissions from wood fuels are already included when the net change of forest biomass stocks is reported.) Methane emissions from waste management are reported under the Waste sector. However, no specific methods are presented under the Land Use, Land-Use Change and Forestry (LULUCF) sector for estimating and reporting emissions or removals due to (wood-based) *C stock changes in HWP*. The default is that harvested wood forms an immediate emission in the year and country of harvest. Or, which is equivalent from atmospheric viewpoint, there are no changes in HWP pools. This default assumption is called the *IPCC default approach* in the present report. However, not even the present *1996 Guidelines* do *prevent* countries reporting their HWP stock changes, provided such data are available (Box 1).

The development of estimation and reporting methods is in progress. At present Intergovernmental Panel on Climate Change (IPCC) is developing Good Practice Guidance (GPG) for Land Use, Land-Use Change and Forestry (LULUCF). The stated objective of this work is to ensure that country inventories on LULUCF are neither over- nor underestimated as far as can be judged, and uncertainties are reduced as far as practicable and facilitate the best use of available resources, taking different national circumstances into account. The GPG report concerning LULUCF will be based on the above *1996 IPCC Guidelines*, which consequently are not completely replaced by the new report. Concerning HWP, estimation methods missing in the *1996 Guidelines* will be outlined in the GPG work. As there is yet no international consensus of the *HWP approach* to be applied, no detailed reporting framework for National GHG Inventories can be presented in this stage. The choice of the approach used in reporting will be decided later on, obviously by the Conference of the Parties (COP).

BOX 5

THE FATE OF HARVESTED WOOD

Harvested wood releases its carbon at rates dependent upon its method of processing and its end-use: waste wood is usually burned immediately or within a couple of years, paper usually decays in up to 5 years (although landfilling of paper can result in longer-term storage of the carbon and eventual release as methane or CO), and lumber decays in up to 100 or more years. Because of this latter fact, forest harvest (with other forms of forest management) could result in a net uptake of carbon if the wood that is harvested is used for long-term products such as building lumber, and the regrowth is relatively rapid. This may in fact become a response strategy.

For the initial calculations of CO_2 emissions from changes in forest and other woody biomass stocks, however, the recommended default assumption is that all carbon in biomass harvested is oxidised in the removal year. This is based on the perception that stocks of forest products in most countries are not increasing significantly on an annual basis. It is the net change in stocks of forest products which should be the best indicator of a net removal of carbon from the atmosphere, rather than the gross amount of forest products produced in a given year. New products with long lifetimes from current harvests frequently replace existing product stocks, which are in turn discarded and oxidised. The proposed method recommends that storage of carbon in forest products be included in a national inventory only in the case where a country can document that existing stocks of long term forest products are in fact increasing.

If data permit, one could add a pool to Equation 1 (1) in the changes in forest and other woody biomass stocks calculation 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.

Box 1. Possible ways of estimate and report GHG balances of harvested wood are shortly outlined in Box 5 of the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Guidelines (1997), Reference Manual (Vol. 3), p. 5–17. http://www.ipcc-nggip.iges.or.jp/public/gl/invs6d.htm

After HWP reporting has been established in the national GHG emission inventories under the UNFCCC, HWP could in principle also be incorporated in the GHG *accounting* system due to the Kyoto Protocol, provided such a decision will be made by the COP. The *accounted* emissions from HWP might differ from those *reported* under the UNFCCC, although accounting is *based on* reported actual emissions. HWP are not mentioned in the Protocol text, but they might be included, for example, as an additional human-induced activity under Article 3.4. Evidently, this could happen during the second commitment period at the earliest. In case C balance in HWP were within the *accounting* system, substantial incentives/disincentives to the consumption and trade of HWP could be provided, those being dependent on the underlying HWP approach.

1.3 Contents of this report

As background information, the report provides in Part I an overview of the GHG lifecycle due to HWP including all the direct and indirect impacts, which HWP may have on the atmospheric GHG balance (Chapters 2 and 3). Chapter 2 describes the GHG lifecycle in general terms giving also some global estimates on wood-based C fluxes and stocks in HWP. The case examples in Chapter 3, from some previous studies by the author, provide an extended view of GHG impacts illustrating the direct fossil C emissions and indirect substitution impacts due to HWP lifecycle. Although emission figures of the case studies cannot be generalised, they still clarify the relative magnitude of different GHG factors due to HWP. The substitution impacts of HWP (material or fossil fuel substitution) can be seen indirectly as lower emission figures in the Energy sector in the present *reporting* and *Kyoto accounting* systems, and consequently no new reporting or accounting is needed for those impacts to avoid any double counting. However, what is important for policy-makers, stakeholders, individual companies etc, is to be aware of the lifecycle of HWP as a whole. If the objective is to reduce the total GHG emissions due to HWP, then not only the impacts reported under the LULUCF sector are important but also those belonging to Energy and Waste sector.

The main scope of this report is to present a critical evaluation of the approaches and methods for estimating wood-based C stocks in HWP and their changes in Part II (Chapters 4, 5 and 6). HWP are for the time being *neither within* the *estimation and reporting* under the UNFCCC, *nor within* the *accounting* system associated with the Kyoto Protocol. However, as they might be included the reporting system in the near future, it is necessary and topical to evaluate the competing approaches and methods being proposed. Chapter 4 presents first three alternative approaches for allocating emissions/removals from HWP to reporting countries. The outcomes (i.e. emission/removal) of the approaches *relative to* the IPCC default approach are also presented. Alternative *estimation methods* applicable to each of the approach are compared and their applicability to national reporting under the UNFCCC are discussed. If HWP in future were also included into the emission *accounting* system, additional quality requirements are imposed on the estimation methods.

In Chapter 5 the incentives provided by the approaches especially for international trade of HWP are discussed. The underlying assumption here is that HWP would be included in the Kyoto *accounting* and the accounting rules would be similar to the defining equations of the approaches. Two alternatives are considered:

1) All countries globally are compelled to emissions reduction commitments of the Kyoto Protocol.

2) Countries are divided into two groups: those compelled to the commitments of the Protocol and those who do not have commitments. In the text we will call the former *compelled* and the latter ones *non-compelled* countries. As international trade of HWP takes place between both country groups, this would create additional incentives due of the unsymmetrical position of the countries, where importers and exporters belong to either to compelled or non-compelled countries.

This section is of course highly speculative, as we do not know what kind of accounting rules for HWP could be negotiated in the future. Those rules do not necessarily be congruent with some of the approaches, and some additional discount factors etc could be included. Further we cannot forecast the development of future market price of carbon and other economic factors. Thus the possible incentives can only be discussed in relative terms, by comparing the approaches to each other.

Chapter 6 discusses issues related closely to the Kyoto process itself, what kind of implications and possible changes for the current modalities, rules and guidelines for accounting greenhouse gas emissions under articles 3.3 and 3.4 of the Kyoto Protocol are needed, if emissions from harvested wood products are considered in the *accounting* system.

Part III (Chapters 7, 8, 9 and 10) presents Finnish studies providing tools for estimating and reporting of GHG balance of HWP. In Chapter 7 a direct inventory method for estimating C stock changes of construction wood in Finland is described and the latest inventory results from year 2000 are presented. Chapter 8 provides an alternative for estimating stock changes of HWP: a dynamical spreadsheet model by which the stock changes are calculated indirectly by the aid of consumption rates and estimated lifetimes of HWP. The advantage in application of this method globally is the availability of international production and trade data of HWP, whereas inventories, if applicable, always require specific national statistics. The EXPHWP spreadsheet model developed by Kim Pingoud is applicable to serve as an optional tool in reporting C balance of HWP in the LULUCF sector, if HWP were included in the reporting framework under the UNFCCC. The model has also been used in the numerical calculations in Chapters 2 and 5. Chapter 10 outlines possible GHG impacts when wood is replacing other materials in construction. In the case study a comparison of two similar multi-storey houses is presented, one built in wood other in concrete.

PART I. ROLE OF WOOD-BASED PRODUCTS IN CARBON CYCLE

2. Carbon balance in wood-based products and its impact on the atmosphere

2.1 Some definitions

In this report as *HWP* is referred all wood-based material harvested and transported from forest and utilised either for energy or as other material commodity. HWP also include here wood fibre products like paper. It does not include carbon in harvested trees that are left at harvest sites. A detailed classification of HWP is given by the United Nations Food and Agriculture Organisation (FAO), and it is described in Appendix A. However, it should be noted that during the *lifecycle* of HWP they can belong to different classes/categories due to recycling (e.g. solid wood products can be recycled to wood fuel, paper can be recycled e.g. to fibre-based isolation material for buildings etc), and manufacturing residues of some HWP can be raw material for other HWP.

Definition of the term lifetime appears to be ambiguous in the literature. By the *lifetime* we can mean the *average lifetime* of some product category as the lifetime of HWP is always distributed. *Half-life* is the time when half of the original stock has decayed, *lifespan* often means the time needed that majority of the HWP pool has decayed, e.g. 90% or 95%. In HWP models also the *decay pattern* varies: the decay can be described by a linear or exponential function (see Appendix B) or it can follow the logistic equation etc. In real life the decay patterns depend on many socio-economic factors, and the true lifetime of HWP in use can be much shorter than their technical lifetime.

Considering HWP from the viewpoint of atmospheric carbon balance, we should note that the lifetime of HWP consists of the *time in use* (and recycled for re-use) and the *time of HWP out of service*, e.g. in landfills.

2.2 Lifecycle of HWP in general

The lifecycle of HWP and its impacts on the atmospheric greenhouse gas balance can be illustrated by the following flow diagram (Figure 1).

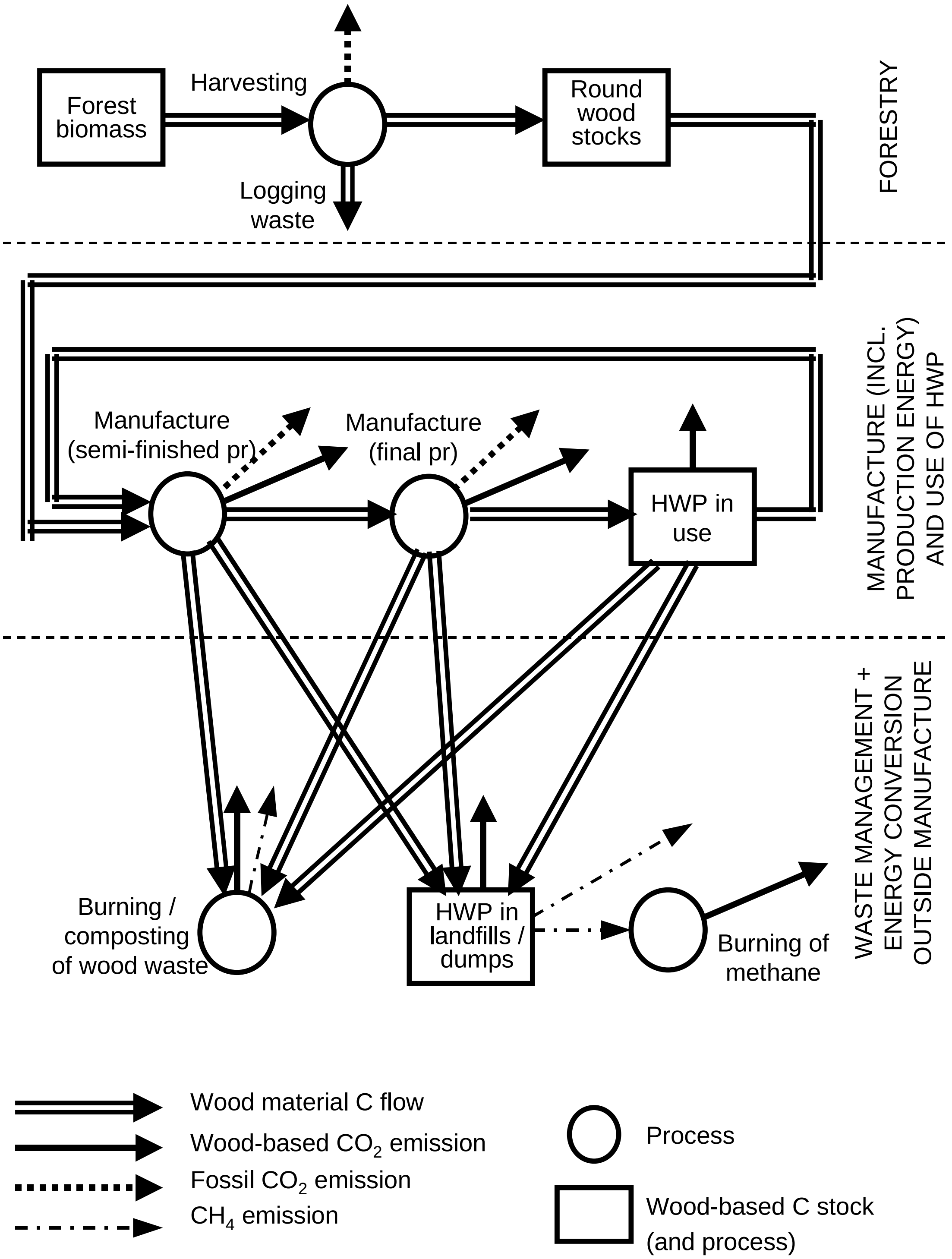


Figure 1. Schematic representation of a lifecycle of HWP. Fossil CO_2 emissions that take place during transportation of wood-based material are not included in figure.

Basically, forest ecosystem is a C stock gathered from the atmosphere through the process of photosynthesis. The C lifecycle of HWP forms a C flux in opposite direction. Wood-based material harvested from forest is divided into many subfluxes passing through various pools and processes before released back into the atmosphere. Growing HWP pool can be interpreted to act as C sink.

Production processes of semi-finished HWP (like sawnwood, wooden panels, paper and paperboard) utilise a substantial portion of the incoming roundwood flux for production energy. Residues of sawmilling, for instance, are raw material for other production processes: manufacture of chip and particle board and chemical pulping. The final or end products consist of long-lived products like, for example, houses in wood, furniture, books etc, short-lived ones like newspapers or pallets. Recycling of HWP is until now a remarkable option only for paper products.

In fact only a small fraction of harvested wood material cycles back to the atmosphere through long-lived HWP pools. The rest is used for energy and short-lived products, or ends up as wood waste decomposing either in aerobic (open dumps, composts) or anaerobic conditions (landfills). This latter also forms a long-lived C pool, which only partly decomposes into methane and carbon dioxide, and partly builds up a very long lasting C stock. In managed landfills major part of this methane can be recovered and burned, and may also be used for energy production. Methane and volatile organic compounds (VOCs) emissions can also take place in combustion of wood fuels, especially in small-scale burning. (VOCs encompasses many compounds including e.g. non-methane hydrocarbons.) Further, there are side-fluxes and emissions of fossil C associated with the fossil-fuel use in transportation and manufacture of HWP.

An extended view of GHG impact of HWP is obtained by considering the indirect impacts of wood based material. Here we enlarge the system boundary to include those materials or processes, which are alternatives for utilisation of wood. For example, in every stage of the lifecycle, where a wood-based C flux is released to the atmosphere there is a potential for energy recovery by burning wood residues, demolished wood products and waste, which in turn can substitute for fossil energy and reduce fossil C emissions. In addition, HWP themselves as material can substitute for other, more fossil-energy-intensive materials, and similarly cause indirect reductions in fossil fuel use and fossil C emissions.

2.3 End uses of harvested wood globally

A starting point for the analysis are the C fluxes associated with the use of HWP. According to FAO (FAOSTAT 2002) the global roundwood production in 2000 was about 3.1 billion m^3, excluding wood that is burned on site (Table 1). Roundwood production converted into carbon represents a C flux of approximately 0.7 Pg C /yr. Harvest rates are expected to increase at 0.5% per year (Solberg et al. 1996). Of the total roundwood production, about 1.5 billion m^3 was wood fuel, used mainly in the tropics. Its production increased fast in the 1990s (FAO 1997). Most of the forest harvest in the boreal and temperate zone is for industrial roundwood. The global production of sawlogs and veneer logs was 950 million m^3 in 2000 (FAOSTAT 2002). This resulted in global sawnwood production of about 420 million m^3, and production of wood-based panels and fibreboard of 210 million m^3. The residues are used for energy and as raw material in pulping or they end up in decomposing. The pulpwood production was about 480 million m^3 and the annual production of paper and paperboard 320 million air dry tons (adt), including paper made from non-wood fibre. The wood-based raw material for paper and paperboard comes besides pulpwood from recycled fibre and wood residues from sawmilling and veneer production mentioned above. A significant share of raw material of pulp and paper industries is used in addition to end-products also to process energy, and in fact the energy component is remarkable in all industrial wood use.

Table 1. Global production of HWP in 2000 according to FAOSTAT 2002. The associated C fluxes have been estimated by assuming approximately that the dry weight of coniferous wood would be 0.4 t/m^3 and non-coniferous 0.5 t/m^3 and that the carbon fraction in biomass is 0.5. In addition, the estimated Charcoal production was 0.04 billion t/yr (metric tons per year). The production of Wood Residues was 0.06 billion m^3/yr and Chips and Particles 0.16 billion m^3/yr, these being mainly by-products of wood processing.

PRIMARY PRODUCTS		
	billion m^3 /yr	Pg C /yr
Roundwood	**3.1**	0.71
Wood Fuel	**1.5**	0.37
Industrial Roundwood	**1.6**	0.34
Pulpwood (Round&Split)	0.48	0.11
Sawlogs+Veneer Logs	0.95	0.20
Other Indust Roundwd	0.15	0.03
SEMI-FINISHED PRODUCTS		
	billion m^3 /yr	Pg C /yr
Sawnwood	**0.42**	0.09
Wb-Panels+Fibreboard	**0.22**	
	billion t /yr	
Paper+Paperboard	**0.32**	0.15

The development of global production rates of semi-finished HWP (FAOSTAT 2002), converted approximately to C fluxes, is presented in Figure 2. The combined flux of solid wood and paper into the pool of HWP in use is nowadays about 0.3 Pg C/yr. A clear growing trend in production rates can also be seen. Exponential trend appears to approximate better the demand for paper products since 1960s, whereas the growth in demand for solid wood products has been more moderate. However, these numbers indicate that there is a growth in the global HWP pool as well.

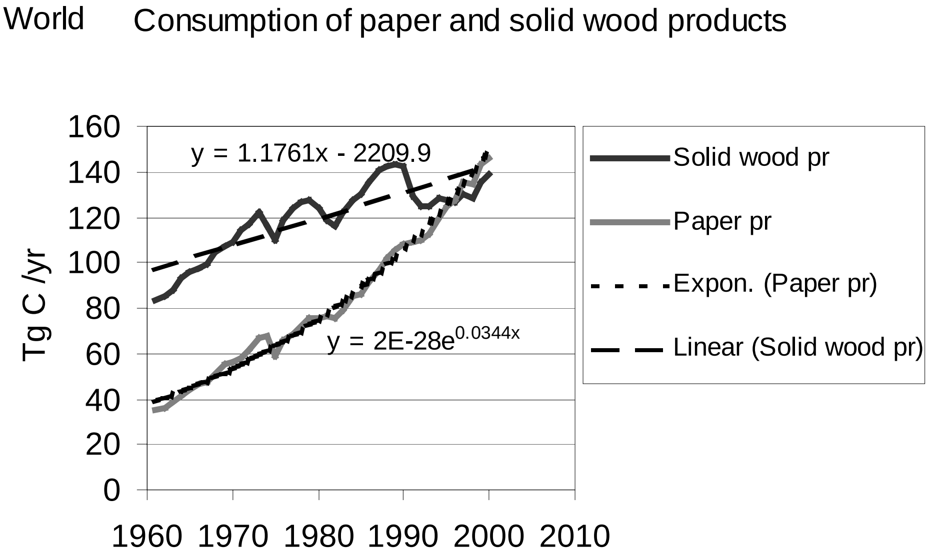


Figure 2. Global production rates of solid wood products (sawnwood and wood-based panels) and paper products (paper and paperboard) given by FAOSTAT (2002), expressed as approximate carbon fluxes. The corresponding trendlines in production rates are also given. Assumptions: 1) Dry weight of solid wood products 0.45 Mg/m^3 and of paper products 0.9 Mg/adt, 2) Carbon content in their dry matter 0.5.

Global statistics on production rates of semi-finished HWP (like sawnwood, wooden panels, paper and paperboard) are compiled by the FAO, whereas there are no coherent global statistics on manufacture of long-lived final products (like houses in wood, furniture, books etc.) and wood material flows related to them.

Important factor affecting the national C balances of HWP is their international trade. Using the assumptions of Figure 2 and the FAO database (FAOSTAT 2002), the annual C flux in international HWP trade was estimated to be more than 130 Tg C /yr in 2000 including primary and semi-finished products. Average exports and imports of semi-finished HWP in the 1990s of some selected countries are presented in Figure 3.

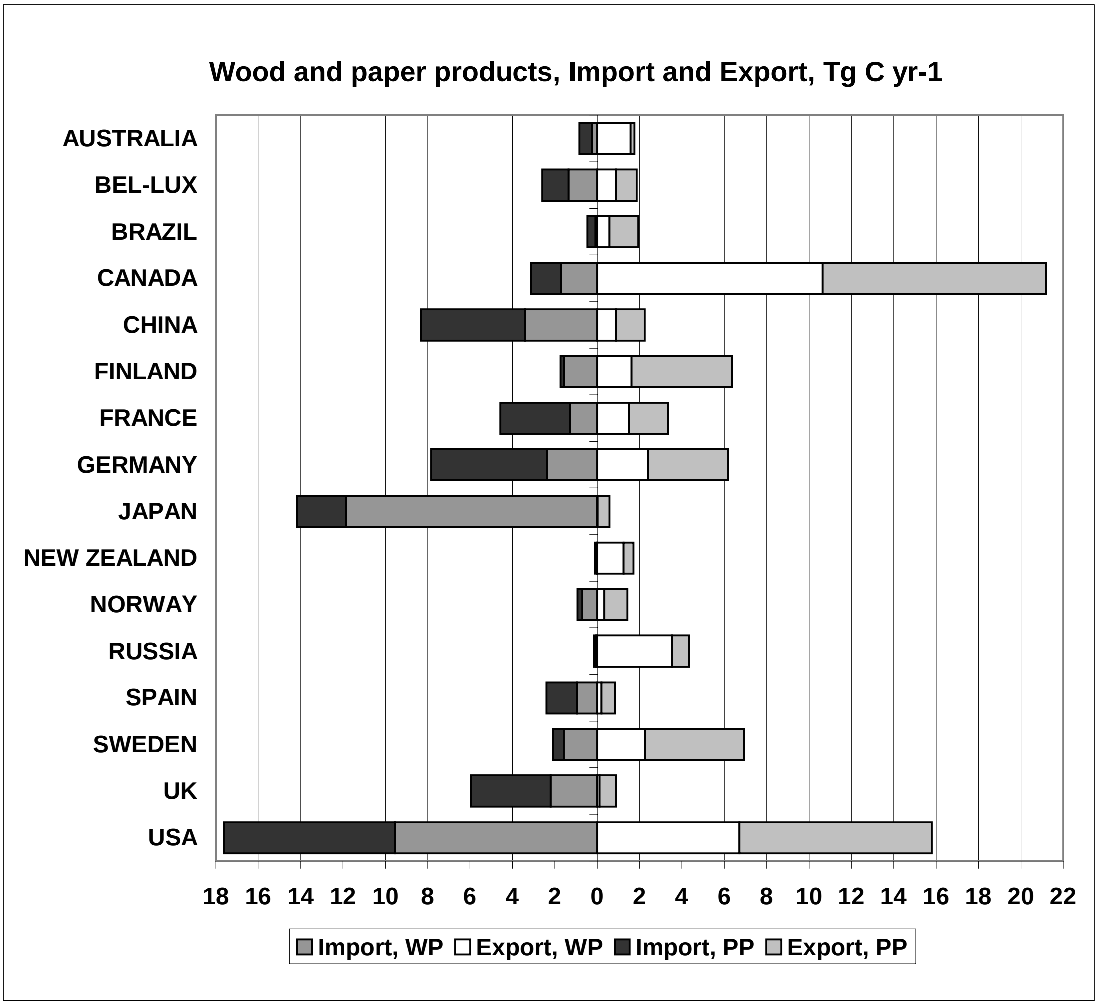


Figure 3. Carbon balance of international trade of semi-finished HWP in some countries estimated by Pingoud (2001). Wood raw material including roundwood, chips etc are excluded. For example, Canada is a major net exporter and Japan a net importer. C conversion factors: Wood products 0.2 t C/m^3, Paper products 0.45 t C/adt.

2.4 Lifetimes and recycling of HWP

2.4.1 General considerations

Consumption and average lifetime of HWP determine, how much carbon is stored in the HWP pool. Only a limited share of HWP ends up in long-term final products due to material losses and residues in every stage of the refining chain, where some by-products can be utilised only for short-lived HWP like biofuels. Consequently, average lifetime of HWP in use is much shorter than their lifetime in ideal conditions, in which the lifetime can be for instance hundreds of years (e.g. wooden frames in buildings).

The true lifetime of a certain wood product is not only determined by its technical lifetime. Changes in construction and renovation practices as well as in the economic cycles of a country affect the use and decommissioning of HWP in use, and even fashion trends have an impact on the demolition of HWP. For example, experiences on business cycles in Finnish construction indicate that during economic recession new construction and demolition of entire houses decreases, but the share of renovation increases (Perälä and Nippala 1998). Due to renovation activities, where old structures are replaced by new ones, average age of wooden structures in a house is lower than the age of the house itself.

Recycling is a mechanism which increases lifetime of HWP in use, but for the present it is of importance only for paper products. Because paper products are mainly short-lived, their increased lifetime does not essentially increase the lifetime of HWP on the average. Lifetimes of most paper products in use are very short, recycling increasing their total lifetime somewhat. Recycling usually means recycling to lower paper grades like tissue, which cannot anymore be recycled for new paper products or for energy. Because of this down cycling, higher share of wood fibres likely ends up in landfills, composting or in wastewater treatment plants instead of, for instance, burning for energy.

Another important factor affecting lifetime of wood products is waste treatment practices. In anaerobic conditions of landfills lifetime of HWP can be very long. A significant part of wood based material such as lignin does not decay at all or decay is very slow (see e.g. IPCC Good Practice, 2000, guidelines on Waste sector). If use life of HWP is short, such as for paper products, and simultaneously their landfilling rate high, their major stocks may actually be in landfills. Consequently, the total lifetime (in use and as landfill waste) of even short-lived wood products may in some cases be very long, the associated C stocks strikingly large and their growth rate rapid, forming a remarkable C sink. Landfilled solid wood decays even slower than paper. It is conceivable that part of solid wood in anaerobic conditions may form a permanent, almost fossil-like C stock (Micales and Skog 1997).

However, a significant change in landfilling practices is taking place to avoid the environmental problems like methane emissions associated with landfills. For example, in Europe the EU directive 1999/31/EC (EC 1999) limits disposal of biowaste into landfills. Biowaste from households (including wood-based waste) and solid wood waste (mainly from construction) are in general not placed into anaerobic conditions of landfills as previously, but end up in composting, burning or burning for energy. This will also influence the C balance and GHG impact of wood-based products in the future.

2.4.2 Quantifying estimates for lifetimes of HWP and their recycling

Basically, lifetime estimates of HWP in use appear to be on uncertain basis and the same applies to their decay patterns. Although statistics on the production and international trade rates of wood products are compiled, decay and disposal rates of HWP are actually not very well known. Simulation models, developed for describing C stocks and stock changes of HWP, include lifetime parameters for HWP in different end-uses (see e.g. Apps et al. 1999, Burschel et al. 1993a and b, Harmon et al. 1996, Karjalainen et al. 1994, Kurz et al. 1992, Winjum et al. 1998). Important parameter, influencing average lifetime all HWP in these models, is how production/ consumption of various HWP groups is *divided* into the subcategories of short, medium and long-term use (with individual lifetimes). Also the decay patters used in the models differ: at least linear, exponential and logistic decay functions and some hypothetical decay tables have been used to describe the decay of HWP in use. Sikkema et al. (2002) have collected from the literature a large number of lifetime parameter values, which have been used in the HWP models (Appendix B). However, the above lifetime parameters and decay patterns are mainly hypothetical, not being based on any empirical verification, although approximate estimates of lifetimes for HWP in various end-uses can be made from wood-using practices. For example, in case of construction wood, experience of renovation intervals of wooden building parts forms one basis for service-life estimates.

Another way of obtaining estimates for average lifetimes is to perform, if possible, direct and sequential inventories of specific HWP stocks in use (Pingoud et al. 2001, Flugsrud et al. 2001, Gjesdal et al. 1996 and 1998, and Pingoud et al. 1996). Besides obtaining direct estimates for C stock changes, these inventories can be used in finding more realistic lifetime or decay rate parameters for the above models. By using well-compiled consumption rates as the input of the model and then fitting the model to the inventory results by tuning the lifetime parameter, an empirical estimate for the average lifetime for HWP in use can be obtained. Stock inventories are most practicable for such major long-lived C pools of HWP, of which some official statistics are compiled. For example, the method applied in the Finnish inventory (Pingoud et al. 2001) was founded on the basic building-stock statistics supplemented by a more detailed database on building materials. To conclude, with the aid of a time series of inventory data it is possible 1) to estimate directly the changes of C stocks and 2) to verify parameter values of the HWP models mentioned above. Direct stock inventories or inventory-based approaches have not been applied frequently, with some exceptions of Pingoud et al. (1996, 2001), Gjesdal et al. (1996, 1998) and Alexander (1997). On the basis of the Finnish inventory it could be concluded that the average lifetime of sawnwood in service (including short-term use) is likely between 30 and 40 years, which means that the yearly decay rate is of the order 2.5 to 3.3%.

Recycling of solid wood products is mostly only for energy, which does not increase their lifetime in use. In Europe the recycling rate of paper reached 49.8% in 2000 (CEPI 2001, Severnside 2002). This is ahead of the world average 37%. The percentage of USA was 45%, Canada 45% and Japan 51%. A certain fraction of the paper consumed, estimated between 15 and 20%, can never be recovered. This includes tissue papers, wallpapers, books kept in archives, etc. In every recycling phase at least 10% of the recycled fibre is lost, and also due to technical reasons new virgin fibre is needed in papermaking. A collection of hypothetical estimates for paper-product lifetimes, used in HWP models, is presented in Appendix B.

The decay rate / lifetime parameters for HWP in landfills can roughly be estimated from parameters developed for municipal organic waste in general, some default parameter values presented in Waste sector guidance in IPCC (2000b).

2.5 Estimates of global C stock changes in HWP

Several studies on the impacts of these measures on the amount of carbon sequestered in HWP have been carried out. Approximate estimates on global C stock in HWP and their present growth rate can be found in the Second and Third Assessment Reports (SAR and TAR) of the IPCC (IPCC 1996 and 2001). According to the SAR (IPCC, 1996), the global stock of C in forest products would be of the order of 4.2 Pg C and the net sink 26 Tg C/yr. Other sources suggest a stock of 10–25 PgC (Sampson et al. 1993, Matthews et al. 1996) and a global sink of 139 Tg C/yr (Winjum et al. 1998, Brown et al. 1999). Above estimates do not make difference between different HWP substocks such as HWP in use and HWP as landfill waste. No specific estimates on global HWP stocks in landfills appear to be available in the literature.

For comparison to above numbers, an estimate of global HWP stocks and their changes was also calculated with the spreadsheet model EXPHWP (Figure 4 and Table 2). This was justified, as the model in the IPCC Good Practice Guidance report draft is proposed to be the basic tool for estimating the C balance of HWP in the national GHG inventories. (A more detailed description of the spreadsheet model is given in Chapter 8) The model uses as input data the global FAO Forestry database (FAOSTAT 2002), which includes national production rates and international trade flows of the major groups of HWP, most compiled since 1961. However, the FAO Forestry database provides also global figures of HWP production, which were used in the estimates below (Figure 4). Some other essential parameters used in the model calculations are given in Table 2.

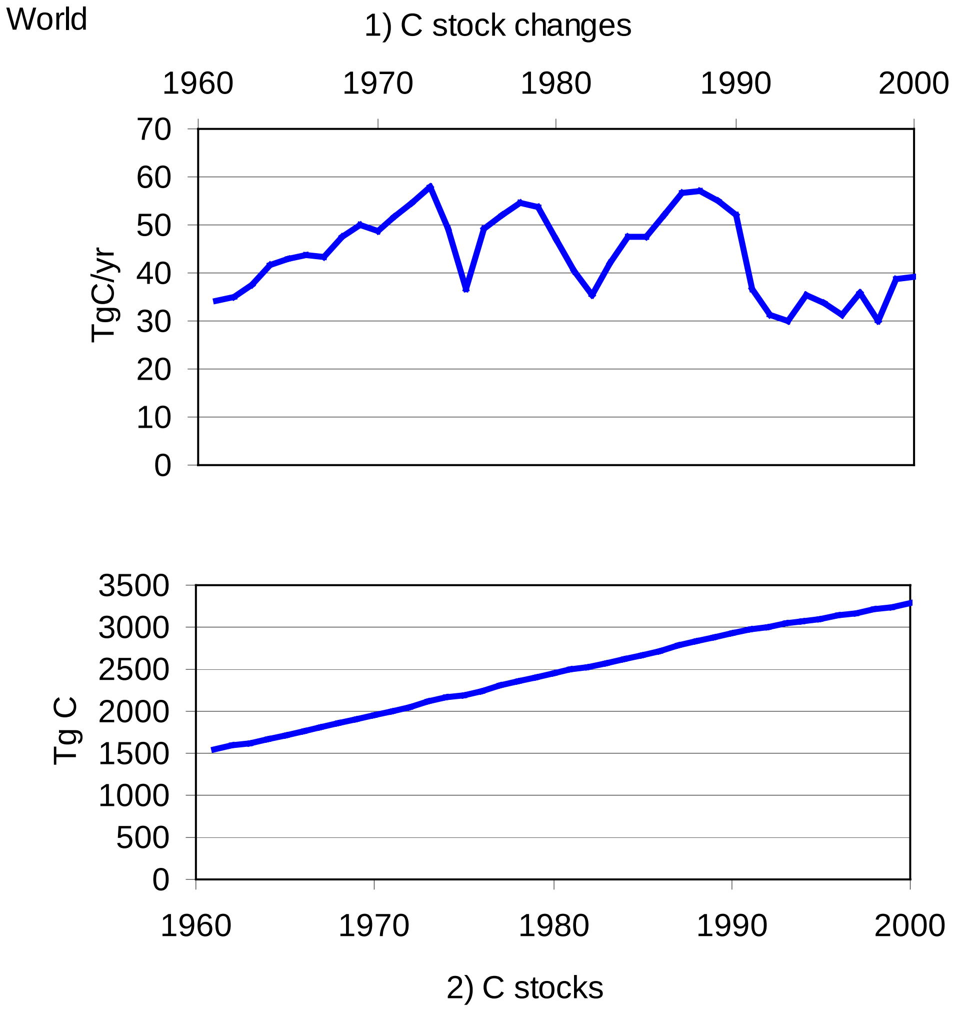


Figure 4. An estimate of global C stock changes (1) and stocks (2) of HWP calculated by the EXPHWP model. This figure includes only HWP in use, although EXPHWP contains a submodel for HWP in solid waste disposal sites (SWDS). The associated model parameters are given in Table 2.

Table 2. Parameter values for the global C stock of HWP in use in the EXPHWP model.

	Solid wood products	**Paper products**
Decay rate (1/yr)	3.3%	100%
Estimated growth of production prior to 1961 (1/yr)	2%	2%
Dry weight (Mg/m^3 and Mg/adt)	0.45	0.90
C content in dry matter	50%	50%
Initial C stock in 1900	0	0

According to the EXPHWP model (Figure 4) the growth of global HWP stock *in use* would have been varying between 30 and 60 Tg C/yr since the 1960s. In addition comes the stock change of HWP in Solid Waste Disposal Sites (SWDS) including aerobic and anaerobic decay in landfills and open dumps. The SWDS are included in the spreadsheet model but due to lack of realistic parameter estimates no results are yet presented.

If decay of solid wood in landfills proves to be negligible, wood waste deposited into landfills may form a very important C sink in the life cycle of HWP and a significant stock of C due to the accumulated wood from former waste flows. Micales and Skog (1997) estimated that of the total amount of HWP disposed of in the USA in 1993, as either paper or wood products, 28 Tg C (out of a total domestic harvest of approximately 123 Tg C/yr) will remain stored in landfills. However, production of methane through anaerobic decomposition deserves to be considered when evaluating the mitigation potential of landfills (Pingoud et al. 1996).

Most studies generally conclude that the sink potential in HWP is quite small at the national or global level (see Table 3). Even if the highest the above-mentioned estimates, 139 Tg C /yr, were correct, the C sink in HWP appears small compared, for instance, to the current rate of net C sequestration into boreal and temperate forests, which was estimated to be on an average 0.68 ± 0.34 Pg C/yr between 1981 and 1999 (Myneni et al., 2001) and about 0.88 Pg C/yr in the early 1990s (Liski and Kauppi, 2000). Options to increase physical sequestration of carbon in HWP include: increasing consumption and production of HWP; improving the quality of HWP; improving processing efficiency; and enhancing recycling and re-use of HWP. The IPCC Special Report on LULUCF (IPCC 2000a, Table 4-1) gives a coarse estimate of the C sequestration *potential* in HWP, which is, i.e. in addition to the present sinks, of the order of 210 Tg C/yr for Annex I countries and 90 Tg C /yr for non-Annex I countries.

Table 3. Estimates of global C sinks in HWP compared to C sinks in boreal and temperate forests. Estimates of C stocks of HWP.

	Reference:	**Stock Change**	**Stock**	
HWP		Tg C /yr	Tg C	
	IPCC 1996	26	4 200	
	Sampson et al.1993		10 000	
	Matthews et al. 1996		15–25 000	
	Winjum et al. 1998	139		
	Pingoud, this study	40	3300	*
	IPCC 2000a	300		**
Boreal and temperate forests				
	Myneni et al. 2001	680 ± 340		
	Liski and Kauppi 2000	880		

* Solid waste disposal sites (SWDS) excluded
**Estimated global sequestration potential

3. Total GHG emissions resulting from lifecycle of HWP

The impact of HWP on GHG balance of the atmosphere can be considered from different perspectives. The first viewpoint is simply the balance of wood-based C associated with the lifecycle of HWP and timing of the C emissions into the atmosphere during their lifecycle, which are not yet included in the GHG emissions reporting under the UNFCCC. This is the main subject of the present report.

The viewpoint can be extended by further taking into account all the side-fluxes of *fossil* C emissions associated with the lifecycle of HWP, resulting mainly from fuel-use in production, transport and other stages of the cycle. These fossil C emissions, already included in the current reporting system (IPCC 1997a, b and c), together with the wood-based ones mentioned above, represent *absolute* C emissions from the HWP lifecycle.

A more extended view is to consider the use of HWP as substitutes for other products. In spite of the above absolute GHG emissions due to HWP, they can be a favourable choice *compared to* alternative products. With HWP we can replace especially fossil fuels and also more energy-intensive materials, which means that we can generate relative GHG emission reductions by using HWP (Hall et al. 1991, Marland and Schlamadinger 1995, 1997). The use of abandoned HWP for energy rather than disposal as waste can provide additional opportunities for displacing use of fossil fuels (Apps et al. 1999). While C sequestration in HWP can reach saturation, the C benefits of energy and materials substitution can be sustained.

Evaluation of the effective benefits of substitution can be complicated in practice. A consistent methodology is needed to perform comparisons between the two systems (e.g. fuel chains) under consideration: the old one to be replaced and the new one based on utilisation of wood biomass. This includes, for instance, consistent definition of system boundaries and, in general, time-varying baselines, so that the additional impacts on the dynamic GHG balance due to substitution could be assessed (see e.g. Schlamadinger et al. 1997, Gustavsson et al. 1998, IEA Bioenergy Task 38). In climate policy the view of substitution is relevant for example in project-based activities under the Clean Development Mechanism (CDM) or Joint Implementation (JI). Increased use of HWP could in theory be one option under these activities, for instance, as a source of renewable bioenergy substituting for fossil fuels. Many problems may appear in their practical application, e.g. leakage, where the GHG balance benefit obtained within the project causes losses outside project boundaries.

The impact of HWP lifecycle on atmospheric GHG balance is illustrated in the following by some few selected case examples, which include 1) wood-based C emissions and their occurrence in the different stages of the lifecycle of sawnwood, 2) fossil C emissions due to production and transport stages of the main HWP groups, and 3) substitution of solid wood products for other construction materials.

3.1 Case example: lifecycle of Finnish construction wood

The refining chain of construction timber is illustrated in Figure 5. The conversion factors and numbers represent approximately the present situation for softwood harvested in Finland. Considering C flows, it can be noted that only about a quarter of original harvested wood biomass ends up in final product being in long-term use of construction. If the reference point is stemwood (incl bark) transported from forest, then the proportion is of the order of 40%. Wood residues building up in manufacturing, such as wood chips and sawdust, are mainly used as raw material for side products like chemical pulp, chipboard and particle board, from which the panel products go mostly to long-term use. The rest of the residues, mainly bark, are used for energy. Energy recovery can take place both in sawmills and elsewhere in forest industries or, for example, in district heating plants. In addition, from wood raw material going into chemical pulp mills major part is utilised for process energy of pulping in the form of black liquor. Further, wood waste from construction sites is nowadays mostly burned for energy. At the end of its useful life construction wood including wood-based panels can also be used for energy purposes. The same applies in principle for recoverable paper waste, which is nowadays basically recycled.

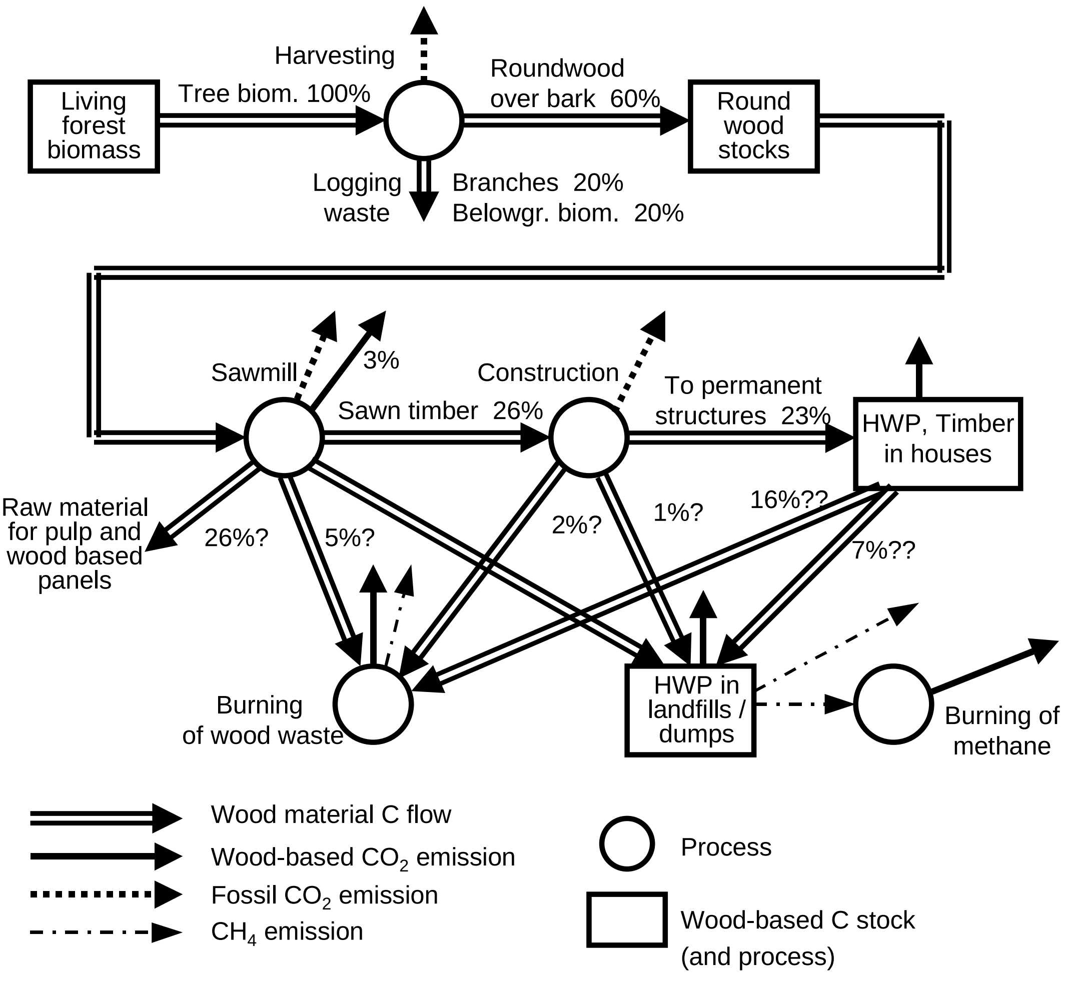
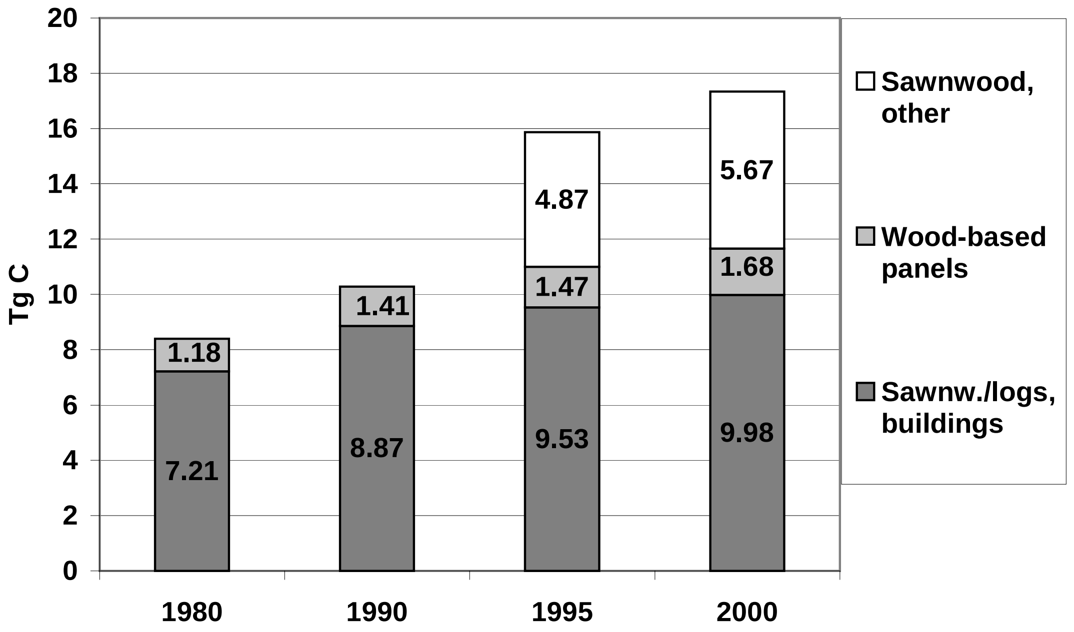


Figure 5. Carbon flows of a typical industrial wood-using chain starting from whole tree biomass. Final product is construction wood in housing. Wood-based C fluxes are expressed as a percentage of the original flux of harvested whole-tree biomass. (The number question marks indicate the uncertainty of the estimates.)

Rotation period of the HWP stocks varies, i.e. the average lifetime of HWP in the stocks (Figure 5). *Roundwood stocks* are substantial, but their rotation period is very short, of the order of some months. In Finland (METLA 2001) they fluctuate on a yearly basis summer stocks being slightly larger than winter stocks. In addition, nowadays there are strong logistical reasons to decrease unnecessary stocks in forest industries. The *construction wood stocks* in housing have formed a long-term C sink in Finland according to inventories (Box 2). Also landfill stocks of demolished HWP appear to grow.



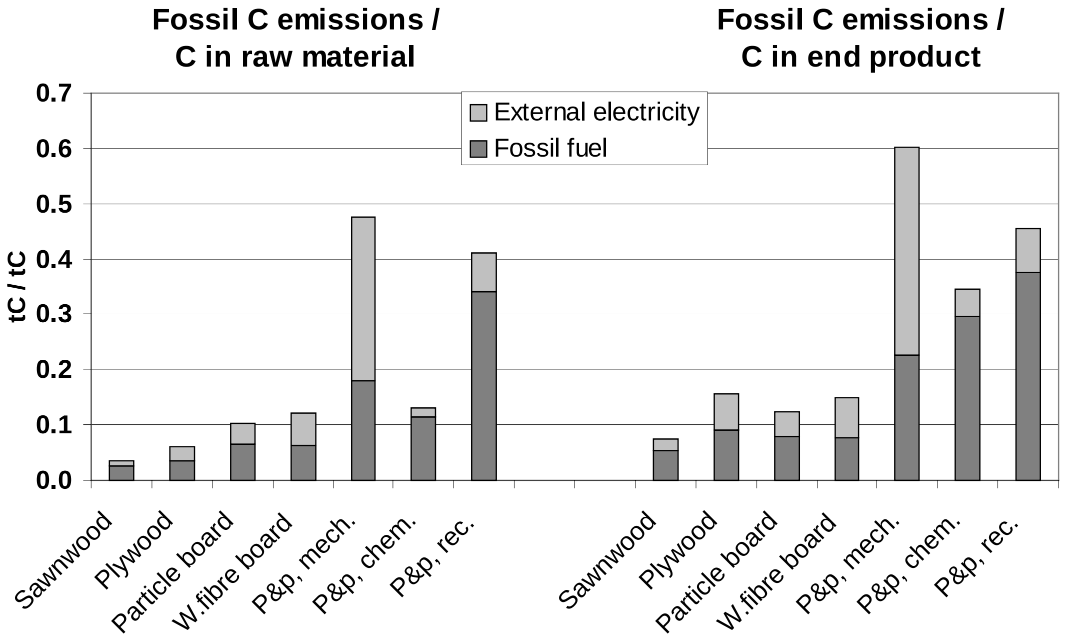
The inventory results indicate for instance that the stock of *sawnwood, logs* and *wood-based panels* in buildings has increased in two decades, thus acting as C sink. The yearly average change was 0.19 Tg C /yr in the 1980s, 0.14 Tg C /yr between 1990 and 1995, and 0.13 Tg C /yr between 1995 and 2000. Average lifetime of sawn wood was estimated by fitting an exponential decay model to the inventories, the estimate being between 30 and 40 years. Due to lack of stock statistics numbers on other use of sawnwood (mainly civil engineering, only estimated in years 1995 and 2000) are more uncertain being based on indirect model calculations. In addition to above long-lived stocks in construction, in Finland there are remarkable stocks of *unprocessed roundwood* and *demolished HWP in landfills*. The average roundwood stocks decreased about 50% from 1990 to 2000 despite the fact that roundwood removals increased by more than 25% during the same interval (METLA 2001), the average stocks being nowadays 1.5 Tg C. Based on previous uncertain model calculations (Pingoud et al. 1996), the landfill stocks of solid wood in 1990 were estimated to be of the order of 15 Tg C, which is of the same order as the above stock in use. However, the total C stock change, C sink, in all wood-based waste including paper waste was estimated to be as much as 2-3 Tg C/yr. The methane emissions might compensate this C sink by increasing the atmospheric GHG emissions by 1.5 to 8 Tg C_{eq} /yr (where C_{eq} means that methane emissions are first converted to carbon dioxide emissions by multiplying with the $GWP_{100\ yr}$ factor 21). The broad confidence interval reflects the uncertainties of the estimate. For comparison, the base year (1990) emissions in Finland without the LULUCF sector were 21 Tg C/yr and the C removal due to forests 6.5 Tg C/yr.

Box 2. Sequential C stock inventories of construction wood in Finland based on building stock statistics and an associated database. Years 1980 to 1995 presented by Pingoud et al. (2001) and year 2000 in section 7.2 of this report. Comparison to other HWP stocks and to other national C sinks.

The sink in HWP in use is a temporary phenomenon. When timber consumption saturates in some future then also timber stock will stabilise with some delay. It has to be noticed that even if C stock of construction wood in buildings remained constant, there will still be a continuous wood-based flux through the system. This is due to renovation and decommissioning activities, where new wooden structures replace old ones. Simultaneously, wood residues and wood-based by-products building up during wood processing can be utilised for bioenergy, and the same applies to wooden construction materials at the end of their useful life. Production of HWP cannot be increased indefinitely, due to the simple fact that biomass production in forests is a finite resource. In the long-term the only sustainable option is a system in steady state without any C sink in forests or HWP in use. However, even in this state the wood-based flux through the system is applicable to continuous bioenergy production, which in turn can replace fossil fuels and cause indirect reductions in fossil C emissions.

3.2 Case example: fossil C emissions of main HWP groups

The refining chain of HWP needs energy inputs, which are partly supplied by fossil fuels causing C emissions. (As noted earlier, these fossil emissions are already incorporated in the present estimation and reporting system of the UNFCCC and accounting due the Kyoto Protocol). HWP are a relatively inhomogeneous group. As mentioned above they have varying life times, from very short-lived paper grades to long-lived timber structures. The manufacture of HWP requires very different amounts of energy depending on product types. The development of energy use in the forest product sector in some countries has been analysed by e.g. Apps et al. (1999) and Farla et al. (1997). The energy demand can be supplied in various ways and depends on national energy sources. Pingoud and Lehtilä (2002) performed a case study of fossil C emissions of manufacturing HWP in Finland, some of its results presented in Box 3.



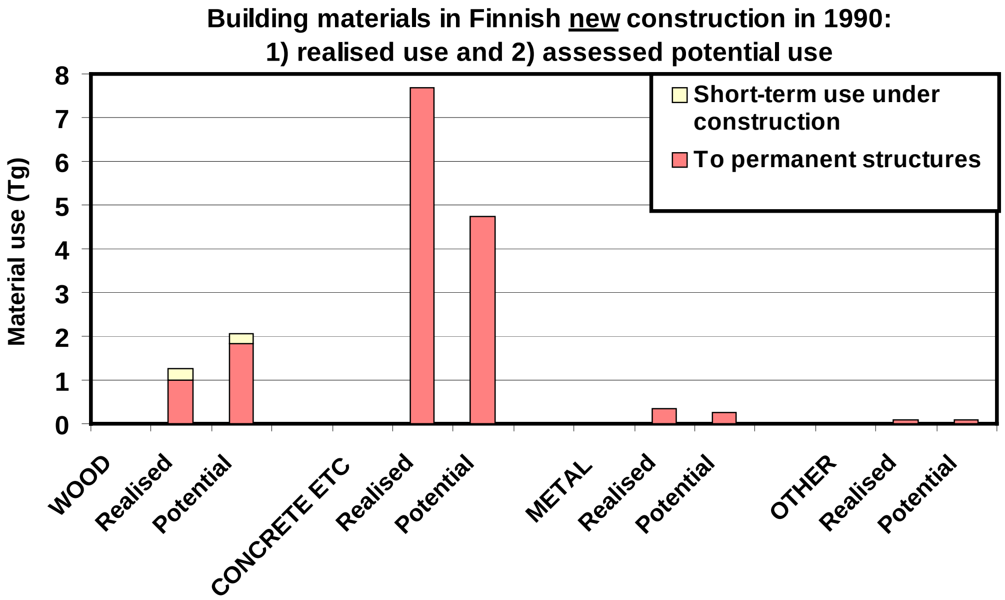
The estimated fossil C emissions of producing HWP showed significant differences. For example, the results show that the specific emissions of fossil C per wood-based C in the end products are of the order of 0.07 for sawn wood and 0.3-0.6 for paper. This means that if 1 t C is sequestered, for instance, in paper products, 0.3-0.6 t of fossil C is already emitted at the stage of production. The sawmill industry is the least energy-intensive and had also clearly the lowest fossil C emissions, despite the fact that in Finland a significant part of its wood residues was utilised elsewhere and not for its own energy production. Similar figures were calculated in the study for the primary energy used in the manufacturing. The results were also compared to fossil C emissions from harvesting and transporting of HWP in a specific case. While in the case considered the transportation distances were above the Finnish average, the combined emissions from harvesting and transport were still not higher than those observed in the production of sawn wood. Especially within the lifecycle of energy-intensive HWP, the production stage appears to be responsible for the major part of the fossil C emissions.

Box 3. Direct and indirect fossil C emissions from the manufacture of HWP in Finland in 1995 including emissions from supplied fuels and indirect emissions from purchased electricity and heat, expressed as fossil C in emissions divided by wood-based C in raw material and wood-based C in end product, respectively (Pingoud and Lehtilä, 2002).

3.3 Case example: material substitution by HWP for other structural materials

Pingoud and Perälä (2000) studied GHG mitigation potentials in construction due to material substitution, some main results presented in Box 4. The *realised Finnish new construction* in 1990 was compared with a fictitious case in which a similar building stock was assumed to be constructed by '*maximising' wood use*. The estimated maximal use was based on an expert evaluation (carried out by the *Construction sector markets team* at VTT Building and Transport), in which a realistic potential market share of wooden materials in each building element of each building type in Finland was assessed (this share being lower than the *technical* potential for wood use). Generally speaking, the lower the existing wood use, the higher is the potential use of construction wood.

In the study demand for building materials were compared in two cases: 1) the realised new construction in Finland in 1990, 2) construction of similar houses but maximising wood use in every building element. In the latter case the assessment of the maximal potential wood use was based on expert evaluation. For example, in elements in which the market shares of wood-based materials are already on high level, the increase potential is usually lower. It was estimated that the amount of wood-based products could have been increased totally by nearly 70%. Consequently, as a similar building stock was assumed to be constructed in this fictitious case 2), increased wood use leads here to decreased use of other materials, i.e. to material substitution, compared to the realised case 1):



Maximisation of wood use would have decreased the use of other building materials in 1990 by over 3 Tg (million tonnes), from 8.2 to 5.0 Tg. When considering material substitution on unit level, it can be noted that 1 kg of wooden materials could have replaced 3.6 kg of concrete, bricks and tiles, 0.12 kg of construction metals, and 0.005 kg of other products. The estimated primary energy consumption of manufacturing building materials was 8.8 TWh in realised new construction 1), whereas in the potential wood use case 2) the energy consumption would have been 7.7 TWh. The fossil C emissions from manufacturing of materials in both cases were estimated as follows:

Fossil C emissions from manufacture of building materials (Gg C)	*Realised case 1)*	*Potential case 2)*	*Potential – realised*
Wood products (energy)	79	89	9
Concrete, bricks, tiles (energy)	297	196	-101
Concrete (cement production)	128	84	-44
Metal products (energy)	133	105	-28
Other products (energy)	95	93	-2
TOTAL	***732***	***566***	***-165***

According to above estimate fossil C emissions would have been 0.17 Tg C less in the potential case than in the realised one. The C stocks of new construction wood within building stock would have been 0.37 Tg C larger. In addition, more bioenergy could be recovered in case 2) due to increased amount of wood residues. If, for example, light fuel oil were replaced by this energy, the calculatory emission reduction would have been of the order of 0.24 Tg C. More bioenergy can be recovered in the future when the construction wood is decommissioned.

Box 4. Potentials of material substitution by HWP in Finnish new construction. Comparison of realised construction in 1990 with a fictitious case in which similar houses were constructed by maximising wood use (Pingoud and Perälä 2000).

The basic idea in the analysis was to compare similar *functional units* with each other. In the fictitious case of *potential wood use* similar types and numbers of houses were assumed to be constructed, the only difference to the realised new construction being the composition of building materials. A similar analysis on material substitution in construction by Buchanan and Levine (1999) showed that a 17% increase in wood usage in the New Zealand building industry could result in a 20% reduction in carbon emissions from the manufacture of all building materials, being a reduction of about 1.5% of New Zealand's total emissions. The reduction in emissions is mainly a result of using wood in place of brick and aluminium, and to a lesser extent steel and concrete, all of which require much more process energy than wood. There would be a corresponding decrease of about 1.5% in total national fossil fuel consumption. Material substitution has also been studied by micro-level analysis. Börjesson and Gustavsson (2000) compared the impacts on GHG emissions, if concrete frames were replaced by wooden ones in a case of an individual house.

Increased production of construction wood increases basically the supply of by-products, which can be used for energy and fossil fuel substitution. It should be noted that displacement factors of wood fuels vary dependent on the fuel quality and its moisture content. In general, C emission factor of wood fuels is higher (in proportion to their primary energy content) and efficiency in their energy conversion lower than by fossil fuels like coal or oil. For instance, typically, wood fuel containing 1 kg of wood-based C could replace light fuel oil containing 0.6 kg fossil C. However, a comprehensive comparison of two alternative fuel chains in their GHG emissions requires a detailed lifecycle assessment with definition of system boundaries, where, in addition to the combustion stage, all the other relevant parts of the chains have to be taken into account (see e.g. Schlamadinger et al. 1997).

PART II. C BALANCE OF HWP – EVALUATION OF APPROACHES AND METHODS

4. Different HWP approaches and alternative estimation methods

In the following we consider HWP from the viewpoint of *estimation and reporting* for the UNFCCC. If HWP will be included in the emissions *accounting* due to the Kyoto Protocol in some later commitment period those accounting rules will be an outcome of a negotiation process and can differ from those applied in HWP estimation and reporting.

The terms *approach* and *method* are distinguished in the following. By *approach* we mean the conceptual framework for reporting national emissions and removals from HWP under the UNFCCC. In practice, the approach determines how the estimated emissions or removals are allocated to different countries. Within each approach there may be many possible *methods*, by which the C balance of HWP is estimated. The method can include various techniques (measurements, use of statistical databases, direct inventories, indirect calculations with models etc). Some methods are relevant to several approaches.

The IPCC expert meeting in Dakar, Senegal (Brown et al. 1999) examined a range of different approaches for estimating the emissions and removals of CO_2 from forest harvesting and wood products, and compared these approaches with the one in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventorie*s (IPCC 1997 a, b and c), here referred as the IPCC default approach. The default approach is basically applied so far in the national emissions estimation and reporting under the UNFCCC. This Chapter aims to be supplementary to the Meeting Report by Brown et al. (1999). Thus its main findings are not repeated exhaustively in the following. It should be reminded that whatever the chosen approach, it is applied both to forest and HWP as they are parts of the same C cycle.

4.1 Theoretical considerations on the approaches

In the IPCC default approach there is an underlying assumption that HWP stocks are in balance. Only emissions and removals related to *forest* stock change are considered. Emissions from harvested wood are attributed to the year of production and to the country of harvest, i.e. where the roundwood is produced.

Stock change = *Stock change forest*
= *Forest growth – slash – roundwood production*

The magnitude of the inaccuracies in the default approach would vary widely country by country. For some countries the effect could be significant.

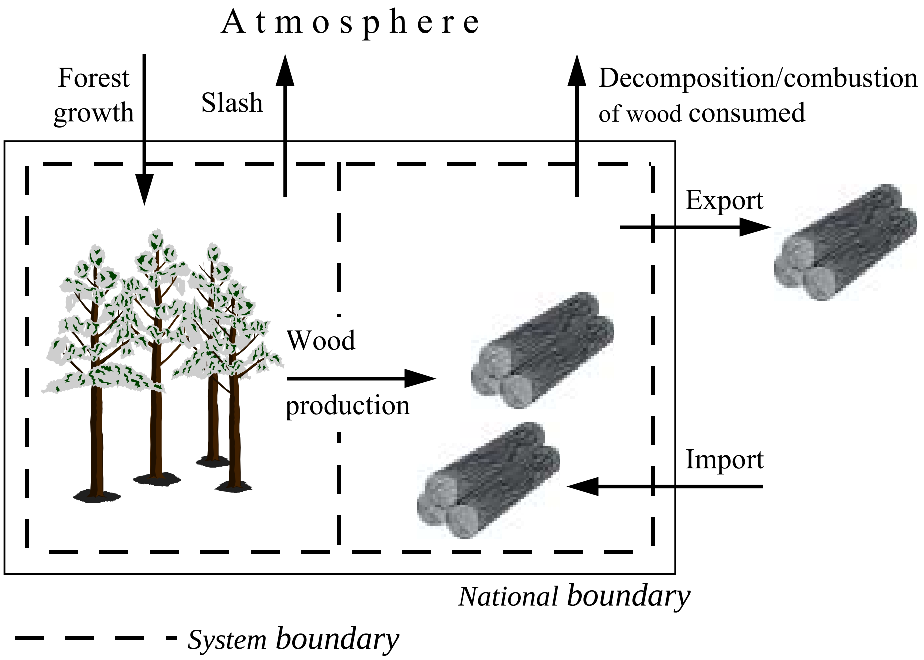
The meeting identified three alternative approaches for estimating CO_2 emissions/ removals from forest harvesting and wood products, summarised in Box 5 and illustrated in Figures 6–8.

Stock change approach - This estimates 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 the 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 also estimates the **net changes in carbon stocks in the forests and the wood-products pool**, but attributes both to the **producing** country. This approach inventories domestically produced stocks only and does not provide a complete inventory of national stocks. Stock changes are counted *wh*en, but not *where* they occur if wood products are traded.

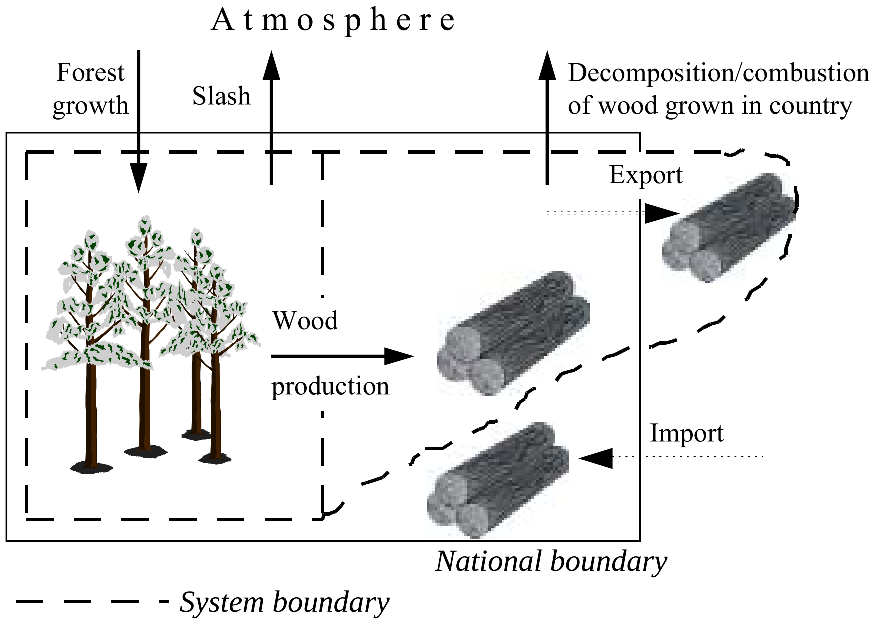
Atmospheric flow approach - This accounts for net emissions or removals of carbon to/from the atmosphere within national boundaries, *where* and *when* emissions and removals occur. **Removals of carbon from the atmosphere due to forest growth** is accounted for in the **producing** country, while **emissions of carbon to the atmosphere from oxidation of harvested wood products** are accounted for in the **consuming** country.

Box 5. The three alternative new approaches, identified in the Dakar meeting, for estimating net emissions from HWP (Brown et al. 1999).



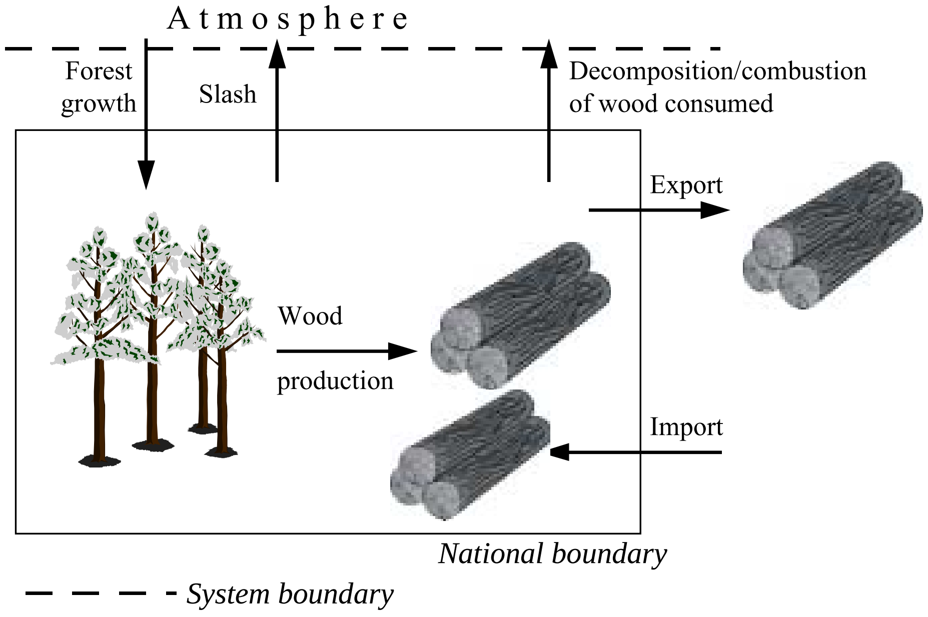
Stock change = (stock change forest) + (stock change consumed products)
= (forest growth - slash -wood production)
+ (wood consumption
- decomposition/combustion of wood consumed)

Figure 6. **Stock change** *approach (Brown et al. 1999, Lim et al. 1999).*



Stock change = (stock change forest) + (stock change domestic-grown products)
= (forest growth - slash -wood production) + (wood production -
decomposition/combustion of wood grown in country)

Figure 7. ***Production*** *approach (Brown et al. 1999, Lim et al. 1999).*



Atmospheric flow = forest growth - slash - decomposition/combustion of wood consumed

Figure 8. **Atmospheric flow** *approach (Brown et al. 1999, Lim et al. 1999). The system boundary is in this case between atmosphere and national biosphere, and the approach is focusing on C fluxes between those two stocks. Also note that: atmospheric flow = (stock change forest)+(stock change consumed products)+ export - import.*

The aim in this presentation is to follow the same terminology as in the IPCC meeting report (Brown et al. 1999). *Wood production* (roundwood production) refers here to the C flux of all wood-based material transported from forest, ending up through processing as final products (such as biofuels or structural materials). The C fluxes of *export* and *import* include all wood-based material transported across national border, including roundwood, semi-finished and final products. *Decomposition/combustion of wood consumed* includes the decay C flux of all types of HWP (fuel use, materials in use, wood-based waste in landfills) into the atmosphere.

4.1.1 Interconnections between the approaches

All the three new approaches, identified in the Dakar meeting, are equivalent in describing the *global* dynamic C balance (emission/removal) of forests and HWP. This means that all the approaches assign the emissions/removals *when* they really occur, whereas the default approach assigns emissions/removals at the time of harvest. The fundamental difference between the atmospheric flow and the other two approaches is the different perspective to the C balance: the atmospheric flow approach considers within the national boundaries the C flows from the atmosphere to the forests (removals) and from decaying slash and HWP to the atmosphere (emissions), whereas the other two approaches consider changes in C stocks of forests and HWP and interpret them as removals or emissions. The production approach also considers C stocks, which are outside the national boundaries. As a consequence of the different viewpoints, the outcomes of the approaches differ in *where* the emissions/removals are assigned, *i.e.*, to which country they are allocated. Whichever of the approaches is chosen for national emission reporting the same approach must be applied in all countries and both to forests and HWP to avoid double-counting and no-counting situations.

To identify the interrelationships between the approaches, it can be noted that the apparent wood consumption in a country is equal to roundwood production plus import minus export:

Wood consumption = *Roundwood production + import – export*
= *Roundwood production – net export*

Wood consumption represents the input C flux to the stock of HWP in a country. The quantity to be reported is *C removal* (= sink). Removal is interpreted to be the positive stock change in *stock change* and *production* approaches and the atmospheric flow (= net C flux from the atmosphere to the system of forests and HWP within a country) in the *atmospheric flow* approach. The definitions of the approaches can now be made easier to compare and (as presented by Flugsrud et al. 2001) the C removal in each case can be expressed either in flux or stock change terms (here forest stock contains only tree biomass, not soil carbon; slash includes felling residues, litter production of living trees and natural mortality of trees):

IPCC default approach:
Removal *= Forest growth – slash – roundwood production* (flux)
= Stock change forest (stock ch)

Stock change approach:
Removal *= Forest growth – slash – net export –* (flux)
decomposition/combustion of wood consumed
= Stock change forest + stock change consumed
products (stock ch)

Production approach:
Removal *= Forest growth – slash–* (flux)
decomposition/combustion of wood grown in country
= Stock change forest + (stock ch)
stock change domestic grown products

Atmospheric flow approach:
Removal *= Forest growth – slash –* (flux)
decomposition/combustion of wood consumed
= Stock change forest + stock change consumed
products + net export (stock ch)

(In above equations it has been taken into account that *roundwood production = wood consumption + net export* and that *wood consumption - decomposition/combustion of wood consumed = stock change of consumed products.)*

Despite of the above interrelationships between the approaches, which apply on country level, we should note the aforementioned fundamental difference in the viewpoint of the approaches. This difference becomes apparent considering the national wood-based C cycle, separated into the subsystems of *Forests* and *HWP* illustrated in Figure 9.

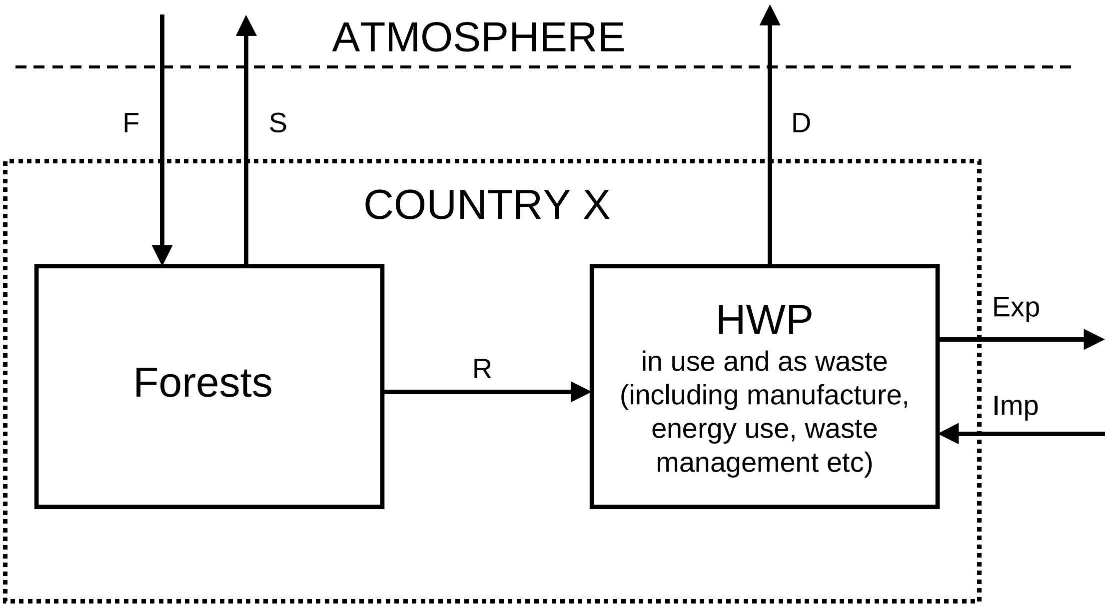
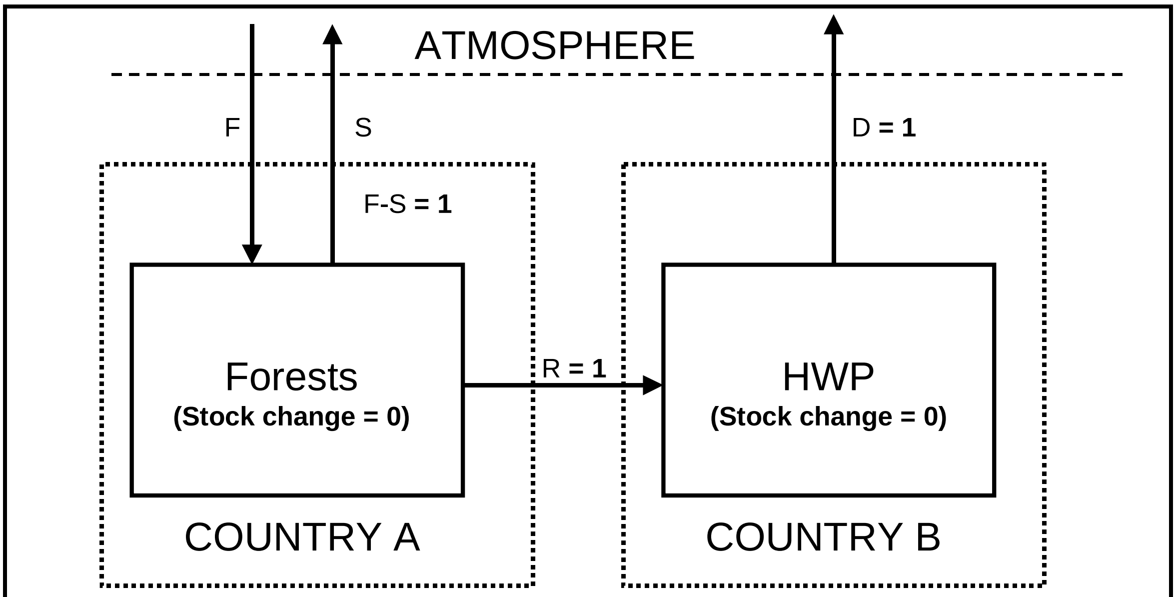


Figure 9. Illustration of the stock change and atmospheric flow approaches. F = Forest growth, S = Decomposition of biomass, R = Roundwood production including all tree-based material transported from forest, D = Decomposition/combustion of HWP, Exp = Export of all wood-based material, Imp = Import of all wood-based material.

Following the viewpoint of the atmospheric flow approach, only one of the subsystems, *Forests*, can act as C sink, due to the photosynthesis process of forest biomass causing flux F. **HWP could only act as a potential source**, although their stock would grow, be renewable and be based on sustainably produced roundwood. In principle, if the atmospheric flow approach were applied down-scaled within national boundaries, only forest owners could be attributed to C removals. Consumers of HWP could only cause calculatory C emissions into the atmosphere due to the decomposition flux D. Net-importer countries of HWP are basically C sources in atmospheric flow approach, as more wood-based C is decomposed within their national boundaries than sequestered in their forest growth.

At present countries report in their communication under the UNFCCC the changes in forest and other woody biomass *stocks*. The IPCC default approach means that only changes in forest C stocks (converted into CO_2) are reported, a stock increase interpreted as negative emission or removal. If HWP were added to the reporting, the stock change approach would be congruent with the present reporting system and would simply mean that the changes in HWP stocks would be added to the forest stock changes. In the production approach this would also include those exported HWP, whose origin is in the reporting country's forest, and exclude those domestically manufactured HWP, whose raw material is imported. It is not fully clear which one of the above two approaches is meant in the *Revised 1996 IPCC Guidelines*, Vol.3 (IPCC 1997c, p. 5.17, Box 5), when outlined the inclusion of HWP in the *reporting* system to the UNFCCC (see Box 1 of this report). However, reporting of some C stocks being outside national boundaries, as in the production approach, might be inconsistent with the generic idea of estimating and reporting GHG emissions and removals within national borders.

The conceptual change induced by the atmospheric flow approach means literally that we should report the net flux *Forest growth – slash* as removal due to forests (which is different from present reporting of *Forest growth – slash – roundwood production*), whereas for HWP we should report the whole flux D = *decomposition/combustion of wood consumed* as an emission into the atmosphere. If atmospheric flow approach were chosen to the base of reporting, this would also require a modification of the *1996 IPCC Guidelines* (IPCC 1997abc) both regarding reporting of forests and HWP. For instance, the above-mentioned Box 5 (cited in Box 1 of this report) could not form the outline for HWP reporting, if the atmospheric flow approach is used. A possible outcome of the atmospheric flow approach is illustrated in Box 6 below.



REPORTED REMOVALS:	**COUNTRY A**	**COUNTRY B**
IPCC default approach	**0**	**0**
Stock change approach	**0**	**0**
Atmopheric flow approach	**+1**	**-1**
Production approach	**0**	**0**

Box 6. A simple example for comparing the outcomes of the approaches. Assumptions: Stock changes in forests and HWP = 0 in countries A and B. Country A is exporting all its roundwood production =1 into country B. F = Forest growth, S = Decomposition of biomass, R = Roundwood production including all biomass transported from forest, D = Decomposition/combustion of HWP. In case of the atmospheric flow approach even if there are no stock changes in forests or HWP, country A reports a removal of 1 unit and country B a removal of –1, i.e. an emission of 1 unit.

4.1.2 Linkages to Energy and Waste sectors in estimation and reporting

Regardless of the HWP approach considered in this report, no principal changes are needed in the estimation and reporting system of national GHG emissions in other sectors. This is because all the emissions/removals associated with HWP will already be reported by each of the three HWP approaches under the *LULUCF* sector. Thus, to avoid any double counting of emissions the use of wood-based fuels or decay of wood-based waste, reporting in the *Energy* and *Waste* sectors should remain C neutral. For example, the imported biofuels are interpreted as emission sources in the atmospheric flow approach. This emission is brought into the reporting system through the negative *net export* term (see the stock change based equations for the atmospheric flow approach in section 4.1.1) and should not anymore be accounted for in the *Energy* sector. In other words, wood-based energy is not free of C emissions in the national GHG budget, but instead of the *Energy* sector it will be reported under the *LULUCF* sector.

4.2 Estimation of removals due to the three approaches

Application of each of the approaches requires that the quantities appearing in their defining equations (section 4.1.1) have to be estimated someway from reality using existing statistics, databases and sampling techniques or indirectly by performing model calculations etc. This section considers alternative methods for obtaining such estimates.

4.2.1 Removals relative to IPCC default

The existing practice for reporting wood harvesting in the *National GHG Emission Inventories* is to report only the C stock changes in forests (expressed as equivalent CO_2 amounts), which is called the *IPCC default approach*. The numerical outcomes of the three 'new' approaches will be presented in this report *relative* to the *IPCC default approach*, i.e. only removal/emission in excess of that of IPCC default will be given. (This means that *stock change forest* is not considered in this connection and it is subtracted from the equations of section 4.1.1.) The difference is called here the *excess removal* and is given by the equations (analogous to those equations in Section 4.1.1):

Stock change approach, difference to the IPCC default:
Excess removal *= Roundwood production – net export –* (flux)
decomposition/combustion wood consumed
= Stock change of consumed products (stock ch)

Production approach, difference to the IPCC default:
Excess removal *= Roundwood production –* (flux)
decomposition/combustion of wood grown in country
= Stock change domestic grown products (stock ch)

Atmospheric flow approach, difference to the IPCC default:
Excess removal *= Roundwood production –* (flux)
decomposition/combustion wood consumed
= Stock change consumed products + net export (stock ch)

Note that in case of the atmospheric flow approach the *excess removal* does not represent the real atmospheric flow (i.e. emission) due to HWP, which is equal to *roundwood production – excess removal* (=D in Figure 9)!

4.2.2 Basic alternatives for estimation methods

The approaches discussed define only a framework for estimation. Regardless of the approach we need an *estimation method* describing a way, how to obtain removal estimates from available data in practice. The two sets of equations above show that in all the approaches, the removal can be estimated using either an *emission* angle or a *stock change* angle as noted by Flugsrud et al. (2001). The two angles are complementary, as all wood consumed goes either to stocks or emission. Different methods are used for estimating the quantities in the definitions. We have to distinguish between the *approaches*, which focus on either stocks or emissions in order to assign removals to countries, and the actual *estimation methods*, which can be based on either stocks or emissions depending on the availability of data.

It is reasonable to develop estimation methods separately for the two major HWP pools, *HWP in use* and *HWP as waste in solid waste disposal sites* (SWDS), the system under consideration shown in Figure 10. There are several grounds for that. Product and waste sector statistics, if available, are compiled separately. Decay patterns of HWP in use and as waste differ essentially from each other. Due to the slow decay of HWP in landfills they may form a significant C stock (and removal when the stock is growing), and cannot be neglected when considering C balances in HWP. For those HWP, being short-lived in use, accumulation into landfills can be a decisive factor in their GHG balance. It is of course possible to consider the whole HWP lifecycle (in use and as waste) as an aggregate in the estimation method (see e.g. Winjum et al.1998, Sikkema et al. 2002). However, the main weakness is then the difficulty to give any good physical interpretation (and any default values) for the decay parameters in such aggregated models. So in fact a slightly more complex system description (in this case HWP divided into two major pools) may give an access to easier estimation of model parameters.

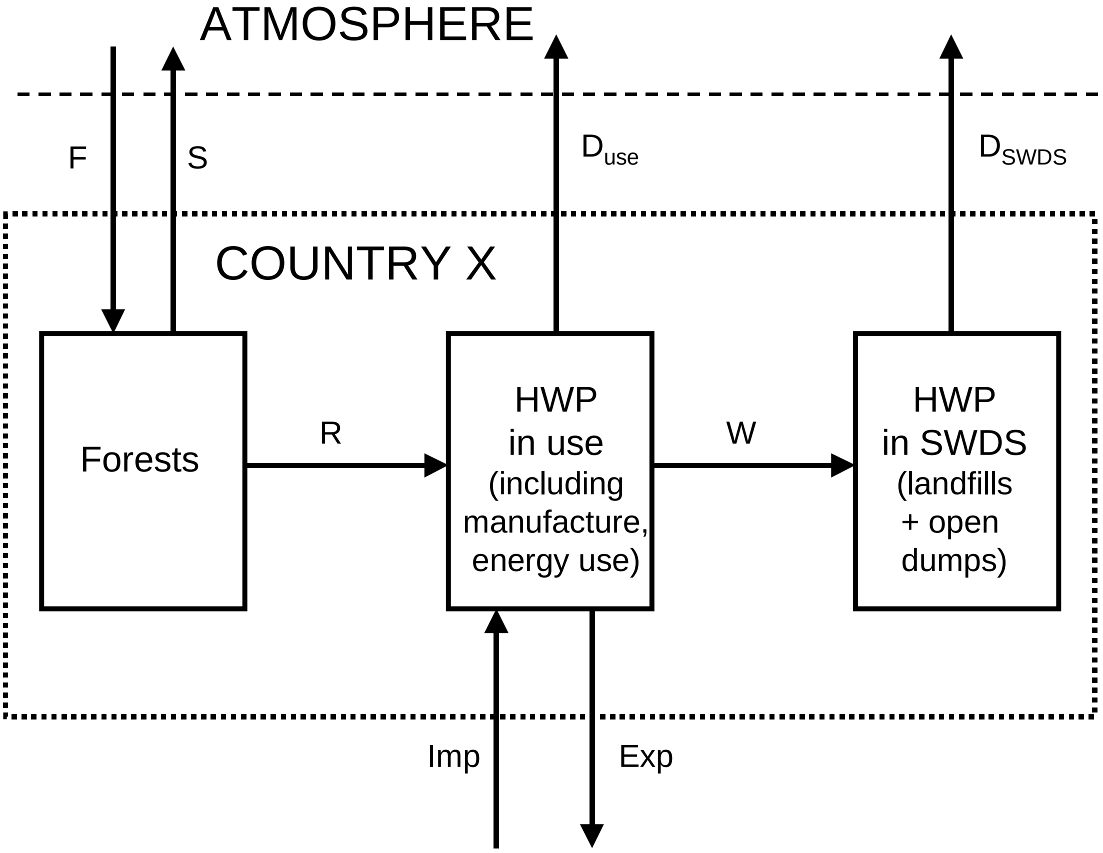


Figure 10. The main HWP stocks and associated flows to be considered in the estimation methods. SWDS = Solid waste disposal sites, which are landfills where decay in essence takes place in anaerobic conditions, or open dumps with mainly aerobic decay. F = Forest growth, S = Decomposition of biomass, R = Roundwood production including all tree-based material transported from forest, D_{use} *= Decomposition/combustion of HWP in use, W = Wood-based waste disposed into SWDS,* D_{SWDS} *= Decomposition of HWP in SWDS or combustion of HWP based methane from landfills, Exp = Export of all wood-based material, Imp = Import of all wood-based material.*

In the following we consider different estimation methods and specifically their applicability to each of the approaches. In principle the basis can be either in estimation of *stock changes* by some means or then in direct estimation of *emissions* from HWP.

4.2.3 Estimation of changes in stocks

Different methods can be used in the estimation of HWP *stock change*. Stock change estimates can be used in all the three approaches. The two main stock methods are based on either *flux data* or *stock data*. Any stock change over a period may be calculated 'from the outside' by a flux method, counting the fluxes into and out of the stock, or 'from the inside' by a stock method, calculating the difference between total stock at the beginning and the end of the period (Flugsrud et al. 2001). In the stock method no flux data are used. Ideally the two methods give the same results, in case all data sources are complete, exact and consistent. The final choice of method will depend on the data available in a particular country and the characteristics of a particular point of storage.

4.2.3.1 Flux data methods

Two main alternatives are available in *flux data* methods. In general, statistics on production, export and import rates of different HWP (i.e. the input flux of the HWP stock) are compiled, but there are no reliable observations on the output flux or decay of the HWP stock.

Lifetime analysis

Lifetime-analysis based methods are applicable in this case. Lifetimes and decay patterns of different HWP are first estimated and the output flux and the C stock change are then calculated on the basis of this information and the input flux (see e.g. Winjum et al. 1998, Karjalainen et al. 1994, Apps et al. 1999). Lifetime estimates of HWP used in various models have been collected by Sikkema et al. (2002). In most cases dynamical models are used to integrate the C stocks in HWP and their stock changes, starting from a (guessed) initial value of the C stock in the past to get an estimate for the C stock and stock change at present. The integration over time is needed to obtain a realistic estimate of the stock of previously consumed HWP and their decay flux. The longer the integration period or the shorter the lifetime of HWP, the less sensitive the stock change estimate is to the initial value. If the real C stock including the old HWP is underestimated e.g. due to too short integration period, then also the decay of old HWP, i.e. the inherited emissions, are underestimated in these lifetime based models. This in turn leads to an overestimate in net C removal in the HWP stocks.

Lifetime analysis has some weaknesses. The estimates of lifetimes of HWP presented in the literature are mostly hypothetical and highly uncertain, loosely based on some practical experience. In more detailed models, every product type is divided into different end use categories (e.g. short-term, medium-term and long-term use), all having lifetime parameters of their own. Additional parameters are needed to describe the division of HWP into the above end-use categories. Increased complexity does not necessarily make such models more reliable or their parameter estimation easier. The main problem is the lack of reliable data. In reality, lifetimes of different types of HWP in use vary both with end use category and time, decommissioning of HWP in use being dependent on economic and fashion trends etc (Pingoud et al. 2001). In addition, as the lifetimes are time-varying parameters, not even the use of long integration periods in model initialisation does necessarily guarantee the reliability of the results.

A specific stock, for which *lifetime-analysis* based methods may be the only alternative in practice, are HWP in solid waste disposal sites (SWDS). The decay of HWP as waste in SWDS can be estimated by methods being similar to those described in the Good Practice Guidance for the *Waste* sector (IPCC 2000b), based on assumptions on lifetimes or equivalently, decay rates of different waste fractions. In these methods one part of waste is assumed to decay exponentially whereas the rest is forming a non-decaying permanent stock in anaerobic conditions of landfills. In general, the uncertainties of methods for HWP in SWDS are greater than those for HWP in use.

Inflow-outflow analysis

Another alternative flux data method is *inflow-outflow analysis* where, instead of the hypothetical assumptions on HWP lifetimes, the outflow of the HWP pool (e.g. waste flows) is observed directly, but no reliable statistics appear to be available for application of such methods. In general, inflow-outflow methods are sensitive to errors in the input, as the stock change is usually a relatively small difference between large inflows and outflows. They are also prone to systematic errors that cannot be corrected by long-term controls.

Practical applicability

In the *lifetime analysis*, the stock change is proportional to the inflow. The uncertainty introduced by this method seems smaller and more easily controlled, and thus *lifetime analyses* are more robust with respect to errors in the input than inflow-outflow analyses as noted by Flugsrud et al. (2001).

Flux data on HWP are easily available in the FAO statistics (FAOSTAT 2002), where data for production, export and import of semi-finished wood products from 1961 are given for most countries in the world. These data might form a basis for a default method applicable for all countries. The quality of HWP data in the FAO database is variable as noted by Brown et al. (1999). The FAO collects these data from countries through questionnaires. Typically, countries collect the commodity data using standard collection procedures specified under trade agreements. The FAO also compares the national data with the UN statistics as a consistency check. The error bar around these data is about ±10-15% for OECD countries and as high as ±50% for non-OECD countries. Data on roundwood production appears to be less reliable than trade statistics as there are no independent checks to verify them. The fact that FAO data are given only from 1961 is also a source of uncertainty when long-lived HWP are considered. Another international database, where data for purpose of HWP approaches can be found, is the *EFI-WFSE Forest Products Trade Flow Database 1962-2000* (Michie and Wardle 2003).

Some approximate estimates of the previous fluxes are needed in the estimation models. The development of production of HWP could be described, for instance, by exponential growth, where the increment percentage before 1961 were estimated from some general economic indices or from development of roundwood consumption.

Contrary to the above input fluxes into HWP stocks in use, there are no long-term international statistics of waste fluxes into SWDS and more specifically, HWP fluxes into SWDS. They may be estimated in some cases directly from waste statistics, by assessing the share of wood based material in the waste flow. Another alternative is to assess the percentage of decommissioned HWP disposed into SWDS and then calculate the input flux to SWDS on the basis of the output/decay flux of the models for HWP in use.

To conclude, flux data methods include a number of assumed parameters. Parameters in flux data methods with a high uncertainty are the assumptions of lifetimes for different HWP in use and especially those for HWP in SWDS. The historical input fluxes into SWDS needed in the methods are also very poorly known.

4.2.3.2 Stock data methods

In *stock data methods* HWP stocks themselves are estimated directly by various methods, for example from statistics concerning HWP in use or by some sampling techniques. These methods could also be called inventory-based. They are in practice limited to some major long-lived HWP stocks, for instance, HWP in building stock, whereas paper stocks do not seem to be suitable for stock data methods. This is because it is so difficult to obtain reliable data on paper stocks and, secondly, for stocks with short lifetimes the stock changes are large relative to the stock, and the stock may change rapidly as noted by Flugsud et al. (2001). Studies by Alexander (1997), Gjesdal et al. (1996), and Pingoud et al. (1996, 2001) present direct stock inventories or stock data methods.

The principal advantage of direct inventories is that no hypothetical assumptions on lifetimes of HWP are needed, as the basic entity to be estimated is the stock itself. A major advantage of stock data methods over flux data methods is that the accumulated stock change over longer periods can be estimated with less uncertainty (Flugsrud et al. 2001). With flux methods, there is usually no gain in precision from longer periods. For example, due to uncertainty in fluxes and very long lifetimes of buildings, the data on building stock are considered more reliable. The commonly available information is the volume or area of the national building stock. The parameter to be estimated is the *conversion factor* describing the tonnes of HWP in building volume or area. In some countries official statistics include information, for instance, of bearing frame materials of buildings. More detailed information on construction is usually gathered in building permits, but this information is restricted to newer buildings. In principle, stock data methods appear to be more robust compared to flux data methods. For example, a fast change in above conversion factor may immediately indicate on errors in estimate. Stock inventories may also be applied in the estimation of both the initial value and lifetime parameters, needed in the methods described in section 4.2.3.1 (see e.g. Pingoud et al. 2001). However, the global applicability of stock data methods is open, as they have been tested only in some few countries. The comprehension of the national statistics on building stock for such purpose should be assessed.

In its simplest form stock data method applies direct conversion factors (Gjesdal et al. 1996, Flugsrud et al. 2001):

$$C\ stock = Total\ utility\ floor\ space,\ m^2 * tonnes\ wood/m^2 * C\ content\ in\ wood$$

More exact conversion factors may be applied, if statistics include information on building types and buildings are grouped into age classes. For example, the inventory of HWP in Finnish construction is in detail described in section 7.1 and by Pingoud et al. (2001). The total C stock is calculated by the formula

$$\text{C stock} = \Sigma_{i,j}[A_{ij}(S_{ij} + P_{ij})]$$

where

C stock = C reservoir of wooden materials in building stock (t C),
A_{ij} = building stock of building type i in age class j (building-m^3)
S_{ij} = amount of C in sawn wood and logs in building type i and age class j (t C / building-m^3)
P_{ij} = amount of C in wood-based panels in building type i and age class j (t C / building-m^3)
and where age class j refers to the decade of its construction.

The cost and time uses for the collection of stock data in the Finnish study (Pingoud et al. 2001) appeared to be reasonable, as the data needed were already mainly produced for other purposes.

The methods can also be combined, stock data method applied to some end use categories of HWP and flux data to others. In the Norwegian studies (Gjesdal et al. 1996, Flugsrud et al. 2001) some major long-lived HWP pools in building stock and furniture were estimated by stock data methods whereas paper and HWP in SWDS were estimated by flux data methods. Some inaccuracy may arise from the fact that the use of flux data and stock data may be partially overlapping (e.g. sawnwood consumption and construction wood in housing stock) and partially some smaller stocks are neglected, when using purely stock data methods (e.g. construction wood outside housing).

4.2.4 Direct estimation of emissions

The direct emission method has been briefly tested in the Norwegian study by Flugsrud et al. (2001). In theory, it gives the same result for a given approach as the methods using stock changes. For this method estimates of all forms of decomposition and combustion of wood materials in a country are needed, including e.g. energy use of wood derived fuels, waste incineration, landfill gas, fires in buildings, natural decay of wood-based materials in buildings etc. In practice some of the estimates will have large uncertainties. The outcome is then calculated by some of the flux equations given in Section 4.2.1. It is presumable that the total emissions will be underestimated by this method, as some emission sources cannot be detected and on the other hand *roundwood production* is well known. According to Flugsrud et al. (2001) it is likely that emissions are underestimated by above method and, correspondingly, stock changes by stock methods. If the direct estimates of both emissions and stock change are too low, then estimates of CO_2 removals will be higher when using the emission angle, which can be seen by comparing the flux and stock change equations in Section 4.2.1. The conclusion of the Norwegian study was that a stock change angle (flux or stock methods) should be used instead of the emission method. This choice also has a certain theoretical advantage: all carbon inflow that is not specifically accounted for as stock change is assumed to be emitted. However, direct emission estimates are a useful independent check of the stock change estimates, and they enable more wellfounded assumptions about the uncertainties.

4.2.5 Summary of the applicability of the estimation methods

The features of the estimation methods considered are summarised in Table 4.

Table 4. Pros and cons of the different estimation methods.

	Pros	Cons
ESTIMATION OF STOCKS		
Flux data methods		
Lifetime analysis	− More robust than inflow-outflow analysis. − Unified FAO database on HWP providing production and trade data of primary and semi-finished products for most countries in the world since 1961. − FAO database quite reliable at least for developed countries.	− Empirical basis of lifetimes of various HWP in different end-not too strong. − True lifetimes of HWP in use are not constant in time, they vary depending on economical and fashion trends etc. − Input fluxes of HWP into solid waste disposal sites poorly known in all countries, especially historical fluxes. − Dynamic model needed to calculate stock change.
Input-output analysis	− Unified FAO database on HWP providing data on input fluxes. − FAO database quite reliable at least for developed countries.	− Output fluxes of HWP stocks poorly known. − No unified databases available. − Sensitive to errors in input-output data, as stock change usually a relatively small difference between large inflows and outflows.
Stock data methods		
	− In direct inventories no assumptions or estimation of lifetimes are needed. − No dynamic models needed. − More robust than flux data methods, accumulated stock change over longer periods can be estimated with less uncertainty. − In future, statistics on construction and building stock could be developed to include information on construction materials.	− Not generally applicable, due to lack of data for most countries. − No unified databases or statistics − Suitable only for major HWP stocks, e.g. in construction. − Country-specific estimation methods needed, including relevant basic statistics and additional sampling techniques.
DIRECT ESTIMATION OF EMISSIONS		
	− No information on HWP stocks needed.	− Input fluxes to HWP pool relatively well known, whereas all emission sources cannot be detected. − Consequently, tends to overestimate the accumulation of C in HWP.

4.2.6 Methods for estimation and reporting under UNFCCC and their applicability to different approaches

In general, production rates as well as exports and imports rates of HWP are basically well compiled, whereas real decay rates or average lifetimes of HWP are poorly known. A common basis for international emissions reporting on HWP could compose the FAO database (FAOSTAT 2002), which includes international statistics on production, imports and exports of roundwood and semi-finished HWP, mainly since 1961. The *EFI-WFSE Forest Products Trade Flow Database 1962-2000* by Michie and Wardle (2003) provides information on international trade of HWP. These can directly be used as input data in the estimation models. Waste statistics is in general poorer, and no global databases directly applicable exist. Especially historical waste flows into SWDS are mainly not known, nor the share of wood-based material in them. Further, in general every country has better knowledge of lifecycle of HWP within in its own borders than in the export markets.

Similar methods and data can mainly be used for the atmospheric flow and stock change approaches, the atmospheric flow approach requiring in addition to stock change the net export term. This extra term in the calculation of the removal compared to the stock change approach causes in principle higher uncertainty. However, there are many uncertainties in the estimation of stock changes in HWP, as discussed in previous sections, whereas data on HWP trade flows are easily available from the national external trade statistics. The statistics of unprocessed and semi-finished HWP are quite accurate, but minor wood material flows (in m^3) associated with traded final products (e.g. furniture, pre-fabricated houses etc.) are basically not compiled. The trade flows given in m^3 or metric tons per year have to be converted into mass of C per year. Estimation of these factors might be much more accurate than estimation of C *stock changes in HWP*[1].

Estimation methods can focus on various parts of the HWP production chain, unprocessed products like roundwood, semi-finished like sawnwood, pulp and paper, or final products, like houses and books. Flux data are in principle needed in the estimation methods for all the approaches. Accounting of stock changes can be carried out by focusing on some of the above parts. In practice, however, the advantage of counting unprocessed or semi-finished products is that the statistics are easily and commonly available for all countries (FAOSTAT 2002). Further, quality of data is in general relatively high and the risk of double counting is small (Flugsrud et al. 2001). The disadvantage is that the fate of the product is less precisely known. For example, when calculating stock changes in a country on the basis of flux data for semi-finished products, it is possible that some of the products are in reality exported as final products to another country. In this case the stock change would be still allocated to the

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[1] This may in some cases influence the relative accuracy of the approaches: If the net export term is dominating the excess removal in the atmospheric flow approach (consisting of two terms: stock change consumed products + net export), its relative accuracy can be artificially better than that of the stock change approach (consisting only of the more uncertain term stock change consumed products). However, as globally the C balance due to HWP is only defined by their stock change, the accuracy of the estimate of the term stock change consumed products is a crucial part of the estimation methods for all the approaches.

producing country of the semi-finished product, as the fate of the final product is not followed. On the other hand, if both semi-finished and final HWP including to the same production chain were simultaneously considered, there would be substantial risk for double counting in the stock change estimates of a country.

The above difficulties can be partially avoided by stock data methods (section 4.2.3.2), which cannot however be applied to all HWP stocks. Combination of flux and stock data methods also embodies risks for double-counting and no-counting situations. When considering the pure net export flux term needed in the atmospheric flow approach, the total C flux of all HWP should be included. The only limitation is the availability of reliable statistics on C flux in the traded final products. In general all methods and approaches will need a detailed documentation in order to be transparent.

4.2.6.1 Method under development for IPCC Good Practice Guidance

An example of HWP estimation methods is that one being under development for the IPCC Good Practice Guidance for the *LULUCF* sector. The main objective is to provide an estimation method for C stock changes in HWP, a task, which was already outlined in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 1997c, p. 5.17), quoted in Box 1 of this report. The spreadsheet model EXPHWP, developed by Kim Pingoud, is in addition to stock change approach incorporating the other two 'new' HWP approaches, as there is no decision on the choice of the HWP approach. The *excess removal* of the different approaches is derived through stock change variables (equations in section 4.2.1). The spreadsheet is aimed to serve as a tool in the national GHG inventories concerning HWP. The model and its algorithms are described in detail in Chapter 8.

In the model there are separate stocks for *HWP in use* and *HWP in SWDS* (Figure 10). Their stock changes are estimated by a flux data method (section 4.2.3.1) based on lifetime estimates of solid wood products and paper products in both above stocks. Solid wood products (sawnwood, wood-based panels and fibreboard) and paper products (paper and paperboard) were separated from each other in the model, as their lifetimes appear to differ from each other essentially. A first-order decay is assumed in HWP stocks, which means that the decay is exponential. In addition, in the SWDS a certain part of waste is assumed to form a permanent stock. Estimation of changes of *HWP in SWDS* is based on methods developed previously under Good Practice Guidance for Waste sector (IPCC 2000b).

The input flux to the aggregated stock of *HWP in use* is the sum of apparent consumption of all *semi-finished* HWP (converted to C flows). The input flux to *HWP* *in SWDS* is calculated from the output flux of *HWP in use* by giving an estimate for the share of decommissioned products disposed into SWDS. As basic data the proposed method uses the FAO Forestry database on wood-based products (FAOSTAT 2002), including the national production rates and international trade flows of major groups of unprocessed and semi-finished HWP, most compiled since 1961. The apparent consumption of semi-finished HWP is calculated based on production, export and import rates. The consumption rates prior to 1961 are in the model estimated by exponential growth. The C stocks and their changes are integrated in the model starting from year 1900 by assuming the initial stock to be zero. In the C flux estimate of the *net export* term, needed in the atmospheric flow approach, trade of all unprocessed and semi-finished HWP is included.

4.2.6.2 Particular difficulties associated with the production approach

Application of the production approach to an estimation framework causes additional difficulties for practical calculations, illustrated in Figure 11. The production approach requires data on stock of HWP from domestically grown wood. This estimation must rely on additional approximations and assumptions, as data are not directly available. While the production approach is intuitive, it lacks transparency due to the number of assumptions required. The basic difficulty is to follow the lifecycle of harvested wood over country borders. For example, wood harvested in one country can be transported as roundwood to a second country, where it is processed and transported as a semi-finished product to a third country, where it is finished and end-used. In addition, HWP can be mixtures of wood harvested in several countries. Further, we do not know the true end use in country Y of the particular wood harvested in country X, as country Y may import roundwood (often of different quality and end uses) from many other countries. The fluxes indicated by dashed lines in Figure 11 have to be excluded from accounting under the production approach. For example, even some HWP which are exported from country X have to be excluded, as they are produced from imported roundwood R_{abr}. Some paper products may in fact be mixtures of fibres of domestic and foreign origin.

Considering specifically the *Waste* sector reporting, application of the production approach would lead to a paradoxical situation. The C stock changes of HWP in SWDS would be reported in the country, which originally produced the roundwood, whereas the methane emissions from the same HWP are reported in the country where the SWDS are located.

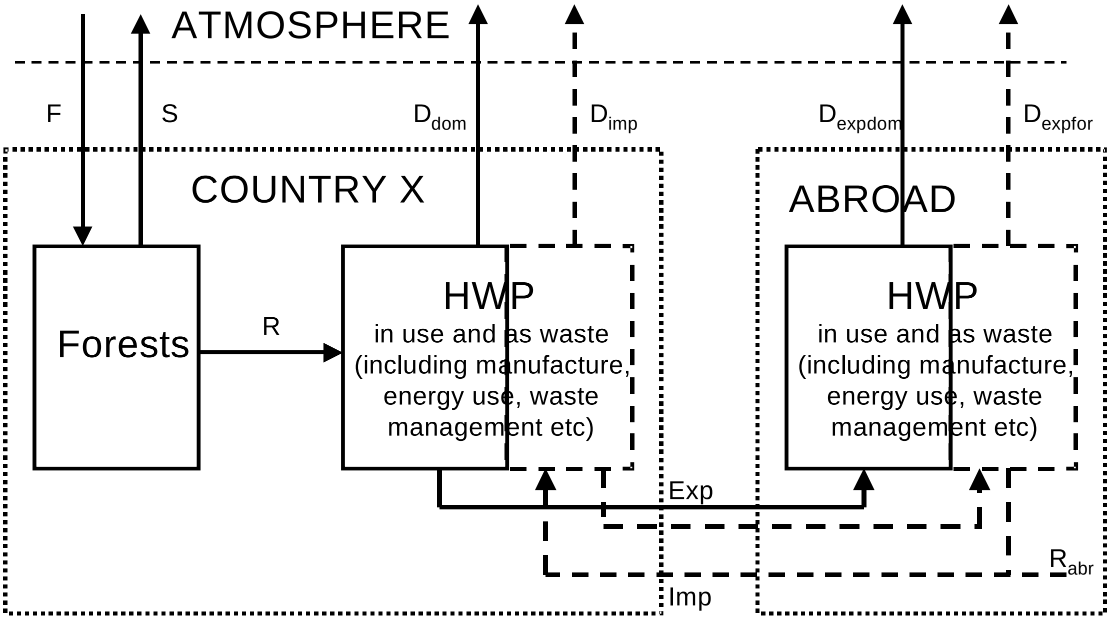

Figure 11. Illustration of the production approach. F = Forest growth, S = Decomposition of biomass, R = Roundwood production including all tree-based material transported from forest, D_{dom} *= Decomposition/combustion of HWP in country X manufactured from domestic roundwood,* D_{imp} *= Decomposition/combustion of HWP in country X manufactured from roundwood grown in foreign forests,* D_{expdom} *= Decomposition/combustion of exported HWP manufactured from domestic roundwood,* D_{expfor} *= Decomposition/combustion of exported HWP manufactured in country X from roundwood grown abroad, Exp = Export of all wood-based material, Imp = Import of all wood-based material,* R_{abr} *= Roundwood production abroad.*

For the stock data methods the calculations for the production approach become infeasible due to the problems with calculating the changes in stocks of all exported wood products in different countries. It is nearly impossible to track the origin of wood and estimate the foreign stock of domestically grown wood. In practice only flux data methods with lifetime analysis may be applied. One pragmatic way of approximating the reality is to make an assumption that the fate of exported wood is similar to that consumed domestically. Similar approximations have to be made concerning imported roundwood, which is used as raw material of domestic forest industries. First the percentage of roundwood consumption of domestic origin has to be estimated, and then perhaps assume that the percentage of semi-finished HWP of domestic origin would be the same in all product groups manufactured. This kind of approximations has been done, for instance, in the EXPHWP model mentioned in section 4.2.6.1. Consequently, because of above approximations the estimation method for the production approach does not lead to same global emissions estimates as those for the stock change or atmospheric flow approaches. The estimation must rely on additional approximations and assumptions, as data are not directly available.

While the production approach is intuitive, it lacks transparency due to the number of assumptions required. For the production approach the way that domestic wood products is calculated is a source of quite high additional uncertainty. Reduction of this uncertainty would require an international reporting system tracking flows of HWP.

5. Incentives of the different approaches and implications for the international trade of HWP

5.1 General issues

First of all it should be noted that although C stock changes in HWP are at the moment neither included in the national *estimation and reporting* for UNFCCC nor in the *accounting* due to the Kyoto Protocol, incentives are still provided for HWP use in climate change mitigation, and they could for instance be one option in *policies and measures* by the governments. This is due to the indirect reduction in fossil C emissions, which can be accomplished by using HWP, as in C *accounting* they are considered neutral with relation to atmospheric C balance. Wood-based biofuels can be used as substitute for fossil fuels and some other HWP as substitute for fossil and energy intensive materials. In fact, main problem for applying policies and measures concerning HWP may at present be the lack of awareness of the substitution impacts and on determining quantitative estimates.

The main subject of this section is, however, the additional incentives due to the previously discussed HWP approaches in comparison with present situation. Here we naturally assume that the same approach is consistently used in all reporting countries. The opposite would lead to double-counting or no counting situations. The difference between the approaches follows from the fact that the emissions and removals are allocated differently, also being dependent on the trade flows between countries. The strength of the thinkable incentives depend, if HWP are *only* included in the national GHG emissions inventories *reported* by one of the above approaches or, if, in addition, HWP are incorporated in the emissions *accounting* due to the Kyoto Protocol having impact on the assigned amounts (AAs) of the Parties.

In the former case, the incentives due to the inclusion of HWP in the national *reporting* system to the UNFCCC are conceivably much weaker, which can be reasoned as follows: In the current reporting guidelines for greenhouse gas inventories (IPCC 1997abc) emissions from forestry and from biofuels are reported separately from the national total. If countries were reporting C emissions from HWP in similar way, i.e. as auxiliary numbers, having no impact on their commitments, the choice of the HWP approach may basically have no impact on the international trade of HWP. However, the choice of the approach could have an impact on the image of HWP. The approach could picture long-lived HWP as renewable or ‘green’ products, which could assist in storing atmospheric C. This could be used for instance in marketing. Another alternative would be the image of HWP as potential C sources like fossil fuels, which should be avoided. Even the materialised incentives might still be quite strong, as simply the choice of the approach for *estimation and reporting* could be anticipatory and prescriptive for the final choice of the *accounting* approach (assuming HWP will be included to Kyoto accounting sometime in the future).

In the latter case, where HWP would be already included in the Kyoto *accounting* in addition to *estimation and reporting*, the potential incentives would be much stronger as they may have direct economic consequences for countries being compelled to the commitments of the Protocol. This inclusion could be topical in the second commitment period at the earliest. The *accounting* rules negotiated in the future are not necessarily similar to anyone of the approaches. For example, some additional discount factors or caps could be applied to C accounting of HWP. In the negotiations it has to be decided, whether HWP and changes in their C stocks could be considered as "human induced" and whether these could fulfil "since 1990 clause" or will only a part of HWP be interpreted to fulfil above conditions. In a practical monitoring system, however, it would be infeasible to separate HWP stocks by certain possible criteria arising from the Protocol text, such as: which stocks were created since 1990, or which HWP stocks originate from forests afforested or reforested since 1990 etc. Another interesting point in accounting is that, as at the moment not all countries in the world are compelled to the commitments of the Kyoto Protocol, this asymmetric situation may create additional incentives to international trade of HWP between compelled and non-compelled countries.

As there are no decisions on the accounting rules and, for example, we do not know the market conditions of C, the quantitative assessment of incentives and disincentives are highly speculative at the moment. Factors like cost of reducing emissions, discount rates and international price of C will determine the true outcomes of the potentially strong incentives provided by HWP approaches in C *accounting*. Therefore, the incentives are discussed in the following only qualitatively, relative to each other rather than in absolute terms.

In section 5.2 the generic incentives of the approaches are considered in case all countries in the world would be compelled to the commitments of the Kyoto Protocol and *account* HWP by one of the approaches. Section 5.3 is devoted to the unsymmetrical case, where some countries are compelled to the commitments and would *account* their HWP and others do not. In section 5.4 some numerical examples of the outcomes of the different approaches and C fluxes associated with the international trade fluxes are given.

5.2 Basic incentives associated with the three approaches

The outcomes and incentives of the approaches have been discussed extensively in the literature earlier. A good summary is presented e.g. in the Dakar meeting report (Brown et al. 1999). Some notable points were also presented in the Edmonton statement (Apps et al. 1997). The incentives of the three approaches compared to the IPCC default approach are shortly given as follows:

1. The stock change approach gives a removal for building up of national forest and HWP stocks whereas the IPCC default approach neglects the changes in HWP stocks. Consequently, the stock change approach provides disincentives to decrease the stocks. In national reporting the stock change approach is neutral with respect to international trade in HWP. Whether HWP are produced within national boundaries or imported, growth in HWP stock is considered a C removal and its decrease an emission.

2. The basic feature of the atmospheric flow approach is separation of biological sinks and sources from each other (see section 4.1.1, Figure 9). Then in fact no incentives are provided to utilise the closed C cycle of HWP through the atmosphere (Atmosphere → Forest → HWP → Atmosphere) as a pump of renewable bioenergy, as the emission part of the above sustainable cycle is penalised (by treating biofuels like fossil fuels). In the atmospheric flow approach net import of HWP is in fact reported as an emission and net export as a removal, in addition to the removal/emission due to stock increase/decrease. A country conducting forest harvest without replanting reports no CO_2 emissions to the extent that harvested material is transferred to another country. Thus the atmospheric flow approach provides a disincentive for the use of imported HWP and imported wood-based fuels are treated similar to fossil fuels. Even if country A reports zero CO_2 emissions after burning self-produced biomass fuel, country A would be better off, if the biomass were sold to country B rather than using it himself. There are, of course, incentives to grow forests and HWP, but purchase and/or use of HWP is uniformly discouraged by the atmospheric flow approach (Apps et al. 1997).

3. In the production approach the wood-producing country gets an additional removal due to exported HWP, if their stock is increasing. However, consistently, stock decrease would be considered as an emission for the producing country. The production approach provides incentives for a country to increase the stocks of those HWP grown in its own forests. However, those HWP are not necessarily inside its boundaries and thus not influenced by its own policies. The production approach may not provide an incentive to an importing country to better manage the use of imported wood since emissions are accounted for in the producing country. Another drawback to the production approach is that the importing country has little incentive to improve the management of waste and reduce the emissions (Brown et al. 1999).

In practice, the approaches may provide more complicated indirect incentives. Crediting of HWP stocks in the stock change approach can increase the use of long-lived HWP in case a market potential exists, and consequently also international trade of long-lived HWP could be boomed. Regarding production approach, it should be noted that there are severe practical difficulties to verify stock changes of the exported HWP. Thus the approximate estimation methods needed may to some extent change its incentives and impacts on international trade on HWP. The atmospheric flow approach gives credits for exporting of HWP and debits for importing forming a kind of a zero-sum game. This could cause pressure on international market price of HWP in case HWP were included in Kyoto *accounting*. In addition, the (potential) ecological image of all HWP would be threatened, as their emissions if included in *accounting* would be treated like fossil fuels. The incentives and indirect impacts of the approaches are summarised in Table 5.

A particular issue is how the different approaches handle trade of biofuels produced from wood. The atmospheric flow approach does not provide an incentive to switch from fossil fuels to *imported* biofuels, because emissions from biofuels are accounted for in the consuming country, and the CO_2 emissions per unit energy output (MJ) are higher for biofuels than for most fossil fuels. But the exporting country would benefit by a decrease in national emissions. For the other approaches there is an incentive to switch from fossil fuels to imported biofuels, because the emissions from imported biofuels are accounted for in the producing country. For *domestically grown* biofuels all approaches provide incentives to switch from fossil fuels because harvest can be balanced by re-growth.

To illustrate the relative magnitude of the factors providing incentives in different approaches it is interesting to compare the estimated magnitude of global C stock change in HWP and the C fluxes of international HWP trade flows with each other. In the atmospheric flow approach the *excess removal* (compared to IPCC default, see section 4.2.1) is calculated as a sum of *stock change consumed products* and *net export*, whereas the other two approaches neglect the export flux considering only stock changes. This gives an insight on the two factors affecting the reported C emission in the atmospheric flow approach. An approximate estimate of the present global C stock change of HWP in use, given in Chapter 2, was a growth of 30-40 Tg C /yr. However, in 2000 the C flow of the whole international trade of HWP was more than 130 Tg C /yr, this number calculated by converting the global trade flows given in the FAO statistics (FAOSTAT 2002) into C. These numbers are illustrative and show that actually the global stock change in HWP is smaller than the zero-sum part of international imports and exports, which in the atmospheric flow approach would be reported as emissions for net importers and as removals for net exporters. Even if stock changes in HWP would be zero, these trade flows would create permanent emissions for net importers and removals for net exporters (see Box 6 in section 4.1.1).

Table 5. Different HWP approaches: summary of their basic incentives for HWP exporting and importing countries.

	Stock change	**Atmospheric flow**	**Production**
Incentives for wood-producing and HWP **exporting** country	To increase domestic stocks in forests and HWP.	Primarily to increase HWP export, secondarily to increase domestic stocks in forests and HWP.	To increase stocks in forests and domestic-grown HWP, also in the export markets.
Incentives for HWP **importing** country	To increase stocks in all domestically consumed HWP.	To avoid import of HWP and wood-based fuels.	No incentives concerning HWP stocks in importing country.
Other impacts	Recognition of C stock in HWP with basically positive impacts in climate change mitigation.	Zero-sum game between HWP exporters and importers, pressure on international market prices of HWP, wood-based fuels treated like fossil ones in international trade.	HWP stock in export markets has an impact on the commitments of the exporter, who has, however, no control over the stock.

5.3 Incentives of the approaches in case of no global commitments

This section focuses on the case, in which HWP would be included in the Kyoto *accounting* of emissions, but all countries in the world would not be compelled to the commitments of the Protocol (which is for instance the case at the moment). As some countries have commitments on emission reductions and others do not, this induces an uneven situation causing some additional incentives to international trade of HWP. As we do not yet know the detailed accounting rules to be applied, we simply assume that one of the approaches as such is applied to C accounting. The extent of the incentives is not assessed but only their direction in qualitative terms.

By the above assumptions, in the *stock change approach* a compelled country will get credit from growth of HWP stocks within its borders (by increasing its AAs). HWP imported from non-compelled countries can assist in growing HWP stocks without, for instance, having any impact on the C balance in forest stocks within compelled countries. This provides an incentive for trade of HWP from non-compelled to compelled countries. In theory, growing the HWP stock in compelled countries could be a consequence of increased harvesting in non-compelled countries and increasing export flows from those countries. In worst case this could in principle promote deforestation, if there were no assurance of sustainable forestry.

The fact that full C accounting is not applied to all forests in compelled countries (i.e. discounting is applied under Article 3.4) is another uneven factor that could cause non-desired incentives within compelled countries. The trade-off could then be such that growth of HWP stocks in a compelled country could be much favourable than increasing their forest stocks, and could give an incentive, for instance, to reduce C stock in their ‘non-Kyoto’ forests.

The accounted removal in the *atmospheric flow approach* consists of the stock change and net export terms (section 4.2). In the atmospheric flow approach the fundamental additional factor in Kyoto accounting is the strong incentive to export HWP from compelled to non-compelled countries, as the export flow could then form a permanent C removal of the compelled country without causing any liabilities for the importers. This net export C flux would form the addition to the AAs of compelled countries and could in theory also promote forest degradation in those countries. We know that the C flux of international HWP trade is more than 100 Mt C /yr. Thus it is possible that also trade between compelled and non-compelled countries could be significant and change essentially the total AAs. On the other hand, as discussed earlier, the trade between compelled countries induces only a zero-sum game, not changing the total amount of AAs, but penalising buyers and crediting sellers. Globally, the net C fluxes of HWP trade are likely from non-compelled to compelled countries. As a consequence of this the total AAs would probably be decreased when using atmospheric approach, assuming that the accounting approach would not impact strongly international HWP trade.

In the *production approach* the wood producing country can account for its HWP stock growth globally: in addition to domestic stocks also stocks in its export markets, which can be non-compelled countries. For a country with strong export flux this would lead to higher additional AAs than in the stock change approach, in case HWP stocks are growing. In the production approach there are less incentives for a compelled country to import and more incentives to export long-lived HWP than in the stock change approach. That is because the production approach counts the accumulation of long-lived HWP in the country where the wood was grown, and the stock change approach in the country where the HWP are in use.

The basic incentives and disincentives of each HWP approach in Kyoto accounting in case of both compelled and non-compelled countries are summarised in Table 6.

Table 6. Incentives for international trade of HWP provided by the different approaches, if HWP included in Kyoto accounting. Notations: + positive incentive for trade between partners, 0 neutral, - disincentives, – + disincentive for importer, incentive for exporter.

Stock change approach			
		Exporter	
		Compelled	Non-compelled
Importer	Compelled	+	+
	Non-compelled	0	0

Atmospheric flow approach			
		Exporter	
		Compelled	Non-compelled
Importer	Compelled	– +	– –
	Non-compelled	+ +	0

Production approach			
		Exporter	
		Compelled	Non-compelled
Importer	Compelled	+	0
	Non-compelled	+	0

Another issue to be analysed when adding HWP into the Kyoto accounting, would be the impact on the present incentives to the use of HWP in material and energy substitution. The exact accounting rules, yet unknown and asymmetric trade-off situation between compelled and non-compelled countries may have consequences, which should be analysed before making final decisions on accounting rules.

The interests and incentives related to international trade of HWP can be analysed in detail by considering countries divided into eight groups on the basis of their major trade fluxes of HWP:

1. Compelled importer, importing mostly from compelled countries (e.g. Spain, Italy),
2. Compelled importer, importing mostly from non-compelled countries (Japan),
3. Compelled exporter, exporting mostly to compelled countries (Finland, Sweden, Canada),
4. Compelled exporter, exporting mostly to non-compelled countries (New Zealand, Canada in case USA not within the Kyoto accounting),
5. Non-compelled importer, importing mostly from compelled countries,
6. Non-compelled importer, importing mostly from non-compelled countries,
7. Non-compelled exporter, exporting mostly to compelled countries,
8. Non-compelled exporter, exporting mostly to non-compelled countries.

The possible impacts of HWP accounting on each group are outlined in Table 7.

Table 7. Possible impacts of HWP accounting *on different country groups in case some countries are compelled to the commitments of the Kyoto Protocol and others are not.*

	Country group	**Trade partner**	**Stock change approach**	**Atmospheric flow approach**	**Production approach**
	Compelled countries				
1.	Importer	Compelled	Growth of HWP pool in interest of importer and might increase trade.	Imports are a potential emission and disincentive for international trade	No essential change to the present situation, but as the exporter has interests to increase HWP stock abroad and trade, this could influence market prices.
2.	Importer	Non-compelled	Growth of HWP pool in interest of importer and might increase trade.	Imports are a potential emission and disincentive for international trade	No
3.	Exporter	Compelled	Advantage for exporter from presumably emerging markets for HWP	Exports are a removal and credit. However, similar additional emission is accounted for the importer, the trade flux is endangered and there is pressure to lower prices of HWP to compensate the emission due to imported HWP.	Exporter might have interests to increase trade, as stock change is credited to the exporter.

4.	Exporter	Non-compelled	No	Exports are a removal and credit, but no additional emissions are caused to importer, which makes it advantageous for the exporter.	Exporter might have interests to increase trade, as stock change is credited to the exporter.
	Non-compelled countries				
5.	Importer	Compelled	No	As compelled countries have increased interests to sell, the importer might get advantage in the form of lower prices.	No essential change to the present situation, but as exporter might have interests to increase trade, this could influence market prices.
6.	Importer	Non-compelled	No	No	No
7.	Exporter	Compelled	Advantage for exporter from presumably emerging markets for HWP	Barriers are built for country's exports.	No
8.	Exporter	Non-compelled	No	No	No

For compelled countries exporting their HWP mainly into non-compelled countries atmospheric flow approach could be attractive, as their export is not endangered and they simultaneously could account their export flux as removal. On the other hand, in trade between compelled countries the exporting country cannot get full benefit from the removal due to export, as the importer has to receive a carbon emission making the imported HWP less attractive. Worst is the case with compelled importer and non-compelled exporter, where importer would get an extra emission and exporter no credit.

Note that even for non-compelled countries the accounting approach may have indirect consequences. Basically, none of the approaches would have impact on the international trade of HWP *between* non-compelled countries, unless the chosen approach would not impact the HWP markets globally, which is also thinkable. In general, however, the stock change and production approaches as an accounting framework would probably have relatively small impact on the market prices of HWP. The atmospheric flow approach instead would change the image of HWP as they are treated like fossil fuels in C accounting of compelled countries. This could conceivably be discounted in the global market prices of HWP.

Considering the long-term implications of the approaches, an important issue is the development of the global comprehension of the commitments provided by the Kyoto Protocol. In short term some countries could get advantage from the asymmetric situation with division into compelled and non-compelled countries. This could, however, change radically when the group of compelled countries is increasing. Thus the short-term advantage of some country groups should not influence the choice of the *accounting* approach.

Another issue is the development of HWP stocks in time. In general, they may form a C removal only as far as their consumption is increasing. However, it is possible that their stock in future will saturate or the stock will even decrease and form a C source. This has to be borne in mind when assessing the long-term consequences of HWP accounting. For instance, in production approach a HWP exporter may in future be responsible for significant emissions, taking place outside its own borders, and without any possibilities to influence on this development.

5.4 The approaches and quantitative outcomes for some countries

The outcomes of the three approaches for some selected countries in Annex B of the Kyoto Protocol are illustrated in Table 8. The *excess emissions* due to HWP (i.e. excess compared to the outcome of the IPCC default approach) are given expressed here as Gg CO_2 and compared to

1) total GHG emissions (in Gg CO_2 equivalent) excluding the *Land Use, Land-Use Change and Forestry* sector (*LULUCF)* in the base year 1990 and,

2) emissions from *LULUCF*, as *reported* in the national GHG inventories.

Note that the given *excess emissions from HWP = - excess removal* in the equations of section 4.2.1. If the emission is negative it means a removal or C sink. The numbers were calculated with the EXPHWP model.

Considering first the *stock change approach*, we see that HWP in use constitute a removal for *all* the selected countries in 2000, the highest negative emission in proportion to base year emissions estimated for Austria and Finland. However, the removal estimates by the model appear to vary more or less yearly depending on the HWP consumption. For instance in Finland, HWP formed even a C source in year 1991. Some bias is caused by the fact that trade and consumption of final products are excluded from the numbers of Table 8. The FAO statistics being the basis of the model includes only roundwood and semi-finished HWP. Thus, for instance, furniture manufactured in a country but exported has been counted in the *stock change* of the producer country. Denmark is an example of such a country. However, according to Table 8 stock change in HWP appears to be quite significant factor in the countries' GHG balance, especially compared to the *reduction commitments* in Annex B of the

KP. As these are at most 8% of the base year emissions, stock changes in HWP could in theory contribute to a remarkable portion in emission reductions. Note also that in some countries with small forest area the estimated changes in HWP stocks are much larger than stock changes in *LULUCF*.

The *production approach* appears to be less favourable than the stock change approach for most of the selected countries. One reason for this is the concentration of roundwood production in fewer countries than consumption of HWP, the wood producing and exporting countries taking all the advantage of the growing HWP stocks.

Most dramatic are the numbers for the *atmospheric flow approach*. From the results we note some countries (Finland, Sweden and Canada) with very large excess removals due to HWP. In case of Finland the removal due to HWP would be more than 30% of the total base-year emissions! The numbers become understandable when bearing in mind that the *excess removal = stock change consumed products + net export* (see section 4.2.1) consists of two terms of which the net export term dominates totally the C removal of the above exporter countries giving a huge credit to their national C balance.

Table 8. Total emissions excluding LULUCF *and emissions from* LULUCF *only for the base year 1990, reported in the national communications under the UNFCCC. Calculated* excess emissions *from HWP (i.e. excess compared to IPCC default approach) in 2000 using the three approaches and compared to reported base-year emissions. Note that a negative emission means removal. Calculations were carried out with the EXPHWP model. The input data of the model, the production and trade data since 1961, are from the FAO database (FAOSTAT 2002). Other parameter values of the model are given in Table 2 (UNFCCC data in documents FCCC/SB/2002/INF.2 and FCCC/WEB/2002/10, http://unfccc.int/).*

Greenhouse gas emissions	Total without CO_2 from LULUCF	CO_2 from LULUCF	Excess emissions from HWP **Stock change approach**			Excess emissions from HWP **Atmospheric flow approach**			Excess emissions from HWP **Production approach**		
CO_2 equivalent (Gg)	Base year 1990	Base year 1990	2000	% of total base-yr	% of LULUCF base-yr	2000	% of total base-yr	% of LULUCF base-yr	2000	% of total base-yr	% of LULUCF base-yr
Australia	**425175**	78124	-2061	-0.5%	-3%	-443	-0.1%	-1%	-2117	-0.5%	-3%
Austria	**77388**	-9215	-3088	-4.0%	34%	-3355	-4.3%	36%	-1835	-2.4%	20%
Belgium	**142741**	-1600	-1443	-1.0%	90%	1342	0.9%	-84%	-694	-0.5%	43%
Canada	**607183**	-61498	-9207	-1.5%	15%	-91509	-15.1%	149%	-33848	-5.6%	55%
Denmark	**69360**	-916	-1892	-2.7%	207%	2286	3.3%	-250%	-106	-0.2%	12%
Finland	**77093**	-23798	-2381	-3.1%	10%	-23582	-30.6%	99%	-4484	-5.8%	19%
France	**559342**	-56232	-6707	-1.2%	12%	-2995	-0.5%	5%	-8077	-1.4%	14%
Germany	**1222765**	-33719	-10844	-0.9%	32%	-6725	-0.6%	20%	-12566	-1.0%	37%
Greece	**104895**	1441	-591	-0.6%	-41%	1536	1.5%	107%	-52	0.0%	-4%
Ireland	**53700**	-89	-879	-1.6%	991%	-225	-0.4%	254%	-932	-1.7%	1050%
Italy	**520571**	-23532	-6529	-1.3%	28%	13733	2.6%	-58%	-1310	-0.3%	6%
Japan	**1246724**	-83903	-1187	-0.1%	1%	29843	2.4%	-36%	5153	0.4%	-6%
Netherlands	**210347**	-1422	-966	-0.5%	68%	4792	2.3%	-337%	-458	-0.2%	32%
New Zealand	**73161**	-21845	-1178	-1.6%	5%	-9383	-12.8%	43%	-4025	-5.5%	18%
Norway	**51965**	-9765	-720	-1.4%	7%	-1409	-2.7%	14%	-182	-0.4%	2%
Portugal	**64948**	-3751	-1146	-1.8%	31%	-2690	-4.1%	72%	-660	-1.0%	18%
Spain	**286428**	-29252	-5512	-1.9%	19%	7848	2.7%	-27%	-1293	-0.5%	4%
Sweden	**70566**	-20292	-1051	-1.5%	5%	-18397	-26.1%	91%	-2808	-4.0%	14%
UK	**742492**	8791	-3434	-0,5%	-39%	15068	2,0%	171%	-3073	-0,4%	-35%
USA	**6130724**	-1097747	-72571	-1.2%	7%	-40302	-0.7%	4%	-46085	-0.8%	4%

The importance of the trade flux term in the *atmospheric flow approach* is illustrated in Table 9. Referring to section 4.2.1 *Excess removal = Stock change consumed products + net export* or equivalently *Excess emission = -Stock change consumed products - net export = -Stock change consumed products + net import*. *Net import* represents the zero-sum part in the *atmospheric flow approach*. It is the additional emission with respect to the *stock change approach* that is added to net importer when using the *atmospheric flow approach*, and the net exporter gets a corresponding additional removal with respect to that in the *stock change approach.* The net exports of HWP (negative imports in Table 9) provide the leading exporter countries with a huge excess removal. Finland, Sweden and Canada could in principle take care of all their reduction commitments by exporting HWP, if the atmospheric flow approach were chosen as the accounting framework. On the other hand, significant excess emissions would be allocated to Denmark, Spain, the Netherlands, Japan and UK.

Table 9. Net imports of HWP in 2000 converted to CO_2 flows and compared to base-yr emissions. Final products such as pre-fabricated houses, furniture, books etc are excluded from these numbers. (+ means that the country is net importer, - that it is net exporter).

CO_2 (Gg/yr)	**Net import 2000**	**% of base-yr emissions**
Australia	1617	0.4%
Austria	-267	-0.3%
Belgium	2785	2.0%
Canada	-82303	-13.6%
Denmark	4179	6.0%
Finland	-21201	-27.5%
France	3712	0.7%
Germany	4118	0.3%
Greece	2127	2.0%
Ireland	654	1.2%
Italy	20262	3.9%
Japan	31029	2.5%
Netherlands	5758	2.7%
New Zealand	-8205	-11.2%
Norway	-689	-1.3%
Portugal	-1544	-2.4%
Spain	13361	4.7%
Sweden	-17346	-24.6%
UK	18501	2.5%
United States	32269	0.5%

The asymmetric situation with compelled and non-compelled countries in the Kyoto accounting is quantified in Table 10 and Table 11 for some selected countries. Considering the big exporters of HWP among compelled countries, Finland and Sweden are examples of countries exporting mainly to other compelled countries (Table 6). Their HWP imports are essentially smaller than exports. Although these countries would get a big credit of their net C export in the atmospheric flow approach, the advantage is questionable due to the potential penalties for their HWP imports into other compelled countries.

Canada's position as big net exporter might be different. Most of its exports (94% in monetary value) are also to compelled countries, but the share of USA is more than 80%. In case USA would not follow the commitments due to the Kyoto Protocol, it would be in the same position as the non-compelled countries. In this case Canada could be placed into group 4 in Table 6, as it could benefit from its HWP exports to USA as a national C removal with no essential penalties for its HWP exports. Thus the atmospheric flow approach could be favourable for Canada at least in the short-term if USA were not joining the group of compelled countries (e.g. in the second commitment period). New Zealand seems to be in similar position as Canada, as major importers of wood based products from New Zealand, with an exception Japan, are non-compelled countries. Slightly less than half of exports from New Zealand are to compelled countries and USA.

Significant non-compelled net exporters are Brazil, Indonesia and Malaysia, which could get penalised for their exports to compelled countries, which however is less than half of their total exports. They could be positioned rather to group 8 than 7.

Table 10. Exports to Compelled and non-compelled countries from some specified countries (FAOSTAT 2002). Countries in the first column are compelled to reduction commitments except Brazil, Indonesia and Malaysia.

Base yr 1999	**EXPORTS TO [1000 USD]:**				
EXPORTER	**COMPELLED**	**Fraction-%**	**NON-COMPELLED**	**Fraction-%**	**TOTAL**
Australia	158 092	22%	551 461	78%	709 553
Canada	23 818 518	94%	1 651 182	6%	25 469 700
Finland	9 581 482	88%	1 343 918	12%	10 925 400
France	4 920 512	87%	763 468	13%	5 683 980
Germany	8 535 002	86%	1 388 978	14%	9 923 980
Japan	538 949	31%	1 190 911	69%	1 729 860
Netherlands	2 331 920	86%	374 550	14%	2 706 470
New Zealand	757 543	58%	546 007	42%	1 303 550
Norway	1 599 041	87%	232 709	13%	1 831 750
Sweden	8 646 911	89%	1 073 979	11%	9 720 890
UK	1 758 536	80%	433 534	20%	2 192 070
USA	8 628 956	58%	6 154 444	42%	14 783 400
Brazil	1 835 190	71%	744 590	29%	2 579 780
Indonesia	2 040 332	43%	2 670 698	57%	4 711 030
Malaysia	1 568 470	50%	1 546 470	50%	3 114 940

Major importers among compelled countries in Table 11 are USA, Japan and Germany. The imports of the non-compelled countries Malaysia, Indonesia and Brazil are an order of magnitude smaller. Japan (belonging to group 2 in above Table 7) is a major importer from non-compelled countries. Specifically the non-compelled exporters (belonging to group 7) to Japan could suffer from the atmospheric flow approach as a basis of C accounting. UK, Germany and France as importers belong basically to group 1. In the atmospheric flow approach the position of important compelled importers within EU would change essentially, if for instance the trade between EU countries were interpreted as internal, which reflects the scale-dependency of the atmospheric flow approach. The option of 'internal' import would aid the position of large European importers to avoid emissions due to HWP. Correspondingly, the 'internal' European exporters like Finland and Sweden would be placed in favourite position with respect to importers from non-EU area.

Table 11. Imports from compelled and non-compelled countries to some specified countries (FAOSTAT 2002). Countries in the first column are compelled to reduction commitments except Brazil, Indonesia and Malaysia.

Base yr 1999	**IMPORTS FROM [1000 USD]:**				
IMPORTER	**COMPELLED**	**Fraction-%**	**NON-COMPELLED**	**Fraction-%**	**TOTAL**
Australia	1 172 939	77%	350 251	23%	1 523 190
Canada	3 614 031	96%	163 349	4%	3 777 380
Finland	846 267	95%	41 224	5%	887 491
France	6 531 815	88%	899 055	12%	7 430 870
Germany	10 247 902	95%	528 998	5%	10 776 900
Japan	6 755 587	55%	5 592 713	45%	12 348 300
Netherlands	4 361 673	76%	1 344 057	24%	5 705 730
New Zealand	264 016	85%	46 828	15%	310 844
Norway	947 112	94%	62 738	6%	1 009 850
Sweden	1 568 710	97%	46 930	3%	1 615 640
UK	8 306 280	92%	677 190	8%	8 983 470
USA	23 054 156	97%	666 944	3%	23 721 100
Brazil	546 766	67%	265 157	33%	811 923
Indonesia	572 472	61%	366 478	39%	938 950
Malaysia	533 422	53%	467 058	47%	1 000 480

Here it should be noted that the trade flows in above Tables are expressed in USD, not as C fluxes. However, it is presumable that these monetary numbers have strong correlation with the true C fluxes in HWP, although semi-finished HWP in general contain less carbon/$ than roundwood.

6. Required changes for the current modalities, rules and guidelines for estimating, reporting and accounting GHG emissions from HWP under articles 3.3 and 3.4

6.1 Current methods, modalities, rules and guidelines

The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 1997abc) form the current basis for the national GHG emissions *estimation and reporting* under the UNFCCC. In the *Guidelines* net changes in C stocks of forests are reported, whereas stock changes of harvested wood are basically neglected as noted earlier. However, more realistic ways of *estimating and reporting* HWP are outlined in IPCC (1997c), quoted in Box 1 of this report. The text can be interpreted to *allow reporting* of HWP stock changes already in present GHG inventories under certain conditions.

The Kyoto Protocol does not mention HWP, but they could in theory be a part of those activities mentioned in Articles 3, paragraphs 3 and 4, and Articles 6 and 12. Whatever will be decided on the possible HWP accounting rules in the future, a prerequisite for accounting is that their estimation and reporting under the UNFCCC will be first established. After development of the estimation and reporting methodology, including also the choice of the HWP approach, HWP can either be included or excluded from the emissions accounting due to the Kyoto Protocol. The last step forward in elaborating better and unified estimation methods for the land use, land-use change and forestry (LULUCF) activities took place in COP7 in Marrakesh. Especially the **Decision 11/CP.7: Land use, land-use change and forestry** and the **Draft decision -/CMP.1 *(Land use, land-use change and forestry)*** of the Marrakesh accords (UNFCCC 2001) are relevant also to HWP estimation, reporting and possible accounting, the essential paragraphs quoted in the following (**bold** by the author):

"The Conference of the Parties,...

2. *Requests* the Subsidiary Body for Scientific and Technological Advice (SBSTA): ...

(c) To incorporate the work of the IPCC as outlined in paragraph 3 (d) below into any revisions of modalities, rules and guidelines prior to the second commitment period, for the accounting of activities under Article 3.4 of the Kyoto Protocol;...

3. *Invites* the Intergovernmental Panel on Climate Change (IPCC):

(a) To **elaborate methods** to estimate, measure, monitor, and report changes in carbon stocks and anthropogenic greenhouse gas emissions by sources and removals by sinks resulting from land use, land-use change and forestry activities under Article 3, paragraphs 3 and 4, and Articles 6 and 12 of the Kyoto Protocol, **on the basis of the *Revised 1996 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories***, taking into account.the present decision (11/CP.7) and draft decision -/CMP.1 *(Land use, land-use change and forestry)* attached hereto, to be submitted for consideration and possible adoption to the Conference of the Parties **at its ninth session**;

(b) **To prepare a report on good practice guidance and uncertainty management** relating to the measurement, estimation, assessment of uncertainties, monitoring and reporting of net carbon stock changes and anthropogenic greenhouse gas emissions by sources and removals by sinks in the land use, land-use change and forestry sector, taking into consideration the present decision (11/CP.7) and draft decision -/CMP.1 *(Land use, land-use change and forestry)* attached hereto, to be submitted for consideration and possible adoption to the Conference of the Parties at its ninth session;...

4. Decides that **any changes to the treatment of harvested wood products** shall be in accordance with **future decisions of the Conference of the Parties**."

In addition, the **Draft decision -/CMP.1 (Land use, land-use change and forestry)** registers some principles, which should be borne in mind when developing possible accounting methods and rules for HWP:

"The Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol,...

1. *Affirms* that the following principles govern the treatment of land use, land-use change and forestry activities:

   (a) That the treatment of these activities be based on sound science;

   (b) That consistent methodologies be used over time for the estimation and reporting of these activities;

   (c) That the aim stated in Article 3, paragraph 1 of the Kyoto Protocol not be changed by accounting for land use, land-use change and forestry activities;

   (d) That the mere presence of carbon stocks be excluded from accounting;

(e) That the implementation of land use, land-use change and forestry activities contributes to the conservation of biodiversity and sustainable use of natural resources;

(f) That accounting for land use, land-use change and forestry does not imply a transfer of commitments to a future commitment period;

(g) That reversal of any removal due to land use, land-use change and forestry activities be accounted for at the appropriate point in time;

That accounting excludes removals resulting from: (i) elevated carbon dioxide concentrations above their pre-industrial level; (ii) indirect nitrogen deposition; and (iii) the dynamic effects of age structure resulting from activities and practices before the reference year;

2. *Decides* that good practice guidance, and methods to estimate, measure, monitor and report changes in carbon stocks and anthropogenic greenhouse gas emissions by sources and removals by sinks resulting from land use, land-use change and forestry activities, as developed by the Intergovernmental Panel on Climate Change, shall be applied by Parties, if decided in accordance with relevant decisions of the Conference of the Parties and the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol;

3. *Decides* that anthropogenic greenhouse gas emissions by sources and removals by sinks shall be accounted for in accordance with the annex to the present decision and reported in annual inventories and reviewed in accordance with relevant decisions relating to Articles 5, 7 and 8 of the Kyoto Protocol, and in accordance with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventorie*s, any future elaboration of these guidelines, or parts of them, and any good practice guidance on land-use change and forestry in accordance with relevant decisions of the Conference of the Parties and the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol;

4. *Adopts* the definitions, modalities, rules and guidelines relating to land use, land-use change and forestry activities under Articles 3, 6 and 12 of the Kyoto Protocol contained in the attached annex for application in the first commitment period."

Decision *11/CP.7* as well as draft decision *-/CMP.1* "formalise" the role of the IPCC in preparation of methods, based on sound science, for estimation, reporting and accounting of emissions from the LULUCF sector. At the moment the report on Good Practice Guidance (GPG) for the LULUCF sector is under preparation. Estimation methods for HWP will also be presented, which are basically neither over- nor underestimating their emissions, and in addition, the uncertainties of the presented methods will be analysed. As the IPCC default approach might not fulfil these "best-estimate" requirements, more realistic approaches and methods for estimating the true carbon balances in HWP are needed in reporting. However, there is no decision on the approach yet. Interpreting Paragraph 4 the choice of the approach shall be in accordance with future decisions of the COP. As there appears to be competitive alternative approaches to allocate the emissions between reporting countries, estimation methods will be presented in the report draft for all these approaches.

Annex of above ***Decision 11/CP.7*** (FCCC/CP/2001/13/Add.1) provides some rules for implementation of Articles 3.3 and 3.4. in the first commitment period, some important paragraphs quoted in the following:

"6. A Party included in Annex I may choose to account for anthropogenic greenhouse gas emissions by sources and removals by sinks resulting from any or all of the following human-induced activities, other than afforestation, reforestation and deforestation, under Article 3, paragraph 4, in the first commitment period: **revegetation, forest management, cropland management, and grazing land management**.",

This decision explicitly excludes HWP from the additional human induced activities under Article 3.4 of the Kyoto Protocol in the *first* commitment period, assuming HWP are not a part of forest management.

"19. **Once land is accounted for** under Article 3, paragraphs 3 and 4, all anthropogenic greenhouse gas emissions by sources from and removals by sinks on **this land must be accounted for throughout subsequent and contiguous commitment periods**."

The spirit of above decision will likely remain in subsequent commitment periods, in which case it might be meaningful also for HWP accounting or could at least give hints, how HWP could be treated if included in later commitment periods in the accounting framework of LULUCF.

"20. National inventory systems under Article 5.1 **shall ensure that areas of land subject to land use, land-use change and forestry activities under Article 3, paragraphs 3 and 4 are identifiable**, and information about these areas should be provided by each Party included in Annex I in their national inventories in accordance with Article 7. Such information will be reviewed in accordance with Article 8."

According to this paragraph the above activities should be identifiable to certain land areas, which might be problematic for HWP accounting discussed below.

"21. Each Party included in Annex I shall account for all changes in the following carbon pools: above-ground biomass, below-ground biomass, litter, dead wood, and soil organic carbon. A Party **may choose not to account for a given pool** in a commitment period, **if transparent and verifiable information is provided that the pool is not a source**."

Although HWP pool is excluded in the first commitment period from above list, the spirit of the paragraph could be applied in subsequent commitment periods also to HWP pool. If HWP were accepted to the Kyoto accounting, it could imply that HWP could be excluded only in case they are not a source[2]. However, how HWP should actually be treated in the Kyoto accounting (as a pool connected to some land area?), is still an open question. A thoroughgoing consideration is needed to find the most feasible way of including them.

6.2 Identification and geo-referencing of HWP stock

There are alternative ways of interpreting C stock in HWP. In theory, each HWP could be identified based on its origin to certain land areas. From this *lifecycle* standpoint a sub-pool of HWP could be linked to a forest covered land area, HWP hence always having a geo-reference to certain land. The *production approach* is actually based on this kind of lifecycle angle.

Needs for further and more detailed identification of land areas in GPG arises especially from Articles 3.3 and 3.4 of the Kyoto Protocol, which identify activities (such as afforestation, reforestation and deforestation) whose effects Parties to the Protocol are required to take into account in estimating emissions and removals of greenhouse gases (see the above-quoted paragraph 20 to ***Annex Decision 11/CP.7***). For the purposes of the first commitment period, these activities need to have occurred since 1990 and are subject to further constraints on timing, previous land-use and the maximum size of the spatial unit used for accounting purposes. These constraints must be verifiable, and so the geographical locations of the areas that encompass units of land subject to them need to be identifiable. Following the aforementioned lifecycle view on HWP, the geographically linked HWP also form a kind of C sub-pool in the land areas being subject to activities accounted under Articles 3.3 and 3.4. In theory, by making some changes to the existing rules, modalities and guidelines, these HWP sub-pools might be possible to be adopted under Articles 3.3 and 3.4. A distinction would then have to be drawn between wood that comes from harvesting and deforestation under Article 3.3

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[2] This, however, appears to be actually contradictory to Revised Guidelines, Box 5, which says that "The proposed method recommends that storage of carbon in forest products be included in a national inventory only in the case where a country can document that existing stocks of long term forest products are in fact increasing." (see Box 1 in this report).

and that one that comes from Article 3.4 under forest management to estimate the stock changes in both HWP sub-pools.

The above way of identifying and geo-referencing HWP, then estimating their stock changes and possibly including them then to accounting appears to be, however, infeasible in practice. Characteristic of HWP is that they are transported, processed and traded both domestically and abroad. HWP form in reality an off-site C stock with respect to land area from which they originate, which complicates essentially the inclusion of HWP in the above forest-origin based framework. If different accounting rules had to be applied to HWP, dependent on their origin, e.g. activities under Article 3.3 or 3.4, from compelled or non-compelled countries etc, a special tracking system of wood fibres through the refining chain would be needed. As HWP can be even composites of wood material from various sources, development of that kind of system would be a complicated task, likely infeasible (cf. the discussion on the *Production approach*, section 4.2.6.2). In addition, it can be questioned if it were altogether acceptable that HWP traded abroad could be included in C reporting or accounting of the *wood-producing* country having no possibilities to control its exported stock. Similar difficulties would arise, if HWP had to be connected to some project-based activities e.g. under the CDM. It would be highly impractical to assess, for example, the stock change of HWP due to a specific forestation project.

6.3 Possible options for considering HWP in the Kyoto Protocol

The basic alternatives for treating HWP under the UNFCCC and the Kyoto accounting in the future are the following:

1) The present situation will continue. Changes in C balances of HWP pools would be recognised neither in national GHG estimation and reporting under the UNFCCC nor in the Kyoto accounting, which means that the IPCC default approach, reporting only estimated changes in forest stocks, will be applied. Consequently, stock changes of HWP stocks are ignored or harvested wood transported from forest is treated like an emission at the year of harvest.

2) Decision/choice will be made on one of the more advanced HWP approaches, recognising changes in their C balance. This approach will be applied to HWP reporting in national GHG inventories under the UNFCCC. Technical guidance (estimation and verification etc) for the application of the approach would be provided by the IPCC Good Practice Guidance report, accepted by the COP. HWP would, however, not be included in the Kyoto accounting.

3) Alternative 2) is chosen and in addition: HWP would also be included in the Kyoto accounting after the first commitment period, the accounting rules to be negotiated based on the chosen approach. These rules could in theory differ from the approach including e.g. caps, discount factors etc, which are not yet foreseeable.

Under the basic alternatives 2) and 3) there are several choices to be made including the approach, the way of interpreting the HWP stock, and under case 3) in addition *how* HWP are included in the Kyoto accounting, for instance interpretation of Articles 3.3 and 3.4. In case 2) and 3) the application of the *lifecycle view* on HWP might unfeasible as discussed in section 6.2. Another alternative, which might actually be the only transparent and feasible way of *estimating and reporting* C balance in HWP or their emissions, would be to consider HWP stock within a country as a whole without paying any attention to the origin of wood fibres. In this case the existing statistics (provided e.g. by the FAO or national sources) or nation-wide inventories of HWP could directly be used in the estimation of C balance in HWP. However, this kind of reporting would require some changes (i.e. exceptions concerning treatment of HWP) to the original terms of reference concerning the IPCC Good Practice Guidance, stated in the Marrakesh accords.

Concerning HWP inclusion in C accounting, case 3), some changes would also be needed in definition of an activity, as it could not any longer be linked to a defined land area. It ought to be judged, whether this kind of system boundaries could be tolerated in the accounting framework, bearing in mind the text of Article 3, paragraph 4, and the decisions of COP 7 quoted above. By these modifications *managing of HWP stocks* could possibly form under Article 3.4 a separate activity, which is not linked to any definite land areas.

6.3.1 Feasibility of the approaches

The established practice in *estimation and reporting* of C balance of forests is to consider *verifiable changes in biomass stocks* (IPCC 1997a, b and c), and not, for instance, the *direct C flux between forests and the atmosphere*. The current modalities, rules and guidelines concerning C *accounting* in forestry sector are consequently in agreement with this standpoint. Considering Articles 3.3 and 3.4 of the Kyoto Protocol, they declare that sources and removals resulting from forestry activities should be *"measured as verifiable changes in carbon stocks in each commitment period"*(3.3) or in case of additional human induced activities (3.4) each Party shall provide data *"to establish its level of carbon stocks in 1990 and to enable an estimate to be made of its changes in carbon stocks in subsequent years."*

How would the different approaches fit into the above framework? The existing practice in the *estimation and reporting* under the UNFCCC is to use the *IPCC default approach* considering only stock changes in forests. The use of either the *stock change approach* or *production approach* only adds the changes in HWP stock to the outcome of the *IPCC default*, and no changes to present forest reporting are required (the *excess removal* by both approaches given by the equations in section 4.2.1). These approaches are both based on a stock change angle and might thus be basically consistent with the established reporting practice. It is not fully unambiguous, for instance, which one of the above stock-based approaches is proposed in the *1996 Guidelines* (IPCC 1997abc) quoted in Box 1. However, the *production approach* is based on a lifecycle standpoint discussed in section 6.2, and appears thus to be infeasible for reporting under the National GHG Inventories (see also discussion in section 4.2.6.2). *Stock change approach* in turn is practicable but it is not fully consistent with the framework outlined in the Marrakesh accords. As the reported stocks in *stock change approach* consist of wood-based material of various origins including imports, they cannot be geo-referenced to those land-areas on which the reporting framework is based. An additional category, e.g. *off-site C stocks*, has to be added to the reporting framework to solve the consistency problem. A solution of the dilemma in *estimation and reporting* is one prerequisite for developing and negotiating possible *accounting* rules for HWP under the Kyoto Protocol.

The *atmospheric flow approach* is based on an emission angle, which differs basically from the present practice in *estimation and reporting* of forestry sector. As HWP and forests belong to the same C cycle, the *atmospheric flow approach* must be applied to forests when applied to HWP. The true atmospheric flow from the atmosphere into forests is *not* equal to the net change in stocks of forest biomass. This gross C flux equals the net C stock change in forest added by the C flux of round wood transported from forests. To be consistent with the definition of the approach, under the national inventories on one hand this true atmospheric flow into forests should actually be *estimated and reported* and on the other hand the true emissions (or decay flux) from HWP into the atmosphere.[3] It is also questionable, if the atmospheric flow approach could be adapted to the *accounting* system without violating the text of the Kyoto Protocol and the existing accounting rules applied to forestry. The *atmospheric flow approach*, however, considers the same HWP stock as *stock change approach*, including all HWP within national borders regardless of their origin.

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[3] However, the outcome of the atmospheric flow approach can also be presented through stock change variables according to equation in section 4.1.1. In the present report calculations were performed through this stock change angle. The *excess removal* with respect to IPCC default (equation in section 4.2.1) was calculated to compare the numerical outcome of atmospheric flow to those of the other approaches.

6.4 Technical feasibility and accuracy of different estimation methods

The feasibility of various estimation methods is an issue dependent to some extent on the chosen HWP approach, as they may have their specific needs. Methods applicable to IPCC default are not relevant in this context, as it considers only stock changes in forests. Here only estimation of the *excess removal* (section 4.2.1) due to HWP is discussed. Possible inclusion of HWP in the Kyoto accounting will highlight the quality requirements of the estimation methods, as true liabilities (influencing the assigned amounts) are caused to compelled countries.

Alternative estimation and reporting methods were discussed in section 4.2. A general conclusion was that methods based on estimation of stocks were more robust for the purpose. Availability of international data on HWP, applicable to the method, is another criterion. This appears to favour the use of easily available flux data and estimated HWP lifetimes to calculate the changes in HWP stocks, although direct inventory of HWP stocks would be a more advisable method. Similar estimation methods can basically be used for the three approaches as they all can be expressed through stock changes (section 4.2.1). The accuracy of the methods depends on their defining assumptions and quality of underlying data. However, application of the estimation methods to the *production approach* appears to be problematic and less accurate, as existing statistics does not support its lifecycle view (see section 4.2.6.2).

6.4.1 Accuracy of the method under development for IPCC Good Practice Guidance

The EXPHWP model discussed in section 4.2.6.1 is one possible tool, which could be applied to estimation of HWP carbon balance (at Tier 2 level) in national GHG emission inventories. It can be classified to *stock change methods applying flux data and lifetime analysis*. The lifetimes of HWP are estimated and the input flux to the HWP pool in use is calculated on the basis of HWP production and international trade, provided by the FAO database (FAOSTAT 2002). The advantage is that a unified basis for estimation, applicable for most countries, can be used and the method is transparent and the results comparable. Thus this kind of method might be applicable to accounting due to the Kyoto Protocol. Accuracy of the method is discussed in the following.

6.4.1.1 Estimates of HWP in use

Lack of verified lifetime data for *HWP in use* induces a basic uncertainty in the above model-based estimation method. In case stock changes in HWP would have an impact on the liabilities of countries, there is a higher risk of manipulation of parameters to obtain more favourable results, stronger sinks etc. The sensitivity of the above Good Practice model to uncertainties in input data like lifetimes will be analysed in the IPCC work. However, these formal methods for assessing uncertainties cannot handle structural deficiencies of the model. In contrast to the model, the HWP lifetime is not constant in reality, i.e. the decay rate in proportion to HWP stock is not constant. For instance, the model is relatively sensitive to the yearly consumption of HWP, and can in principle indicate a temporary source in case HWP are a sink in real world and vice versa, but in the long run it can still be accurate enough.

Further, one systematic source of error is included in the above estimation method based on the FAO database. In the C balance model of HWP the national consumption rates of *semi-finished* HWP is used as input flux. The possible international trade of *final* HWP (like furniture, pre-fabricated houses etc) is not considered, which means that HWP stock changes are allocated to the country, where the semi-finished HWP were consumed.

Higher-tiered methods (Tier 3), like direct inventory of HWP stocks in major end use categories (e.g. in houses), could be one means of obtaining more accurate results or verifying the calculations by the above lifetime models. (For example, we could assume that there should be at least some correlation with the true building stock volume and long-lived HWP stocks estimated by the models.) However, the more complex the methods, the less transparent and comparable they might be. Specific national methods and databases have to be used, and due to lack of such data for most countries those methods could not be applied generally.

6.4.1.2 Estimates of HWP in landfills

The accuracy of estimates of HWP in landfills is an order of magnitude lower when using the EXPHWP model. The input flux into landfills is in the model roughly approximated from the output flux of HWP in use, by giving a time varying parameter expressing the fraction disposed into landfills. The basic HWP production data are relatively accurately compiled at least in developed countries, whereas HWP waste statistics concerning landfill disposal is very poor everywhere, especially records on historical waste flows. Consequently, estimates of above landfilling fraction are on weak empirical basis. Nor do we have too much data on average lifetimes of HWP in the (mostly) anaerobic conditions of landfills. All these are factors increasing the inaccuracy of the landfill model, which, however, is a very essential part of the estimation method, due to the long lifetime of HWP waste in the anaerobic conditions of landfills. Problematic might also be the assumption of a permanent HWP stock in landfills.

6.4.1.3 Consequences of inaccuracies in the estimation method

Conservative estimates of change in HWP stocks (in use and as waste) lead to underestimation of removals due to HWP in *stock change approach*. For a net importing country this kind underestimation leads in *atmospheric flow approach* to overestimation of true emissions from HWP. It can be questioned how these inaccuracies should be handled in *estimation and reporting* and possible emissions *accounting*.

6.5 Trade-offs and leakage

Trade-offs and leakage would obviously be an integral part of an *accounting* system of HWP, as a growth of HWP stock in one place can be reflected in decrease of forest biomass stocks elsewhere. Issues related to trade-offs and leakage were already discussed in Chapter 5 and are not repeated here. Negative effects due to HWP accounting could be prevented by requiring some certificates for round wood used (sustainability of forestry etc) or imported HWP, but due to earlier mentioned tracking problems (such as distinction of HWP stocks based on their origin) that could be a difficult task in practice. The trade-off is naturally dependent on the chosen HWP accounting approach and rules too, and it of course depends on many other economic factors not discussed here.

PART III. FINNISH STUDIES ON GREENHOUSE GAS BALANCE OF WOOD-BASED PRODUCTS

7. Method for inventory of C stock of construction wood in Finland

As noted in section 4.2.3.2 a way of diminishing the uncertainty associated with lifetime estimates is to perform direct inventories of HWP stocks. By direct inventory it is possible to obtain stock estimates independent from input or output flow estimates. This kind of method can also be used to verify flux data methods and calculation models associated with them. Stock inventories may be most practicable for major C pools of HWP in use, such as HWP in building stock. With the aid of a time series of inventory data it is possible 1) to estimate directly the changes of C stocks and 2) to verify parameter values of the calculation models discussed above.

The objective of the study presented in the following was to continue the time series of carbon inventories in Finnish construction. The previous studies created results for years 1980, 1990 and 1995 (Pingoud et al. 2001) and in this study similar results were calculated for year 2000.

7.1 Method

The inventory of materials in Finnish construction is mainly derived from three official data bases maintained by Statistics Finland: 1) the statistics on building stock (Statistics Finland 1997), 2) the statistics on construction and housing (Statistics Finland 2001a) and 3) the construction and housing yearbook 2001 (Statistics Finland 2001b). The statistics of building stock include information on floor areas in different building types, divided into 12 main type categories (Statistics Finland 1997). The building-stock statistics do not include free-time residential buildings (or holiday homes) that are an important part of Finnish wood construction. Also different types of outbuildings and buildings used for agricultural production are out of official building-stock statistics. Those building types are, however, included in new building registers during many years.

The statistics on construction and housing (Statistics Finland 2001a) includes, for example, the information on new building permits in 15 type categories. The statistics cover the construction of all new buildings and extensions, and the resulting stock of new dwellings. Building permits include information about the gross floor area (m^2) and building volume (m^3). In official Finnish building permits, information on bearing frame materials has been collected since 1952 and on main facade material since the beginning of the 1980s.

The land use and building statute (Statutes of Finland 895 1999) defines when building permit is required in Finland. For example, a small outbuilding without fireplace and with a square area of less than 8 m^2 does not need a building permit if not specified differently in the local plan. Those small outbuildings are typically wooden in Finland. In addition, only a notice-type planning permission for minor construction is required for construction of some special structures, such as stands, platforms and sheds. This kind of permission is not a building permit and is thus not included in the statistics on construction and housing.

The information of the above statistics, results of specific enquiries and other information on construction are regularly combined at the VTT Building and Transport, Business Intelligence Group, to constitute a more detailed database on Finnish building stock, new buildings, construction materials, working man-years. The database is more detailed than the official statistics: for example, certain building types are included, which are not within the official stock statistics. The building stock and the new construction parts of the database are updated yearly nowadays. The database is used regularly in various assessments and prognoses concerning the construction industry in Finland. Most of these assessments are confidential and unpublished. The inventory of the wood product pool and its C content, considered in this study, is only one application of the above database.

On the basis of statistics and individual sample surveys in Finland, VTT Building and Transport has estimated for its stock database the average floor heights of each building type in each age class (i.e. decade of construction). As the official statistics on building stock includes only floor areas, these are converted to building volume using average floor heights. In the database, buildings are divided into separate parts (bearing frames, facades, floors, roofs etc.) and classified according to building type and age class. For each building type and age class, the use of different construction materials in separate parts of buildings is estimated with the aid of sample surveys and information gathered from building permits. The estimate of wooden materials in permanent use is also based on estimates of material losses during construction. Technical changes and consumer trends have had an important impact on material use in Finnish buildings during recent decades.

The calculation of C stock in wood products is based on the quantities of sawn wood, wood-based panel products and bearing logs (especially in the case of free-time buildings) in buildings and their C content. The major tree species, used as raw materials in the Finnish wood-products industry, are spruce (*Picea abies*) and pine (*Pinus sylvestris*), whereas the average share of hardwood, mainly birch (*Betula sp.*), is just 5%, used predominantly in plywood industry. The volume of wooden products has been estimated in dry matter weight of products per building-m^3 in each type and age class. The C content of wood products was estimated to be 50% of their dry weight. The total C stock is calculated by the formula

$$C = \Sigma_{i,j}[A_{ij}(S_{ij} + P_{ij})]$$

where

C = total C reservoir of wooden materials in building stock (t C),
A_{ij} = building stock of building type i in age class j (building-m^3)
S_{ij} = amount of C in sawn wood and logs in building type i and age class j (t C / building-m^3)
P_{ij} = amount of C in wood-based panels in building type i and age class j (t C / building-m^3)
and where age class j refers to the decade of its construction.

According to the experience of developers and users of the database (Lehtinen et al. 2000) the accuracy of this material inventory should be better than ±10% (see also Vainio et al. 1998 and 1999). The material content of the building stock is mostly rather well known, as Finnish buildings are rather new and the detailed information collected in recent building permits and in building completions can be utilised when updating the stock database.

In addition to Finnish building stock the amounts of wood products and their C stock in gardens (e.g. fences and yard equipment) were approximately estimated on the basis of specific amount (sawn wood m^3/building m^3) in different building types. All building types have different quantities of sawn wood in yard structures, the amount of which was estimated from cost specifications of building construction in Finland. The above C stock inventories were performed for the years 1980, 1990, 1995 and 2000. The inventories of 1980, 1990, 1995 have been published previously (Pingoud et al. 1996 and 2000). The inventory for 2000 was carried out in 2002, and the results are presented in this report for the first time.

The basis of this latest inventory (2000) was extended so that the stock of sawn wood in buildings not subject to building permits (e.g. the small buildings and some agricultural building types), was also included as well as the estimated quantities of wood used in civil engineering structures. The above buildings are not within the official statistics of building stock. This extended stock is substantial, because in Finland there are many rural areas and much space is available to build many kinds of outbuildings. This estimate is based on statistics of production, import and export of playhouses, small shelters and storehouses etc. and on samples of their number and construction on building sites.

Sawn wood is also used in civil engineering: in bridges, docks, poles and piers. A coarse approximation of wooden stock in civil engineering was based on its estimated capital value (FIM) in transportation networks, telecommunications networks, energy and water supply networks and others (MANK 2002). The amount of sawn wood (m^3) per capital value (FIM) was approximated in these infrastructure sectors. Additional information could be obtained from some confidential reports about the end use of sawn wood and wood-based panels in civil engineering area, made at VTT Building and Transport. The accuracy of this extended inventory appears to be of the order of ±15%, because the use of treated wood is known on the basis of production statistics and the use of wooden materials in sectors outside construction is known.

7.2 C stock of construction in 2000

The carbon pool has increased during last decades. The C pool accounted for by sawn wood, logs and wood-based panels in building stock and garden construction was 8.4 Tg C in 1980, 10.3 Tg C in 1990, 11.0 Tg C in 1995 and 11.7 Tg C in 2000 (see Box 3 in section 3.1). The yearly average change was 0.19 Tg C /yr in the 1980s, 0.14 Tg C /yr between 1990 and 1995, and 0.13 Tg C /yr between 1995 and 2000. The total stock including civil engineering and house construction not subject to permission is given from 1995 and 2000.

The total C stock used in construction (including construction with and without building permits, and civil engineering) was estimated to be 17.4 Tg C in 2000 (Figure 12). Detailed numbers of this inventory are presented in Appendix C. Most important carbon stock comes from detached houses. Also important sectors are small buildings, free-time buildings and agricultural and other separate buildings. Use of wood products in big buildings is not yet too common. However, nowadays there are in Finland still some good examples to build big buildings from wood based materials. Civil engineering is in total a significant carbon stock but this area is divided to very many products. More than 60% from wooden carbon stock is constructed after 1970s.

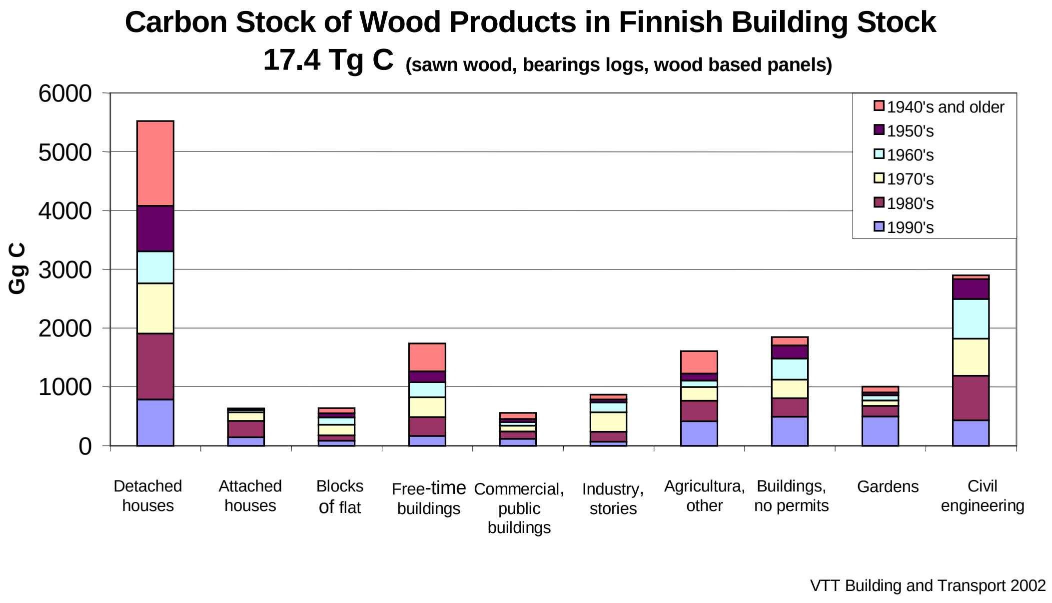


Figure 12. C stock of sawn wood, bearing logs and wood-based panels in Finnish construction in 2000 divided into building types and building age classes. Total stock = 17.4 Tg C.

The C stock in Finnish construction equals approximately 3.5 Mg C per capita and is equivalent to 2.4% of the C reservoir in Finnish forest biomass**.** Here it should be noted that almost all timber used for construction until 2000 is grown in Finnish forests. In addition a clear majority of sawn timber is exported. When considering both domestically used and exported wood products, the total C reservoir of wood products coming from Finnish forests might be approximately equivalent to 7% of forest biomass assuming that exported and domestically used products have similar life cycles.

Use of wood in Finnish building construction is very common compared with many other European countries. About 75–80% of Finnish sawn wood is used in construction branch. In the above, inventory-based, total C stock estimate of 2000 some smaller wood-based product stocks are still excluded. Some very approximate flow-based estimates indicate that the stock in poles could be of the order of 0.3 Tg C and that of furniture 0.05 Tg C (Pingoud et al. 2001). A similar flow-based estimate of paper products stock in 1990 was 0.4–0.7 Tg C (Pingoud et al. 1996).

Finland had a building stock of 1.9 billion m^3 in 2000. Of this stock about 40% consisted of housing, 23% of industrial buildings, 18% of public and commercial buildings and 19% of other buildings. In Finnish dwelling stock there are almost same number block of flat dwellings and single-family houses (Vainio 2000). It is important to recognise that the age distribution (Figure 13), in which the C stock of construction wood is distributed by construction year of the building, does not describe the true age of wooden structures. Their age distribution is even newer than that of buildings, because renovation activities of old buildings involve considerable quantities of new construction wood.

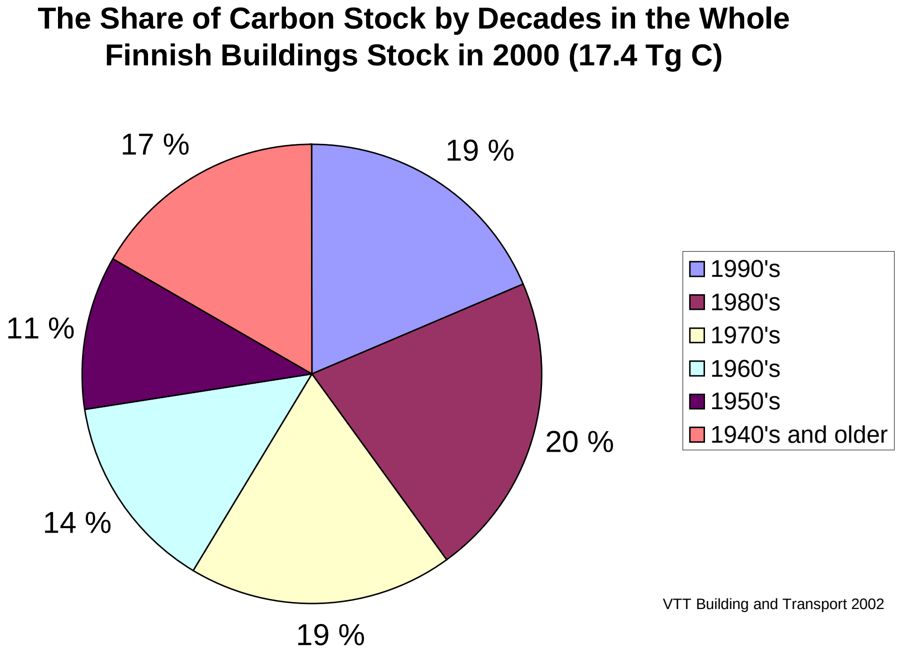


Figure 13. The percentage of C stock (sawn wood, bearing logs, wood-based panels) in buildings of different age classes. More than 60% of C stock is in buildings constructed since the 1970s.

In Finland construction of wooden buildings is common. More than 30% of the construction wood in the building sector are localised in detached houses (Figure 12). Free-time residential buildings (holiday homes), agricultural buildings, and other small buildings are also important C pools. Sawn-wood products form a much larger stock than wood-based panels. However, in Finland relatively little wood is currently used in public, commercial and industrial buildings. For example, in public construction the share of timber-framed buildings has varied between 8% and 18% within the last 15 years (Statistics Finland 1997a). In addition, the construction of multi-storey blocks in wood is limited by fire safety regulations, which, however, have been liberalised since 1997. Apart from houses the entire civil engineering sector is an important C pool of sawn wood products, but the use of wooden products varies considerably in different sites.

7.3 Would it be possible to inventory C stock of construction wood in other European countries?

7.3.1 Background

Finland has rather good statistics about wood material concerning forests, production, export and import of wood-based materials. Statistics Finland has collected construction statistics in wood framed new buildings until year 1952. Also Finnish building stock information in wood framed buildings is estimated regularly. The Business Intelligence Group at VTT Building Technology has estimated the whole wooden material use in different building parts in new buildings and building stock, as the group is concentrated to assess market conditions of all kinds of materials in construction area. Kim Pingoud (VTT Processes) and Anna-Leena Perälä (VTT Building Technology) have done estimates of Finnish wooden building stock (dry weight) and the associated C stock.

7.3.2 Building statistics in Europe

The situation in other European countries is different. Construction markets in whole Europe are orders of magnitude larger than in Finland, whereas the average use of wooden products per capita is much lower than in Finland. The basics to estimate the amount of wood products in construction are coarse, but the measure is large. In addition, there could be substantial potentials for increased use of wooden products in the future.

The Euroconstruct network collects European construction market and forecast information from individual countries. New data and forecasts are coming twice a year (Euroconstruct 2000). There is information about construction market volumes (Euro, different building types, house buildings by units and building stock). Table 12 provides an example of end use of softwood in UK. Every member in different countries produces the latest information about construction, but there is no information about the use of wooden materials.

Table 12. Distribution of end use of sawn softwood in UK in 1996 (Trada 1999).

	End use (%)
Construction	70%
Pallets and packaging	14%
Fencing	12%
Others	4%
Total	100% (8.4 mill. m^3 sawn soft wood)

Every European country produces construction statistics. In addition, more detailed information about buildings from each country is provided, but the type of information varies. General statistics information in different countries can be read in Eurostat-statistics, but it does not include building materials such as frame material. Typical building statistics are given in sources (SBD 1998ab, DETR 1998 and DAIEI-SES 1999).

Only German new construction statistics include information about wood frames in new buildings. In Germany the share of wood frame buildings in new construction in 1998 was 12% (in building units) and 7% (in building m^3). The share was in single family houses 13% of building units and in agricultural buildings 26% of units. It has been estimated that the share of wood framed housing construction is in Europe slightly more than 5% of housing starts (Figure 14).

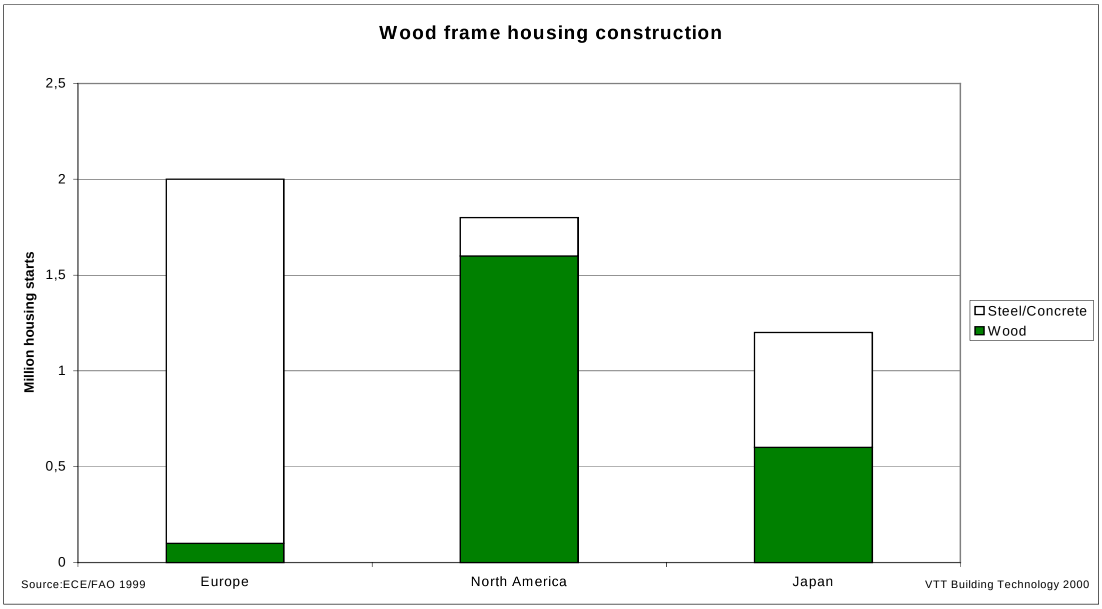


Figure 14. Estimate of starts of wood framed housing construction in Europe, USA and Japan (ECE/FAO 2001).

In UK new buildings timber frames have a relatively small share of the residential market, accounting for 7% of new starts in 1998 (Trada 1999). New wooden houses are mostly built in Scotland. Outside official statistics and end use studies such as the Trada (1999) Technology report summarise that about 70% of sawn softwood goes to building construction in UK (Table 12).

7.4 Building stock in European countries

In the following some collected information and sources concerning the building stock in Europe is presented. It should be noted that the statistics are not similar in European countries. If the goal was to estimate wooden product stock in construction, more detailed information and statistics would be needed from most countries. However, some basic references needed when assessing of the amount of wood-based construction materials are given in the following. The five biggest countries in the number of inhabitants and size of building stock are Germany, United Kingdom, France, Italy and Spain.

Wooden products can be used in housing construction, non-residential buildings or civil engineering area. This paper includes numbers in housing stock. For instance in Finnish building stock there are 40% residential buildings, 35% production buildings and 25% public, commercial and other buildings. If we look at the use of wooden products, the most important area is the housing stock.

A typical way to measure housing stock is the number of dwellings. In Table 13 there are numbers from housing stock and also from new construction. The housing stock in Germany is nowadays 36.8 million dwellings, in UK 24.5 million dwellings, in France 28.9 million dwellings and in Italy 25 million dwellings. The housing stock varies in most European countries between 336–493 dwellings/1000 people. Similar number for other European countries can be found in references (Euroconstruct 2000 and SBD 1998a).

Building stock information can provide the age of dwellings. For instance in UK about 40% of dwellings have been completed before 1938 (Marketing Book 1998). The situation is similar in most European big countries, whereas for instance the Finnish building stock is much younger.

It is also typical to register dwellings by room numbers or square area. However, normally there is no information about wood structures. Some countries, like Finland and Germany, collect in new construction permits information about wooden structures. Additional data and additional statistics of long-lived HWP stocks in construction would be needed to perform any stock inventories of HWP in European building stock. However, some end use studies can be found in any European countries. One interesting database on the wood use in West Germany during 1970–1990 was calculated in a Swedish study (Flinkman 1993), but this study does not give direct information on wood material in long-term use in building stock. Some general European information can be found also in reports (Statistics Finland 1999 and Nippala et al. 1995) but they do not include wooden materials in construction.

Table 13. Population and building stock in some European countries.

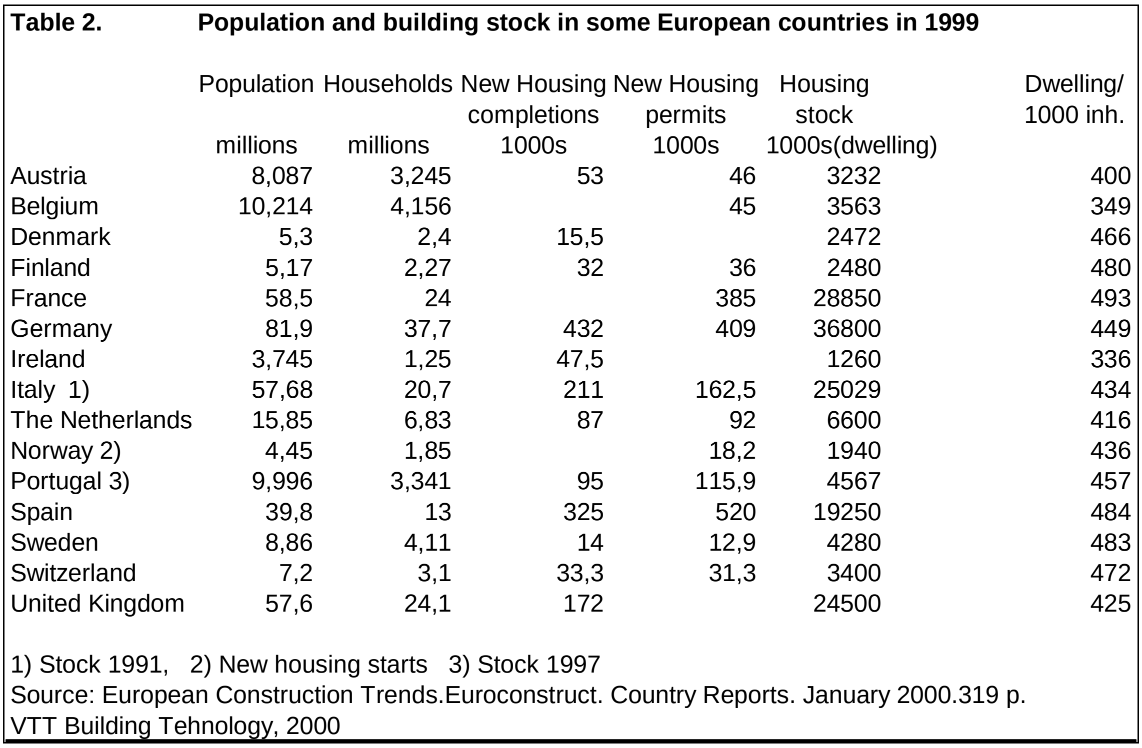


Table 2. **Population and building stock in some European countries in 1999**

	Population millions	Households millions	New Housing completions 1000s	New Housing permits 1000s	Housing stock 1000s(dwelling)	Dwelling/ 1000 inh.
Austria	8,087	3,245	53	46	3232	400
Belgium	10,214	4,156		45	3563	349
Denmark	5,3	2,4	15,5		2472	466
Finland	5,17	2,27	32	36	2480	480
France	58,5	24		385	28850	493
Germany	81,9	37,7	432	409	36800	449
Ireland	3,745	1,25	47,5		1260	336
Italy 1)	57,68	20,7	211	162,5	25029	434
The Netherlands	15,85	6,83	87	92	6600	416
Norway 2)	4,45	1,85		18,2	1940	436
Portugal 3)	9,996	3,341	95	115,9	4567	457
Spain	39,8	13	325	520	19250	484
Sweden	8,86	4,11	14	12,9	4280	483
Switzerland	7,2	3,1	33,3	31,3	3400	472
United Kingdom	57,6	24,1	172		24500	425

1) Stock 1991, 2) New housing starts 3) Stock 1997

Source: European Construction Trends.Euroconstruct. Country Reports. January 2000.319 p.

VTT Building Tehnology, 2000

7.5 Construction wastes

Wooden construction wastes (construction and demolition wastes) is also one C stock of HWP. In report (EC 1998) the flux of wood wastes in some European countries during are estimated (Table 14), from which a substantial fraction is disposed into landfills. More detailed information on wood waste fluxes into landfills is presented in Chapter 9. Some wooden wastes can be burned or recycled.

Table 14. Construction and demolition waste in European countries.

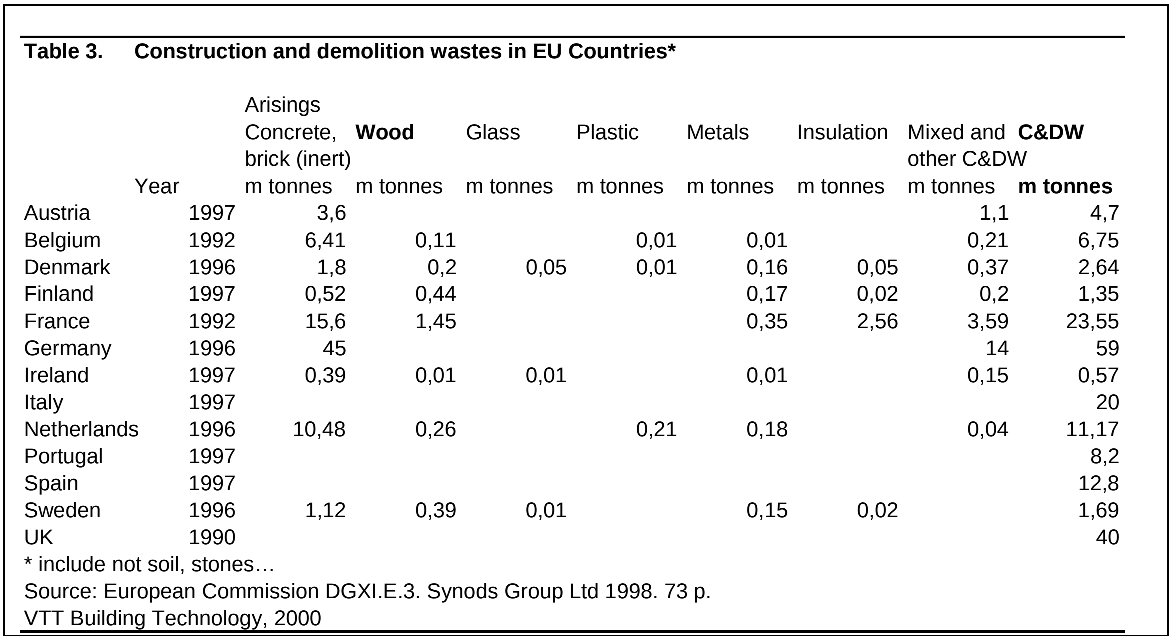


Table 3. Construction and demolition wastes in EU Countries*

	Year	Arisings Concrete, brick (inert) m tonnes	**Wood** m tonnes	Glass m tonnes	Plastic m tonnes	Metals m tonnes	Insulation m tonnes	Mixed and other C&DW m tonnes	**C&DW** **m tonnes**
Austria	1997	3,6						1,1	4,7
Belgium	1992	6,41	0,11		0,01	0,01		0,21	6,75
Denmark	1996	1,8	0,2	0,05	0,01	0,16	0,05	0,37	2,64
Finland	1997	0,52	0,44			0,17	0,02	0,2	1,35
France	1992	15,6	1,45			0,35	2,56	3,59	23,55
Germany	1996	45						14	59
Ireland	1997	0,39	0,01	0,01		0,01		0,15	0,57
Italy	1997								20
Netherlands	1996	10,48	0,26		0,21	0,18		0,04	11,17
Portugal	1997								8,2
Spain	1997								12,8
Sweden	1996	1,12	0,39	0,01		0,15	0,02		1,69
UK	1990								40

* include not soil, stones…

Source: European Commission DGXI.E.3. Synods Group Ltd 1998. 73 p.

VTT Building Technology, 2000

7.6 Conclusions

Wood framed new buildings in Europe are about 5% from all buildings. European building statistics of *new* buildings include no information about wood framed buildings, except in Finland, Germany and perhaps UK. General statistics on *building stock* provide information about all buildings or houses by decades but there is no information of wood frames or HWP in general. End use studies of wood can be found in many countries from different years. The FAO statistics produce the production, import and export of sawn wood and wood-based panels, but there is not information about use of construction field or buildings. The share of wood framed buildings in Europe is small at present, but the share of wood materials in some special building parts like roofs can still be remarkable. A requirement for more reliable HWP stock estimates would be collection of information on building materials in the largest European countries.

8. Method based on lifetime analysis: EXPHWP model for estimation of carbon balance in HWP

8.1 General description of the method

In the following a method is described, which countries could apply in their national emissions reporting to estimate additions to carbon stored in harvested wood products (HWP). It uses production and trade data from the United Nations Food and Agriculture organisation and estimates carbon stock change for both products in use and in solid waste disposal sites to provide "neither over nor underestimates so far as can be judged." The intent is to aid in meeting IPCC *Good Practice Guidance* aims for methods "that are transparent, documented, consistent over time, complete, comparable, assessed for uncertainties, subject to quality control and assurance, efficient in the use of the resources …, and in which uncertainties are … reduced as … information becomes available." The method uses data on HWP production and trade starting several decades in the past, and tracks annual additions to pools of HWP in use, removals from use; additions to solid waste disposal sites (SWDS) and decay from SWDS. The method is consistent with IPCC guidance for estimating emissions from SWDS.

The method is also described in the paper by Skog et al. (2003), in which also an uncertainty analysis of the method is performed using data from United States. Uncertainty is evaluated by postulating the uncertainty in the form of probability density functions (pdfs) for 14 variables and using Monte Carlo simulation to generate pdfs for change in carbon stored in HWP. Results for the United States suggest uncertainty is most sensitive to uncertainty in solidwood products production data; the factor used to convert products to carbon, and the proportion of solidwood and paper that goes to SWDS after use. According to Skog et al. (2003) uncertainty in use life of solidwood products has limited effect because an error causes offsetting changes in products in use and in SWDS. The method provides a starting point for meeting the aims of IPCC *Good Practice Guidance.*

8.2 Aims of IPCC Good Practice Guidance and the model

Storage of carbon in woody biomass in forests in a country is supplemented by storage of carbon in harvested wood in wood and paper products (harvested wood products or HWP). Intergovernmental Panel on Climate Change (IPCC) guidelines for countries to report HWP carbon storage under the United Nations Framework Convention on Climate Change (UNFCCC) allow countries to estimate carbon storage in HWP if they can provide a method. It is proposed to serve as a Tier 2 level method that most countries could use in their national HWP estimation and reporting under the UNFCCC.

The *1996 IPCC Guidelines* provide a default method for estimating change in carbon stored in harvested wood products described in Box 1. The IPCC provides good practice guidance suggesting how countries should make estimates of carbon emissions and changes in sinks for various sectors (IPCC 2000b). Efforts are underway to provide guidance on estimating carbon change related to land use, land use change, and forestry that could include guidance related to HWP. The method suggested here for estimating carbon change in HWP seeks to meet objectives for good practice guidance.

"*Good practice guidance* assists countries in producing inventories that are accurate in the sense of being neither over nor underestimates so far as can be judged, and in which uncertainties are reduced as far as practicable. *Good practice guidance* further supports the development of inventories that are transparent, documented, consistent over time, complete, comparable, assessed for uncertainties, subject to quality control and assurance, efficient in the use of the resources available to inventory agencies, and in which uncertainties are gradually reduced as better information becomes available." (IPCC 2000b, Section 1.1)

The objective was to present general method countries could use to estimate recent and current year additions to carbon stored in HWP. One key concern in making these estimates is evaluating their uncertainty, which however will not discussed in this report. In the following the equations of *stock change approach* are used in order to illustrate the estimation method. The estimation method can be adapted to make estimates for the other accounting approaches by applying the equations presented in section 4.2.1. The estimation method focuses on changes in carbon stocks and not on emissions from stocks as they are burned or undergo decay. Total emissions in a year could be estimated as the carbon in timber harvested for products and fuel in the year minus additions to carbon stored in wood and paper.

8.3 Method

Two general methods could be used to estimate change in HWP carbon stocks. The first is to use direct estimates of inventories of HWP in use and in waste disposal sites at two points in time and calculate the change in carbon stored. Such a method was described in Chapter 7. As noted this kind of inventory information may be available for wood in housing stock for some countries but is generally not available for other wood and paper uses or for waste sites. The second method is to use data beginning a number of decades in the past and estimate, up to the present time, annual additions to pools of HWP in use, removals from use, additions to solid waste disposal sites (SWDS), and decay from sites. Direct inventories at two or more times of carbon stock in housing or structures can also be used to aid in estimating use life that can be used in the second method. This has been done for Finland (Pingoud et al. 2001).

In this Chapter a second type of method is proposed – tracking additions to, and removals from products in use and products in SWDS. This method is based on a dynamic spreadsheet model. The method is intended to be consistent with the Tier 2 method used for the Waste Management sector (see IPCC 1997c, Chapter 6; IPCC 2000b, Chapter 5). The Tier 2 method for the Waste Management Sector estimates methane emissions from SWDS in a country by beginning several decades in the past and tracking additions to the pool of waste in SWDS and methane emissions from the pool. The factors a country uses to compute amounts of HWP carbon retained in SWDS should be consistent with the factors used to compute the methane emissions from SWDS.

The Excel spreadsheet model EXPHWP was developed by Kim Pingoud, and it implements the estimation method shown below and can provide estimates for any country where FAO data and estimation parameters are available.

8.3.1 Estimating Annual Change in Carbon Stored in HWP

This method is termed the First Order Decay method because carbon in each of four carbon pools is estimated to leave the pool at a constant percentage rate of the contents of the pool. Numerical integration method is simple: integration of the stocks is performed by the *implicit* backward Euler method with a time step of 1 year (as in the data). An implicit method was chosen to ensure the stability of the calculations. For instance, the decay rate parameter of paper products can be quite high, i.e. average lifetime quite short in proportion to the time step of one year, which would cause stability problems if using an *explicit* method. The approximate difference equation describing the dynamics of C stock of HWP is explained in Box 7.

Assume that the dynamics of the HWP pool can be described by the differential equation (1):

$$dx/dt = -y(t) + u(t) \quad (1)$$

where x(t) is the pool at time t, u(t) is the input flux to the pool or consumption and y(t) = kx(t) the output or decay flux of the pool. Thus the *decay flux* is at any given time *directly proportional to the pool* at that time, which means that the decay is assumed to follow first-order kinetics leading to exponential decay.

One finite difference approximation of equation (1) is equation (2), called (implicit) backward Euler approximation (see e.g. Burden and Faires 2001):

$$(x_{i+1} - x_i)/\Delta t = -kx_{i+1} + u_{i+1} \quad (2)$$

where i is the time step. Note that the function on the right hand side in eq.(1) is in eq.(2) approximated at time step i+1 instead of i. Using time step i would lead to the (explicit) forward Euler method. If the time step $\Delta t = 1$ yr, we get: eq. (2)$\Rightarrow$ eq.(3): $x_{i+1} = 1/(1+k)*(x_i + u_{i+1})$, which approximation is used in the EXPHWP model.

Some remarks:

a) The method is stable even when average lifetime (inverse of decay rate) is less than the time step of 1 year. In explicit forward Euler: $x_{i+1} = (1-k)*x_i + u_i$, and we may be in numerical troubles with k>1 (possible negative stocks in paper products etc). (Note that when $k \rightarrow 0$ then $1/(k+1) \approx 1-k$, and when k is large $1/(k+1) \approx 1/k > 0$).

b) This kind of approximation reacts faster to the input flow, i.e. HWP consumption, the stock in year i is influenced by the consumption in year i (unlike in the explicit Euler),

c) More advanced numerical integration methods could of course be used, but this kind of a simple and robust method appears to be good enough, bearing in mind the impreciseness of the basic data.

Box 7. The first order linear differential equation describing the dynamics of HWP stock and its approximation by the backward Euler algorithm.

By applying the backward Euler method the equations for stock change approach are given by:

(1) Change in carbon held in HWP in a country in year t (Tg/ yr) =

$$(SWU_t - SWU_{t-1}) + (PU_t - PU_{t-1}) + (SWDS_t - SWDS_{t-1}) + (PDS_t - PDS_{t-1})$$

Where

SWU_t	total carbon in solidwood products in use in year t (Tg) (solidwood products include lumber, veneer, wood panels, and other products using solid wood rather than wood fiber as is used in paper)
PU_t	total carbon in paper products in use in year t (Tg)
$SWDS_t$	total carbon solidwood products in disposal sites in year t (Tg)
PDS_t	total carbon paper products in disposal sites in year t (Tg)

Amounts of carbon in solidwood and paper products in use are computed for the current year by beginning calculation in the year 1900 and continuing recursively through to the current year using Equations 2 and 3:

(2) $SWU_t = (SWU_{t-1} + (SWP_t + SWIM_t - SWEX_t)*CSW) * (1/(1 + SWdiscard))$

(3) $PU_t = (PU_{t-1} + (PP_t + PIM_t - PEX_t)*CP) * (1/(1+Pdiscard))$

Equations 2, 3, 7 and 9 are derived as approximations to continuous additions and discards from carbon in the four different pools – solidwood products in use, paper products in use, solidwood products in SWDS and paper in SWDS. Here is the derivation of this approximation for Equation 2.

Begin with the estimated change over a time interval --- Δt

$(SWU_t - SWU_{t-1})/\Delta t = - Swdiscard * SWU_t + (SWP_t + SWIM_t - SWEX_t)*CSW$

We approximate continuous additions and discard by using time steps of one year, that is Δt equals 1. Solving this equation for SWU_t gives Equation 2. This is the backward Euler estimation method. It is used instead of the forward Euler method because to take into account decay from additions in the current period and because it is more stable for high discard rates – that is, for short use life, such as for paper.

Where

SWP_t	solidwood products produced in year t (cubic meters)
$SWIM_t$	solidwood products imported in year t (cubic meters)
$SWEX_t$	solidwood products exported in year t (cubic meters)
CSW	Carbon weight per unit of solidwood products (Tg C per cubic meter)
PP_t	paper products produced in year t (metric tons)
PIM_t	paper products imported in year t (metric tons)
PEX_t	paper products exported in year t (metric tons)
CP	Carbon weight per unit of paper products (Tg per metric ton)
Swdiscard	the fraction of all solidwood products in use in a year that are taken out of use by the end of that year
Pdiscard	the fraction of all paper products in use in a year that are taken out of use by the end of that year

Solidwood carbon and paper carbon in disposal sites are held in three types of stocks – 1) permanent stocks, 2) stocks undergoing complete anaerobic decay and 3) stocks undergoing complete aerobic decay. Our method assumes that wood and paper going to aerobic conditions decay rapidly and completely and we do not include them. That is, the amounts we include in SWDS are only the amounts in permanent stocks and amounts undergoing anaerobic decay.

(4) $SWDS_t = SWDS\_perm_t + SWDS\_anaerobic_t$

(5) $PDS_t = PDS\_perm_t + PDS\_anaerobic_t$

Where

SWDS_perm	total solidwood carbon in disposal sites that is never emitted (Tg)
SWDS_anaerobic	total solidwood carbon in disposal sites that is undergoing anaerobic decay (Tg)
PDS_perm	total paper product carbon in disposal sites that is never emitted (Tg)
PDS_anaerobic	total paper product carbon in disposal sites that is undergoing anaerobic decay (Tg)

Amounts of solidwood carbon in disposal sites are computed for the current year by beginning computations in the year 1900 and continuing recursively through to the current year using Equations 6 and 7.

(6) $SWDS\_perm_t = SWDS\_perm_{t-1} + SWU_t * SWdiscard * SWWSf_t * CF_t * (1-DOCfwood)$

(7) $SWDS\_anaerobic_t = [\, SWDS\_anaerobic_{t-1} + SWU_t * SWdiscard * SWWSf_t * CF_t * DOCfwood \,] * (1/(1 + SWanaerobic\_decay))$

Amounts of paper product carbon in disposal sites are computed for the current year by beginning computations in the year 1900 and continuing recursively through to the current year using Equations 8 and 9.

$$(8)\ PDS\_perm_t = PDS\_perm_{t-1} + PU_t * Pdiscard * PWSf_t * CF_t * (1-DOCfpaper)$$

$$(9)\ PDS\_anaerobic_t = [\, PDS\_anaerobic_{t-1} + PU_t * Pdiscard * PWSf_t * CF_t * DOCfpaper \,] * (1/(1 + P\_anaerobic\_decay))$$

Where

$SWWSf_t$	the fraction of total discarded solidwood products (total includes amounts recovered for recycling) that is sent to disposal sites in year t
$PWSf_t$	the fraction of total discarded paper products (total includes amounts recovered for recycling) that is sent to disposal sites in year t
CF_t	the fraction of wood or paper sent to disposal sites that is held in anaerobic conditions
DOCfwood	the fraction of wood held in anaerobic conditions that decays to CO2 and CH4
DOCfpaper	the fraction of paper held in anaerobic conditions that decays to CO2 and CH4
SWanaerobic_decay	the fraction of solidwood undergoing anaerobic decay that decays to CO2 and CH4 in a year
P_anaerobic_decay	the fraction of paper undergoing anaerobic decay that decays to CO2 and CH4 in a year

If independent annual estimates are available of wood and paper sent to solid waste disposal sites each year they may be used instead of the terms (SWU_t * SWdiscard * $SWWSf_t$) and (PU_t * Pdiscard * $PWSf_t$) in Equations 6 – 9.

8.3.2 Data Sources for Production and Trade

Data on solidwood and paper product production and trade is available for most countries from 1961 to 2001 from the United Nations Food and Agriculture Organization Forest Products database (FAOSTAT 2002). Data on production and trade (SWP_t, $SWIM_t$, $SWEX_t$, PP_t, PIM_t, PEX_t) are estimated for the model from 1900 to 1961 using an estimated rate of increase in production that occurred between 1900 and 1961 (rate = r).

Production and trade data for t = 1900 to 1960 were estimated using Equation 10.

(10) Production (or trade) $_t$ =

$$\text{(Production (or trade) for 1961)} * e^{(r*(t-1961))}$$

8.3.3 Results

Data for several countries have been browsed from the FAO database (FAOSTAT 2002) and some selected results calculated by the EXPHWP model were presented in Chapters 2 and 5.

9. Carbon flows of wood products into landfills

Because of the long lifetime of HWP in landfills, their influence on the total lifecycle C balance is substantial. Unfortunately waste statistics concerning HWP is relatively poor and especially the historical waste fluxes are basically unknown. In the following case study HWP waste fluxes into Finnish landfills are estimated.

Systematic compilation of statistics on wastes has been started on in Finland only recently. The inventories cover the years from 1997 to 2000 made by Finnish environment institute and Statistics Finland. Rougher calculation for the year of 1990 has also been done. In this study, carbon flows of wooden wastes in landfills were estimated with help of these statistics.

Wood based wastes were evaluated to consist of wood, paper and cardboard coming from solid municipal and construction wastes as well as from forest and other industrial wastes. Garbage, waste of gardens and sludge may also to some extent contain wood based materials, but due to lack of data these fractions were not taken into account. The contribution of these fractions in terms of carbon content is, however, probably insignificant. Statistics of wood based wastes that were taken into consideration are presented in Table 15.

Table 15. Statistics of estimated wood based wastes in terms of 1000 tons (wet weight) disposed in landfills in Finland in the year of 1990 and between 1997 and 2000.

	solid municipal waste		**solid construction waste**		**solid industrial waste**	
year	**paper and cardboard**	**wood**	**paper and cardboard**	**wood**	**paper and cardboard**	**wood**
1990	655	159	0	311	46	128
1997	429	58	0	137	4	62
1998	453	62	0	137	5	38
1999	448	61	0	137	5	38
2000	448	59	0	137	4	38

We assumed that amount of wastes disposed in landfills has decreased linearly between 1990 and 2000 by using method of least square.

Moisture of paper and cardboard disposed in landfills was evaluated to be 10%, whereas 20% moisture content was assessed for wood wastes. Carbon content in dry matter was estimated to be 50% for every waste fraction. Contribution of degradable organic carbon (DOC) in wet matter corresponding assumed moisture contents was assessed to be 40% for paper and cardboard, and 30% for wood, respectively (Petäjä 2002). These numbers are mainly based on IPCC (2000). Using factors mentioned above, annual input for carbon to landfills could be calculated (Table 16). Some 60–70% of annual carbon input results from paper and cardboard wastes, principally coming from municipal wastes.

Table 16. Annual carbon input of wood based wastes (in terms of 1000 tons) to landfills in Finland in the year of 1990 and between 1997 and 2000.

	solid municipal waste		**solid construction waste**		**solid industrial waste**	
year	**paper and cardboard**	**wood**	**paper and cardboard**	**wood**	**paper and cardboard**	**wood**
1990	295	64	0	124	21	51
1997	193	23	0	55	2	25
1998	204	25	0	55	2	15
1999	202	24	0	55	2	15
2000	201	24	0	55	2	15

The rate of refuse decomposition in landfills depends on many different factors. These include for instance the waste management and processing variables, composition and moisture of waste and factors that have influence on bacterial growth. Cellulose and hemicellulose can both be degraded under the anaerobic conditions found in landfills, where as lignin doesn't. Anaerobic circumstances are dominant in landfills, and thus lignin doesn't significantly decompose.

We divided the annual input data to three individual categories based on estimated period of decay. Paper and cardboard were assessed to be fast degradable (1), where as wood was estimated to degrade significantly slower (2). Lignin was assumed to be non-degradable (3) in landfill conditions, being stored in disposal sites.

The carbon stock in landfills in year *t* was modeled using formula:

$$S_t = S_{t-1} - kS_{t-1} + I_t$$

where

S_t = carbon stock in landfills in year *t*

k = decay constant

I_t = carbon input in year *t*

Decay constant *k* was assumed to be 0.1 for fast and 0.015 for slow degradable components. Half-lives corresponding these values are some 7 and 46 years, respectively.

10. Case study on material substitution: house in wood vs. house in concrete

Wooden block of flats have been developed in many countries in the last few years. One of these has been built in 1997 in Viikki district of Helsinki, being one of the first present day wooden blocks of flats in Finland. Currently, there are several wooden blocks of flats in Finland.

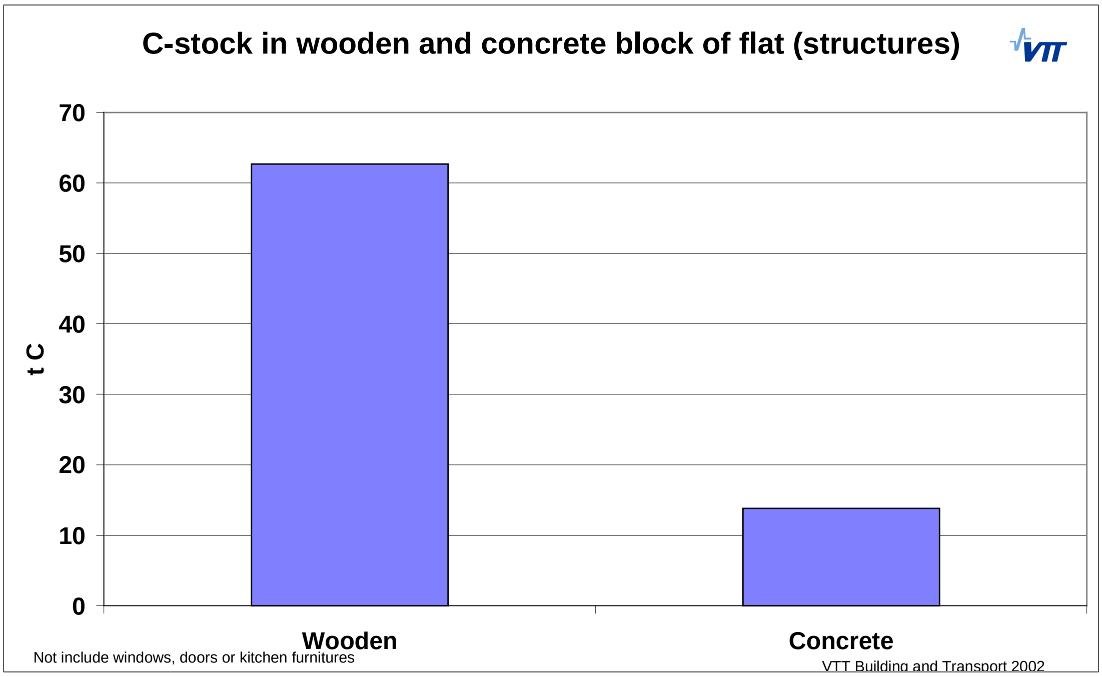
The aim of the case study was to compare carbon stock and some other environmental indicators between wooden and concrete blocks of flats. Calculation included all detailed structure materials, like ground, base floor, walls, roof, stairs, balconies and all surfaces. Windows, doors, kitchen furniture and HVAC as well as electric materials were excluded, owing to similarity in both buildings. Material inventory indicated weight of some 500 tons for the wooden block of flats against 2000 tons for concrete building. The difference results mainly from significantly lighter materials in outside walls, slabs, inside walls, roof and in balconies of the wooden building.

The C stock of HWP stored in structures was 65 Mg C for the wooden block of flats, and 13 Mg C for suchlike concrete building (Figure 15). Many building parts in the wooden block of flats like outside walls, floor surfaces, slabs and roof, include relatively much carbon. Roof as well as ceiling and floor surfaces build the largest share of carbon stock in the concrete case (Figure 16).

Some calculations have been done also from production energy and CO_2-emissions in the same wooden and concrete block of flats. Basic environmental data was in many building materials (Table 17).

Table 17. Production energy and CO_2 emissions in typical materials in Finland. Source: RTS 1997...2000.

Materials	Production energy	CO_2 emissions (ekv)	Source:
	kwh/kg	g CO_2 (ekv)	
Mineral raw material	0,01…0,16	2,5…90	RT: 29,30
Glass products	2,5…6,3	710	VTT (97)
Cement	1,42	690	VTT (97)
Mortar (100/600)	0,37	120	RT:13
Ready mixed beton	0,17	85	RT:32
Concrete element	0,48	150	VTT (97)
Other min. products	0,41…2	170…440	RT:many
Mineral wool	5,5	1620	RT:4
Sawn wood	0,81…1	100	RT:97
Chipboard	3,75	560	RT:24
Other 4 products	1…4,4	310…600	RT:7,25
Steel plate	1,9	819	RT:35
Galvanized steel	3,4	660	RT:35
Other metals	7…130		VTT
Oil&plastic products	7…30	1200…5100	VTT (97)
Source: RT environmental notes in 1997…2000 done by VTT			



C-stock in wooden and concrete block of flat (structures)

Not include windows, doors or kitchen furnitures

VTT Building and Transport 2002

Figure 15. The C stock of HWP in the wooden block of flats in Viikki and the corresponding C stock of similar house built from concrete.

Energy is needed in producing building materials and transporting them to building sites. Surprisingly, the production energy needed was almost the same in both buildings.

When we calculate materials and all surface materials like paints together there is no essential difference between two buildings (Figure 17).

According to calculations, CO_2 emissions from the construction of block of flats were some 190 t CO_2 for the wooden case, and appr. 300 t CO_2 for the concrete one. The difference is mainly based on lower CO_2 emissions from production of materials used in slabs and walls in wooden block of flats (Figure 17). Although the overall energy consumptions are close to each other, different types of energy sources are used in production of various materials.

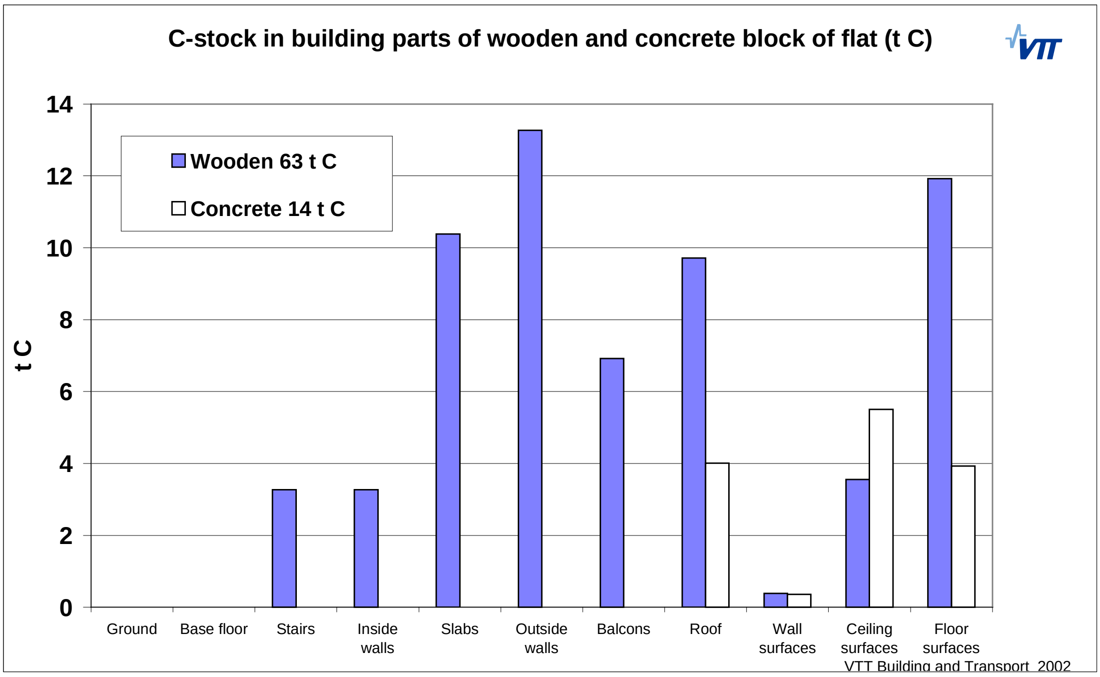


Figure 16. Carbon stock of different building parts in wooden and concrete block of flats. Carbon of wooden block of flats is mainly stored in outside walls, floor surfaces, slabs, roof and balconies.

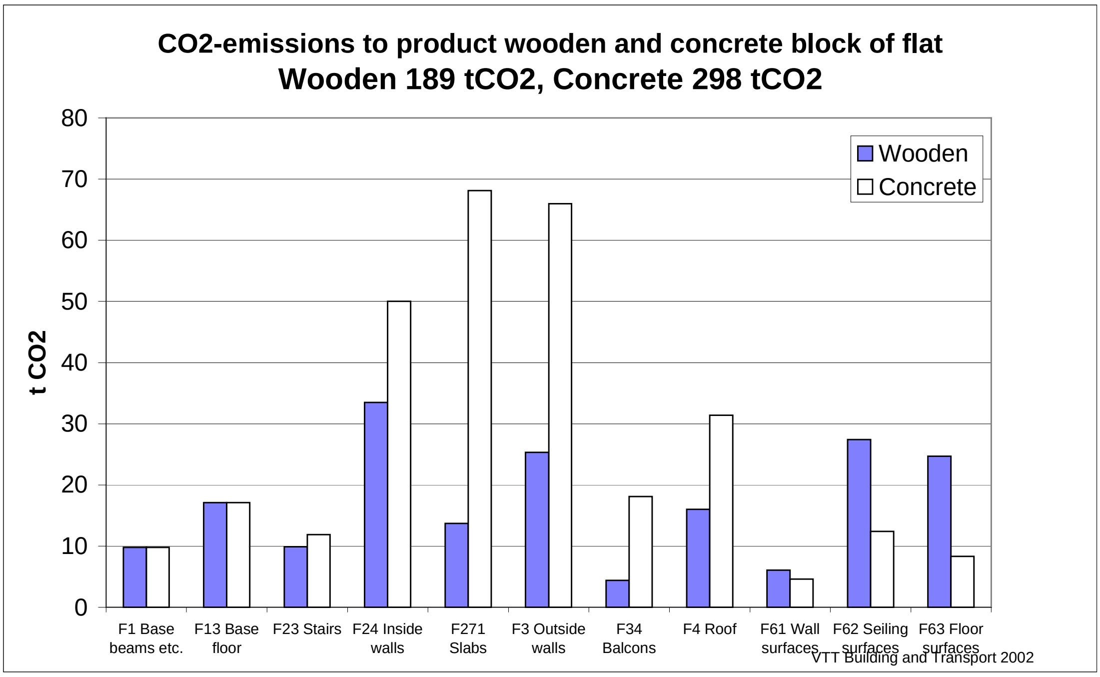


Figure 17. Fossil CO_2 -emissions of production of building material to the wooden block of flats are more than 30% lower than in the case of the concrete one.

The case study shows how the whole material use in different building parts influences the comparison between the two houses. In the wooden house the HWP were not especially energy intensive, whereas the gypsum plates used in the wooden house increased essentially its energy intensity. For instance, wooden slabs implied many material levels and many of them were gypsum plates.

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Appendix A: FAO classification of HWP

YEARBOOK OF FOREST PRODUCTS DEFINITIONS

- ROUNDWOOD
- FUELWOOD + CHARCOAL
- INDUSTRIAL ROUNDWOOD
- SAWNWOOD
- WOOD-BASED PANELS
- PULP
- PAPER AND PAPERBOARD
- SPECIES

ROUNDWOOD (1)

1861 ROUNDWOOD
1862 ROUNDWOOD (C)
1863 ROUNDWOOD (NC)

Wood in the rough. Wood in its natural state as felled, or otherwise harvested, with or without bark, round, split, roughly squared or other forms (e.g. roots, stumps, burls, etc.). It may also be impregnated (e.g. telegraph poles) or roughly shaped or pointed. It comprises all wood obtained from removals, i.e. the quantities removed from forests and from trees outside the forest, including wood recovered from natural, felling and logging losses during the period - calendar year or forest year. Commodities included are sawlogs and veneer logs, pulpwood, other industrial roundwood (including pitprops) and fuelwood. The statistics include recorded volumes, as well as estimated unrecorded volumes as indicated in the notes. Statistics for trade include, as well as roundwood from removals, the estimated roundwood equivalent of chips and particles, wood residues and charcoal.

FUELWOOD+CHARCOAL(1)

1864 FUELWOOD+CHARCOAL

The commodities included are fuelwood, coniferous and non-coniferous and the roundwood equivalent of charcoal (using a factor of 6.0 to convert from weight (MT) to solid volume units (CUM).

1629 FUELWOOD
1627 FUELWOOD (C)
1628 FUELWOOD (NC)

Wood in the rough (from trunks, and branches of trees) to be used as fuel for purposes such as cooking, heating or power production.

1630 CHARCOAL(2)

Wood carbonized by partial combustion or application of heat from an external source. It is used as a fuel or for other uses. Figures are given in weight (MT).

INDUSTRIAL ROUNDWOOD(1)

1865 INDUSTRIAL ROUNDWOOD
1866 INDUSTRIAL ROUNDWOOD(C)
1867 INDUSTRIAL ROUNDWOOD(NC)

The commodities included are sawlogs or veneer logs, pulpwood, other industrial roundwood and, in the case of trade, also chips and particles and wood residues.

1868 SAWLOGS+VENEER LOGS

These commodity aggregates include sawlogs and veneer logs coniferous and non-coniferous.

1601 SAWLOGS+VENEER LOGS(C)
1604 SAWLOGS+VENEER LOGS(NC)

Sawlogs, veneer logs and logs for sleepers.
Logs whether or not roughly squared, to be sawn (or chipped) lengthwise for the manufacture of sawnwood or railway sleepers (ties). Shingle bolts and stave bolts are included. Logs for production of veneer, mainly by peeling or slicing. Match billets are included, as are special growth (burls, roots, etc.) used for veneers.

1870 PULPWOOD+PARTICLES
1608 PULPWOOD+PART(C)
1611 PULPWOOD+PART (NC)

Pulpwood, chips, particles and wood residues.
In production, the commodities included are pulpwood coniferous and non-coniferous. In trade, the aggregate includes, in addition, chips or particles and wood residues.

1614 PULPWOOD(Round & Split)

Wood in the rough other than logs - for pulp, particle board or fibreboard. Pulpwood may be barked or unbarked and may be in the form of roundwood or splitwood. In production, it may include the equivalent of wood chips made directly from roundwood.

1619 CHIPS+PARTICLES

Wood chips and particles
Wood that has been deliberately reduced to small pieces from wood in the rough or from industrial residues, suitable for pulping, for particle board and fibreboard production, for fuelwood or for other purposes.

1620 WOOD RESIDUES

Miscellaneous wood residues
Wood residues that have not been reduced to small pieces. They consist principally of industrial residues, e.g. sawmill rejects, slabs, edgings and trimmings, veneer log cores, veneer rejects, sawdust, bark (excluding briquettes), residues from carpentry and joinery production, etc.

1871 OTHER INDUST ROUNDWD
1623 OTHER INDUST ROUNDWD (C)

1626 OTHER INDUST ROUNDWD (NC)

Other industrial roundwood

Roundwood used for tanning, distillation, match blocks, gazogenes, poles, piling, posts, pitprops, etc.
(Note: "OTHER INDUSTRIAL ROUNDWOOD" include pitprops.)

1651 IND RWD-WIR(C)

Industrial roundwood-Wood in the rough (Coniferous)
This commodity aggregate includes all industrial wood in the rough(sawlogs and veneer logs, pulpwood and other industrial roundwood) of coniferous species.

1657 IND RWD-WIR(NC)TROP

Industrial roundwood-Wood in the rough (Non-Coniferous-Tropical)
This commodity aggregate includes all industrial wood in the rough of non-coniferous species of tropical origin.

1670 IND RWD-WIR(NC)OTHER

Industrial roundwood-Wood in the rough (Non-Coniferous-Other)
This commodity aggregate includes all industrial wood in the rough of non-coniferous species of origin other than tropical.

SAWNWOOD(2)

1872 SAWNWOOD+SLEEPERS

The aggregate includes sawnwood and sleepers, coniferous or non-coniferous.

1632 SAWNWOOD(C)
1633 SAWNWOOD(NC)

Sawnwood, unplaned, planed, grooved, tongued, etc., sawn lengthwise, or produced by a profile-chipping process (e.g. planks, beams, joists, boards, rafters, scantlings, laths, boxboards, "lumber", sleepers, etc.) and planed wood which may also be finger jointed, tongued or grooved, chamfered, rabbeted, V-jointed, beaded, etc. Wood flooring is excluded. With few exceptions, sawnwood exceeds 5 mm. in thickness.

WOOD-BASEDPANELS(2)

1873 WOOD-BASED PANELS

The aggregate includes the following commodities: veneer sheets, plywood, particle board and fibreboard compressed or non-compressed. Starting from 1995 the *Fibreboard, Compressed* has been disaggregated in *Hardboard* and *Medium density fibreboard (MDF)*; and the *Fibreboard, non-compressed* has been re-labeled *Insulating board*.

1634 VENEER SHEETS

Thin sheets of wood of uniform thickness, rotary cut, sliced or sawn, for use in plywood, laminated construction, furniture, veneer containers, etc. In production, the quantity given excludes veneer sheets used for plywood production within the country.

1640 PLYWOOD

Plywood, veneer plywood, core plywood including veneered wood, blockboard, laminboard and battenboard. Other plywood such as cellular board and composite plywood. Veneer plywood is plywood manufactured by bonding together more than two veneer sheets. The grain of alternate veneer sheets is crossed generally at right angles. Core plywood is plywood whose core (i.e. central layer, generally thicker than the other plies) is solid and consists of narrow boards, blocks or strips of wood placed side by side, which may or may not be glued together. (This item includes veneered wood in sheets or panels in which a thin veneer of wood is affixed to a base, usually of inferior wood, by glueing under pressure). Cellular board is a plywood with a core of cellular construction while composite plywood is a plywood with core or certain layers made of material other than solid wood or veneers.

1646 PARTICLE BOARD

A sheet material manufactured from small pieces of wood or other ligno-cellulosic materials (e.g. chips, flakes, splinters, strands, shreds, schives, etc.) agglomerated by use of an organic binder together with one or more of the following agents: heat, pressure, humidity, a catalyst, etc. (Flaxboard is included. Wood wool and other particle boards, with inorganic binders, are excluded).

1874 FIBREBOARD

Fibreboard (fibre building board)
A panel manufactured from fibres of wood or other ligno-cellulosic materials with the primary bond deriving from the felting of the fibres and their inherent adhesive properties. Bonding materials and/or additives may be added. It is usually flat pressed but may also be moulded. (Similar products made from pieces of wood, wood flour or other ligno-cellulosic material with added binders are excluded - as are, for example, boards of gypsum or other mineral material). The aggregate includes fibreboard compressed (Hardboard and Medium Density Fibreboard) and insulating board.

1649 FIBREBOARD, COMPRESSED

Fibreboard Compressed includes fibreboards with a density greater than 0.50 g/cm^3. This commodity for the time reported (1961-1994) was not disaggregated. Starting from 1995 the Fibreboard compressed has been disaggregated in Hardboard and MDF as defined below.

1647 HARDBOARD

Hardboard is a type of fibreboard with a density exceeding 0.80 g/cm^3.

1648 MDF

MDF (Medium Density Fibreboard) is a type of fibreboard with a density exceeding 0.50 g/cm^3 but not exceeding 0.80 g/cm^3.

1650 INSULATING BOARD

Insulating Board is a type of fibreboard with a density exceeding 0.35 g/cm^3 but not exceeding 0.50 g/cm^3. Note: this commodity used to be labeled "fibreboard non-compressed".

PULP(3)

1875 WOOD PULP

The following commodities are included in this aggregate: mechanical, semi-chemical, chemical and dissolving wood pulp.

1654 MECHANICAL WOOD PULP

Wood pulp obtained by grinding or milling: coniferous or non-coniferous rounds, quarters, billets etc. into fibres or through refining coniferous or non-coniferous chips. Also called groundwood pulp and refiner pulp. It may be bleached or unbleached. It excludes exploded and defibrated pulp, and includes chemi-mechanical and thermo-mechanical pulp.

1655 SEMI-CHEMICAL WOOD PULP

Wood pulp, chemi-mechanical and semi-chemical Wood pulp obtained by subjecting coniferous or non-coniferous wood to a series of mechanical and chemical treatments, none of which alone is sufficient to make the fibres separate readily. According to the order and importance of the treatment, such pulp is variously named: semi-chemical, chemi-groundwood, chemi-mechanical, etc. It may be bleached or unbleached.

1667 DISSOLVING WOOD PULP

Wood pulp, dissolving grades chemical pulp (sulphate, soda or sulphite) from coniferous or non-coniferous wood, or special quality, with a very high alpha-cellulose content (usually 90% and over), readily adaptable for uses other than paper manufacture. These pulps are always bleached. They are used principally as a source of cellulose in the manufacture of products such as synthetic fibres, cellulosic plastic materials, lacquers, explosives.

1656 CHEMICAL WOOD PULP

Sulphate (kraft) and soda and sulphite wood pulp except dissolving grades, bleached, semi-bleached and unbleached. Where detail is available, statistics for the following four component pulps (1660,1661,1662,1663) are given:

1660 UNBLEACHED SULPHITE PULP

Wood pulp, sulphite, except dissolving grades. Wood pulp obtained by mechanically reducing coniferous or non-coniferous wood to small pieces that are subsequently cooked in a pressure vessel in the presence of a bi-sulphite cooking liquor. Bi-sulphites such as ammonium, calcium, magnesium and sodium are commonly used. The class includes semi-bleached and unbleached pulps.

1661 BLEACHED SULPHITE PULP

Wood pulp, sulphite, except dissolving grades. Wood pulp obtained by mechanically reducing coniferous or non-coniferous wood to small pieces that are subsequently cooked in a pressure vessel in the presence of a bi-sulphite cooking liquor. Bisulphites such as ammonium, calcium, magnesium and sodium are commonly used. The class includes bleached pulp.

1662 UNBLEACHED SULPHATE PULP

Wood pulp, sulphate (kraft) and soda, except dissolving grades. Wood pulp obtained by mechanically reducing coniferous or non-coniferous wood to small pieces which are subsequently cooked in a pressure vessel in the presence of sodium hydroxide cooking liquor (soda pulp) or a mixture of sodium hydroxide and sodium sulphite cooking liquor (sulphate pulp). The class includes semi-bleached and unbleached pulps.

1663 BLEACHED SULPHATE PULP

Wood pulp, sulphate (kraft) and soda, except dissolving grades. Wood pulp obtained by mechanically reducing coniferous or non-coniferous wood to small pieces which are subsequently cooked in a pressure vessel in the presence of sodium hydroxide cooking liquor (soda pulp) or a mixture of sodium hydroxide and sodium sulphite cooking liquor (sulphate pulp). The class includes bleached pulp.

1668 OTHER FIBRE PULP

Pulp of fibrous vegetable materials other than wood. Including straw, bamboo, bagasse, esparto, other reeds or grasses, cotton linters, flax, hemp, rags, other textile wastes. Used for the manufacture of paper, paperboard and fibreboard.

1669 RECOVERED PAPER

Waste and scrap of paper or paperboard. This commodity includes paper and paperboard that has been used for its original purpose and residues from paper conversion. This includes waste and scrap collected for re-use as a raw material for the manufacture of paper and related products.

PAPER and PAPERBOARD$^{(4)}$

1876 PAPER+PAPERBOARD

The following commodities are included in this aggregate: Newsprint, printing and writing paper, other paper and paper- board.

1671 NEWSPRINT

Uncoated paper, unsized (or only slightly sized), containing at least 60% (percentage of fibrous content) mechanical wood pulp, usually weighing not less that 40 g/square m and generally not more than 60 g/square m of the type used mainly for the printing of newspapers.

1674 PRINTING+WRITING PAPER

Other printing and writing paper
Paper, except newsprint, suitable for printing and business purposes, writing, sketching, drawing, etc., made from a variety of pulp blends and with various

finishes. Included are such papers as those used for books and magazines, wallpaper base stock, box lining and covering calculator paper, rotonews, duplicating, tablet or block, label, lithograph, banknote, tabulating card stock, bible or imitation bible, stationary, manifold, onionskin, typewriter, poster, etc.

1675 OTHER PAPER+PAPERBOARD

Includes construction paper and paperboard, household and sanitary paper, special thin paper, wrapping and packaging paper and paperboard and other paper and paperboard not elsewhere specified. Where detail is available, statistics for categories composing the above (1676, 1681, 1683) are given as follows:

1676 HOUSEHOLD + SANITARY PAPER

Household and sanitary paper; special thin paper
Household and sanitary paper includes absorbent paper, creped or uncreped, sometimes embossed, made from bleached or unbleached chemical wood pulp, sometimes with a mixture of pulp from waste paper and mechanical pulp. Included are towelling, napkin, facial tissue, toilet tissue, wadding disposable tissues.

1681 WRAPG+PACKG PAPER+BOARD

Wrapping and packaging paper and paperboard
Paper or paperboards included are the following: vegetable parchment, greaseproof and glassine paper. Papers made from pure chemical wood pulp or from mixture of chemical wood pulp, cotton fibre pulp, treated (e.g. highly hydrated or hard beaten) to render the resulting paper resistant to oil, grease and water. They are used primarily for packaging frozen, moist or greasy materials such as butter, margarine, meat or fish, linerboard; paper or paperboard used as facing material on corrugated or solid paper or paperboard boxes and containers. Fluting medium: paper or paperboard used as medium when combining paper and paperboard for conversion into a corrugated board. Sack kraft paper: strong paper made from sulphate pulp and used in the manufacture of single, or multiwall, sacks. Other kraft wrapping paper: all other wrapping and packaging papers made principally from sulphate pulp. Folding boxboard: all types of paperboard used in the manufacture of folding boxes. Other wrapping and packaging paper and paperboard.

1683 PAPER+PAPERBOARD NES

Other paper and paperboard not elsewhere specified
Includes: Kraft papers for waxing, asphalting, water proofing, laminating, impregnating, spinning or twisting, gumming,etc.,paper manufactured principally from furnishes other than sulphate pulp not included elsewhere, such as rope and jute paper,folder stock, blotting paper, filter paper, photographic sensitizing paper,etc. and paperboards not included elsewhere such as shoe board, gasket board,transformer board,press textile board,index pressboard, panel board (automotive) trunk and suitcase board, matrix board.

Construction paper and paperboard:
Papers, paper felts and paper boards used in the construction of buildings and other structures for insulation, vapour seal, roofing and flooring underlay etc. They are made from fully refined material such as wood pulp, waste paper, other vegetable pulp and mineral fibre. Low thermal conductivity, moisture resistance, fire

resistance permanency, insect and vermin resistance are desirable characteristics of these materials (excluded are papers, felts or boards impregnated, saturated laminated or further manufactured in any way and fibreboard or fibre building board, in the form of insulating board, medium hardboard and hardboard).

Special thin paper:
papers made for special purposes, their common characteristics being their relative thinness. They may be made from mechanical or chemical wood pulps, bleached or unbleached, but frequently from pulps containing flax, hemp or cotton fibre.
Principal characteristics of some of these papers are:
uniformity of surface and caliper, freedom from pinholes,strength close formation, low permeability, chemical purity - all related to special uses. Examples of types of paper included are:
carbonizing tissue, condenser and capacitator paper,cigarette paper, lens tissue, pattern tissue, tea bag paper.

NOTES

(1) Figures are given in solid volume of roundwood (or roundwood equivalent) without bark.

(2) Figures are given in solid volume.

(3) Figures are given in weight (air-dry = 10% moisture)

(4) Figures are given in weight.

SPECIES

(C) Coniferous

All woods derived from trees classified botanically as Gymnospermae - e.g. fir (Abies), parana pine (Araucaria), deodar (Cedrus), ginkgo (Ginkgo), larch (Larix), spruce (Picea), pine, chir, kail (Pinus), etc. These are generally referred to as softwoods.

(NC) Non-Coniferous

All woods derived from trees classified botanically as Angiospermae - e.g., maple (Acer), alder (Alnus), ebony (Diospyros), beech (Fagus), lignum vitae (Guiaicum), poplar (Populus), oak (Quercus), sal (Shorea), teak (Tectona), casuarina (Casuarina), etc. These are generally referred to as broadleaved or hardwoods.

NC(TROP) Non-Coniferous Tropical

Non-coniferous woods originating from tropical countries.

NC(OTHER) Non-Coniferous Other

Non-coniferous woods originating from countries other than tropical.

Appendix B: Literature review of HWP life spans

This appendix includes a literature review on lifetime parameters, quoted from the study of Sikkema et al. (2002). It should be noted, however, that the numbers referred here are not necessarily based on any empirical findings. They are rather parameter values being used in some HWP models. As the discard or decay patterns used in the models differ from each other, there is risk of confusion when discussing lifespans.

Sikkema et al. (2002) make the following definitions, which are not fully consistent with the terms used in the main text of this report:

Products are a certain time in use before they are discarded (referred to as 'anthropogenic use' after Hoen and Solberg, 1994). After this use, a product can either be recycled, dumped in a landfill or burned for energy. When regarding landfills, it can take some time before products are totally decomposed. Sikkema et al. (2002) call this the "decay time" in the following Tables. In the main text, the term decay is used as a general concept both for HWP in use and in landfills (but the decay parameters of course differ from each other in use and in landfills).

The studies that were included in the review reported lifespans and lifetimes in different ways. Part of the studies regarded the time until total decomposition, so both including anthropogenic use and decay time. Since in some assumptions the decay time can be considerable, this can yield a huge overestimation of the time of anthropogenic use. If the *decay time in landfills* is included, it is mentioned in the Tables.

The three simplest patterns to look at life spans (all being used for anthropogenic use only, or anthropogenic and decay time together) are the following (see Fig. B-1):

- One is to assume that all products are equally long in use before they are fully discarded at the end of the lifetime. Here the total life span is equal to a product's life time

- Another approach is to assume that a fixed fraction of the *initial amount* of product is discarded or decayed every year, which results in a *linear* discard or decay over time. The lifetime can then be indicated with both a maximum lifetime or an average lifetime. The maximum time it takes before all products are gone, is the inversion of the discard or decay rate. Since the discard or decay is linear, half of this time represents the average life span. So if the annual discard or decay is 2.5%, maximum life span is 40 years.

- The third approach assumes an exponential discard or decay over time. This means that every year a *fixed fraction* (=α) of the *current amount* of product is discarded or decayed every year. This is usually reported with a *'half-life'* (= $\ln 2/\alpha$), the time it takes to discard or decay half of the initial amount of the product, or *average lifetime* (= 1/α). In the case of exponential discard or decay, the decaying time is *infinite*. The assumption of *decay of 90% of all wood products* results in a *total life span* of 3.3 times the *'half-life'*.

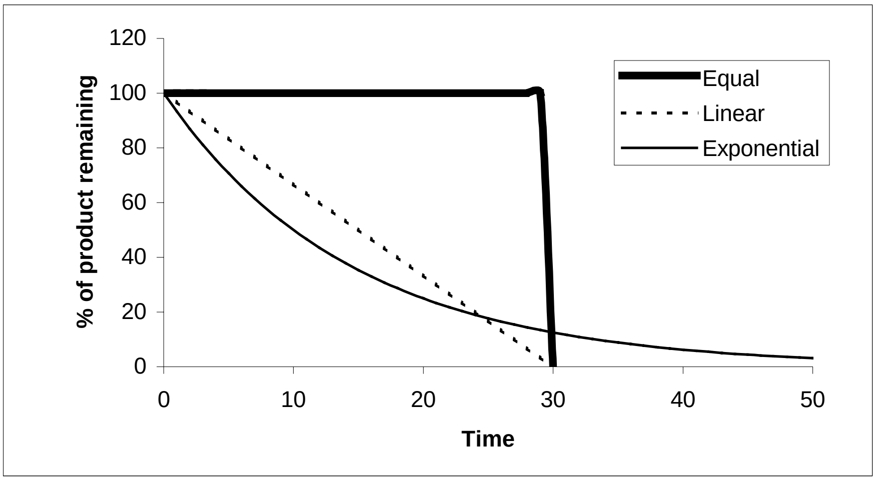

Figure B-1. Three patterns for the discard of wood products.

Table B.1 Sawnwood

Reference	Country	Commodity / end product	Half life	Life span[4]	Decay time[5]
Pingoud et al 2001	Finland	Sawn wood products		40[6]	Excluded
Burschel et al. 1993b	Germany	Construction wood		65	Excluded
Burschel et al. 1993b	Germany	Furniture		15	Excluded
Skog 1998	US	Single-family homes (pre-1980)	80	264	Excluded
Skog 1998	US	Single-family homes (post-1980)	100	330	Excluded
Skog 1998	US	Multifamily homes	70	231	Excluded
Skog 1998	US	Mobile homes	20	66	Excluded
Skog 1998	US	Nonresidential construction	67	221	Excluded
Skog 1998	US	Pallets	6	20	Excluded
Skog 1998	US	Manufacturing	12	40	Excluded
Skog 1998	US	Furniture	30	99	Excluded
Skog 1998	US	Railroad ties	30	99	Excluded
Heath et al. 1996	US	Products (wood in buildings, repairs and improvements, pallets, furniture and fixtures)		40	Excluded
Wolf 1990	NL	Sawn wood		40	Excluded
Karjalainen et al. 1994	Finland	Medium-long (part of sawn timber and plywood)	30	99	Excluded
Karjalainen et al. 1994	Finland	Long	65	215	Excluded
Harmon et al. 1996	US	Short-term structures		10	?
Harmon et al. 1996	US	Long-term structures		100	?
Winjum et al. 1997	US	Long term high latitudes		100	Included
Winjum et al. 1997	US	Long term low latitudes		50	Included
Skog website	Finland	Domestic sawnwood		80	
Skog website	Finland	Export sawnwood		50	
Skog website	New Zealand	Domestic sawnwood		80	
Skog website	New Zealand	Export sawnwood		50	
Skog website	US	Domestic sawnwood		80	
Skog website	US	Export sawnwood		50	
Schlamadinger and Marland 1996	Theoretical	Long-lived products		60-120	
Price et al. 1996	Canada	Construction lumber		100	Included
Sikkema and Nabuurs 1994	NL	Sleepers		50	Excluded
Sikkema and Nabuurs 1994	NL	Window frames		30	Excluded
Sikkema and Nabuurs 1994	NL	Furniture		15	Excluded
Sikkema and Nabuurs 1994	NL	Parquet		30	Excluded
Sikkema and Nabuurs 1994	NL	Construction wood		15	Excluded
Sikkema and Nabuurs 1994	NL	Pallets		2	Excluded
Borough and Miller 1999	Australia	Medium long term (packing crates, furniture)		25	Excluded

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[4] Anthropogenic use

[5] E.g. in landfills

[6] average lifetime

Table B.1 (continued)

Reference	Country	Commodity / end product	Half life	Life span	Decay time
Borough and Miller 1999	Australia	Long term (construction and fence posts)		50	Excluded
Borough and Miller 1999	Australia	House construction parts (framing, flooring, plywood, particle board for building purposes)		90	Excluded
Enzinger and Jeffs 2000	New Zealand	Medium-long (furniture)		25	Excluded
Enzinger and Jeffs 2000	New Zealand	Long term (construction material)		50	Excluded
Burschel et al. 1993a	US	Nonresidential construction	67	221	?
Burschel et al. 1993a	US	Single family homes	60	198	?
Burschel et al. 1993a	US	Multifamily homes	50	165	?
Burschel et al. 1993a	UK	Buildings	80	264	?
Burschel et al. 1993a	Switzerland	Open bridges	30	99	?
Burschel et al. 1993a	Switzerland	Roofed bridges	45	149	?
Burschel et al. 1993a	US	Furniture	12	40	?
Burschel et al. 1993a	Germany	Kitchen, bedroom	17	56	?
Burschel et al. 1993a	Germany	Living room furniture	13	43	?
Burschel et al. 1993a	Germany	Upholstered furniture	9	30	?
Burschel et al. 1993a	Germany	Construction wood	65	215	?
Burschel et al. 1993a	Germany	Furniture	15	50	?
Lochu	France	Traditional building		50	Excluded
Lochu	France	Wooden roofs		30	Excluded
Lochu	France	Inside walls		20	Excluded
Lochu	France	Furnishings		20	Excluded
Lochu	France	Wainscot, parquet		30	Excluded
Lochu	France	Decoration strips, frames		20	Excluded
Lochu	France	Chests, scaffolds		1	Excluded
Lochu	France	Regular house doors		10	Excluded
Lochu	France	Carpented doors		30	Excluded
Lochu	France	Window and window posts		30	Excluded
Lochu	France	Construction wood		40	Excluded
Lochu	France	Sliding doors, shutter		20	Excluded
Lochu	France	Glued construction wood		40	Excluded
Lochu	France	Industrial building		40	Excluded
Lochu	France	Agricultural buildings		30	Excluded
Lochu	France	Stairs		30	Excluded
Lochu	France	Furniture		12	Excluded
Lochu	France	Packing		1	Excluded
Lochu	France	Other industrial branches		10	Excluded

Table B.1 (continued)

Hoen and Solberg 1994	Norway	Construction material		80	Excluded
Hoen and Solberg 1994	Norway	Furniture & interiors		20	Excluded
Hoen and Solberg 1994	Norway	Pallets		2	Excluded
Burschel et al. 1993a	UK	Pallets, packing wood	2	7	?

Table B.2 Wood based panels

Reference	Country	Commodity	Half life	Life span	Decay time
Wolf 1990	NL	Wood based panels		10	Excluded
Wolf 1990	NL	Veneer		40	Excluded
Karjalainen et al. 1994	Finland	Medium-long (part of sawn timber and plywood)	30	99	Excluded
Skog website	Finland	Domestic wood panels		30	
Skog website	Finland	Export wood panels		30	
Skog website	New Zealand	Domestic wood panels		30	
Skog website	New Zealand	Export wood panels		30	
Skog website	US	Domestic wood panels		30	
Skog website	US	Export wood panels		30	
Sikkema and Nabuurs 1994	NL	Wood based panels		5	Excluded
Borough and Miller 1999	Australia	Short medium term (e.g fibreboards)		10	Excluded
Borough and Miller 1999	Australia	Plywood, particle board (like kitchens, furniture.), sleepers		30	Excluded
Borough and Miller 1999	Australia	Pallets, hardboard packaging, particleboard (shop fitting)		10	Excluded
Enzinger and Jeffs 2000	New Zealand	Short-medium term (fiberboard)		7	Excluded
Hoen and Solberg 1994	Norway	Composites, plywood, etc.		17	Excluded

Table B.3 Industrial roundwood

Reference	Country	Commodity	Half life	Life span	Decay time
Wolf 1990	NL	Polewood		3	Excluded
Borough and Miller 1999	Australia	Treated pine poles, hardwood poles, furniture		50	Excluded
Burschel et al. 1993a	UK	Fences	20	66	?
Lochu	France	Treated wood?		20	Excluded
Lochu	France	Fences, gates		10	Excluded
Hoen and Solberg 1994	Norway	Impregnated lumber		40	Excluded

Table B.4 Paper and paperboard

Reference	Country	Commodity	Half life	Life span	Decay time
Burschel et al. 1993b	Germany	Paper and packing		1	Excluded
Skog 1998	US	Paper (free sheet)	6	20	Excluded
Skog 1998	US	Paper (all other)	1	3	Excluded
Wolf 1990	NL	Paper and paperboard		1	Excluded
Cannell and Dewar 1995	UK	Paper and packaging (from thinning)		5	Included
Karjalainen et al. 1994	Finland	Short (fuelwood, newsprint, some of packing paper, paperboard, printing and writing paper)	4	13	Excluded
Karjalainen et al. 1994	Finland	Medium-short (rest of packing paper, paperboard, printing and writing paper)	13	43	Excluded
Skog website	Finland	Domestic paper and paperboard		3	
Skog website	Finland	Export paper and paperboard		3	
Skog website	New Zealand	Domestic paper and paperboard		3	
Skog website	New Zealand	Export paper and paperboard		3	
Skog website	US	Domestic paper and paperboard		3	
Skog website	US	Export paper and paperboard		3	
Price et al. 1996	Canada	Pulp		30	Included
Sikkema and Nabuurs 1994	NL	Paper		1	Excluded
Borough and Miller 1999	Australia	Short term (paper etc.)		1	Excluded
Borough and Miller 1999	Australia	Softwood pallets, paper and paper products		3	Excluded
Borough and Miller 1999	Australia	Tissue		0	Excluded
Borough and Miller 1999	Australia	Newsprint		0	Excluded
Borough and Miller 1999	Australia	Packaging		1	Excluded
Borough and Miller 1999	Australia	Printing and writing		3	Excluded
Enzinger and Jeffs 2000	New Zealand	Short term (paper)		3	Excluded
Burschel et al. 1993a	US	Books	6	20	?
Burschel et al. 1993a	US	Newspapers, packing paper	1	3	?
Burschel et al. 1993a	UK	Paper	2	7	?
Burschel et al. 1993a	Germany	Paper, packing	1	3	?
Gjesdal 1996	Norway	Newsprint, household and sanitary paper		1	Excluded
Gjesdal 1996	Norway	Liner board, fluting, folding boxboard		1	Excluded
Gjesdal 1996	Norway	Printing/writing (80%)		1	Excluded
Gjesdal 1996	Norway	Printing/writing (20%)		10	Excluded
Gjesdal 1996	Norway	Paper (average)		1	Excluded
Gjesdal 1996	Finland	Paper (average)		2	Excluded
Hoen and Solberg 1994	Norway	Pulp/paper		1	Excluded
CEPI 2001c	CEPI countries	Paper	1	3	Excluded

Appendix C: Inventory of wood-based products in Finnish construction in 2000

Sawn wood and bearing logs in Finnish building stock in 2000

Dry weight
1000 t

	1990's	1980's	1970's	1960's	1950's	1940's and	Total
Detached houses	1259	1807	1327	817	1181	2320	8713
Attached houses	247	462	265	58	17	33	1081
Blocks of flat	117	119	224	159	82	116	816
Free-time buildings	318	635	652	497	357	918	3377
Commercial, public b	192	209	153	108	102	173	938
Industry, stories	122	320	650	332	95	159	1676
Agricultural, other	829	673	464	218	237	754	3175
Buildings, no permits	992	630	630	720	450	270	3692
Gardens	1000	360	180	180	100	180	2000
Civil engineering	870	1500	1270	1355	665	139	5800
Total	5946	6717	5815	4444	3284	5062	31268

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Total (%)	19	22	19	14	11	16	100

Estimated carbon stock
1000 t C

	1990's	1980's	1970's	1960's	1950's	1940's and	Total
Detached houses	630	904	664	409	591	1160	4356
Attached houses	123	231	132	29	8	16	541
Blocks of flat	58	60	112	79	41	58	408
Free-time buildings	159	318	326	249	178	459	1688
Commercial, public b	96	105	77	54	51	87	469
Industry, stories	61	160	325	166	47	79	838
Agricultural, other	414	337	232	109	118	377	1588
Buildings, no permits	496	315	315	360	225	135	1846
Gardens	500	180	90	90	50	90	1000
Civil engineering	435	750	635	678	332	70	2900
Total	2973	3358	2908	2222	1642	2531	15634

	1990's	1980's	1970's	1960's	1950's	1940+early	Total
Total (%)	19	22	19	14	11	16	100

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Wood-based panels in Finnish building stock in 2000

1000 t

	1990's	1980's	1970's	1960's	1950's	1940's and	Total
Detached houses	315	443	378	264	368	569	2337
Attached houses	46	92	30	10	3	7	187
Blocks of flat	60	66	125	94	52	64	460
Free-time buildings	10	18	19	16	10	26	99
Commercial, public	37	47	40	14	15	28	181
Industry, stories	14	17	12	8	2	5	58
Agricultural, other	14	10	7	3	2	7	43
Buildings, no permit	0	0	0	0	0	0	0
Gardens	0	0	0	0	0	0	0
Civil engineering	0	0	0	0	0	0	0
Total	495	693	610	409	453	705	3365
Total (%)	15	21	18	12	13	21	100

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Estimated carbon stock
1000 t C

	1990's	1980's	1970's	1960's	1950's	1940's and	Total
Detached houses	157	221	189	132	184	284	1169
Attached houses	23	46	15	5	2	3	94
Blocks of flat	30	33	62	47	26	32	230
Free-time buildings	5	9	10	8	5	13	49
Commercial, public	18	24	20	7	8	14	90
Industry, stories	7	9	6	4	1	2	29
Agricultural, other	7	5	3	1	1	4	21
Buildings, no permits							
Gardens							
Civil engineering							
Total	248	346	305	204	226	352	1682
Total (%)	15	21	18	12	13	21	100

	1990's	1980's	1970's	1960's	1950's	1940's and	Total
Total (%)	15	21	18	12	13	21	100

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Title

Greenhouse gas impacts of harvested wood products

Evaluation and development of methods

Abstract

Greenhouse gas (GHG) impact of wood and paper products, in the following referred as harvested wood products (HWP), is twofold: 1) HWP form a renewable pool of wood-based carbon, whose changes act as carbon sink or source, 2) manufacture and whole lifecycle of HWP cause fossil carbon emissions. In estimation and reporting GHG emissions under the UNFCCC, treatment of carbon balance in HWP, impact 1) is still open. Climate political debate has raised alternative and competing accounting approaches, which in totally different way allocate HWP emissions or removals between countries. The alternative approaches are discussed and numerical examples illustrating the position of various countries are discussed. The next possible step could be to include HWP accounting in the commitments of the Kyoto Protocol. In this case, substantial barriers for international trade of HWP and use of renewable bioenergy might be formed, dependent on the choice of the HWP accounting approach.

In this study a dynamic spreadsheet model of carbon balance in HWP was developed, which countries could use in their national emissions estimation and reporting under the UNFCCC. The model requires as basic input data the production and international trade rates of HWP, provided worldwide and since 1961 by the FAO database, which is easily accessible through the internet. The report presents a short description of the above model. In addition, a more robust method for estimation of national HWP stocks is presented, based on direct inventory of building stock. The GHG impacts of type 2) are also shortly illustrated by Finnish case studies, two of which consider material substitution in Finnish new construction.

Keywords
greenhouse gases, emissions, environmental impacts, carbon balance, wood products, Kyoto Protocol, UNFCCC, IPCC, dynamic models

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Countries are so far not reporting carbon balance in wood and paper products in their greenhouse gas emission inventories under the United Nations Framework Convention on Climate Change, nor are wood based products included in the commitments due to the Kyoto Protocol. However, at present some countries would like to include wood-based products to above reporting and also to the Kyoto commitments. This study evaluates various approaches and methods, which have been suggested for this kind of reporting and accounting. Their possible incentives for international trade of wood products are discussed. In addition, some alternative methods for estimating carbon balance in wood based products are presented and position of some selected countries is illustrated by numerical calculations based on information from the FAO database.

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