Applying the IPCC GPG for LULUCF approaches for assessing changes in carbon stocks and emissions of green-house gas for Harvested Wood Products in Italy

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Index

1 Introduction

1.1 Role of HWP in the Carbon Cycle

Woody plants capture carbon dioxide (CO_2) from the atmosphere through photosynthesis, releasing oxygen and part of the CO_2 through respiration, and retaining a reservoir of carbon in living and dead biomass (above- and below-ground). At harvesting, whereas a portion of C contained in the logging residue (slash and other materials) is left in forest, a major part of the C is removed from the forests and remains fixed in the harvested wood products (HWP).

HWP include all wood material that leaves the harvest sites: some of it is stored for a very short time period (e.g. fuelwood or mill residues that are burned in the year of harvest); some is stored for a very long time (e.g., wood for sawnwood and used for long living wood products, such those meant for the building sector).

At the end of their life cycle, wood products can be recycled, stored in land fills or used for generating energy, thus substituting fossil fuels.

Because of this storage, the amount of HWP decaying could be less than the total amount of wood harvested, thus acting like a C sink. Important is not only the sequestration of carbon but also the substitution effect, when wood is used instead of other more energy intensive materials or for generating energy instead of fossil fuels. In addition, wood exploitation can contribute to the limitation of risks of C losses due to biotic and abiotic disturbances (such as forest fires, pests and diseases, etc.).

Many studies suggest that at global level the storage of carbon in HWP is likely to be increasing, thus being important for mitigating the accumulation of green-house gas (GHG) concentration in the atmosphere (Winjum et al. 1998, UNFCCC, 2003).

The question on how to account emissions or stock-changes for HWP in the context of the UNFCCC has been extensively discussed and assessed internationally. Different approaches have been proposed and they differ in how they allocate emissions between wood producing and consuming countries, and in what processes they focus on (Brown et al. 1998, Apps et al. 1997, Winjum et al. 1998, Lim et al. 1999).

In the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (in shorthand, IPCC GPG for LULUCF) (Penman et al. 2003) three alternative approaches (stock-change approach, production approach and atmospheric-flow approach) are discussed in an Appendix (Appendix 3a.1 Harvested wood products: Basis for future methodological development) (Nabuurs et al. 2003).

At the tenth session of the Conference of the Parties to the UNFCCC, the SBSTA invited Annex I Parties to provide data and information on changes in carbon stocks and emissions of GHG's from HWP by the 1st of August 2005. It also invited Annex I Parties to submit, by 1 August 2005, updated data and information on HWP and on experiences with the use of the Revised 1996 IPCC Guidelines for Greenhouse Gas Inventories and the IPCC GPG for LULUCF to generate such data and information.

1.2 GPG LULUCF

As said before, in the IPCC GPG for LULUCF (Penman et al., 2003) the alternative approaches were further discussed in Appendix 3a.1. If, however, the HWP pool or pools are included in the basic national inventory system, they must be adapted to the same reporting framework with the present five pools (Nabuurs et al., 2003).

In details, the three mutually exclusive alternatives for the reporting system are:

Stock-Change Approach for HWP

The carbon stock-changes in HWP, when summed with the stock-changes in the forest carbon pools will be reported as emissions/removals in the country where they occur. The HWP stock-change in a country could be estimated using either 'transfers into and out of the HWP pool' or the difference between the carbon stock of HWP at times 1 and 2, as outlined for dead wood in Chapter 3 of the GPG. Stock-changes are reported within national boundaries. Carbon stocks in products that are exported and used in another country will be considered in the calculation of the GHG inventory of that other country.

Production Approach for HWP

This approach is similar to the previous one. It differs in the treatment of traded wood products and takes only the domestic grown wood into account. Carbon stock-changes for exported wood products remain accounted for the wood producing country (or the country where the product was produced). Emissions/ removals are reported when but not where they occur.

Atmospheric-Flow Approach for HWP

Another conceptual alternative would be reporting based on atmospheric flows in which the exchange of carbon dioxide between the forest pools (including HWP) and the atmosphere is considered. A net CO_2 flow from the pools to the atmosphere would be reported as the equivalent emission and a net flow in opposite direction as the equivalent removal. This, however, has to be applied to all pools not only to HWP[1]. To reiterate, the HWP approach cannot be chosen independently from the general inventory framework, i.e. a similar approach has to be applied both to HWP and the other pools in the LULUCF/AFOLU sector.

Although the stock-change and atmospheric flow of a single pool are not the same (because transfers between pools are not recorded in the atmospheric flow approach), summing up the stock-change of all biosphere and HWP carbon pools globally would give the same result as summing up the atmospheric flows to these pools. The basic historical reason for reporting stock-changes instead of atmospheric flows is that it is in general easier and more relevant to estimate the carbon stock than atmospheric carbon exchange of the pool. For instance, forests go through a large exchange of CO_2 with the atmosphere through photosynthesis and respiration, but our focus is on the net change over time of the forest biomass and the carbon contained in it. Similarly, HWP receive significant inputs from forests at harvest, and HWP release significant outputs of CO_2 to the atmosphere when they decay or are burnt, but our real interest is in the net gain or loss of HWP over time.

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[1] The current practice in national inventories is to report stock-changes in forests. Consider a country A that operates a "sustainable forest" (which is in equilibrium with respect to its biomass carbon stocks) and exports to country B which burns the biomass as fuel. Country A reports a zero balance, and country B reports a zero balance. The total impact on the atmosphere is zero.

However, what is essential in this connection is that the atmospheric flow approach would necessitate a fundamental revision of the reporting frameworks reflected in the 1996 Guidelines and the 2003 GPG LULUCF, as well as in the Terms of Reference of the 2006 IPCC Guidelines, which are all based on changes in carbon stocks.

Should the atmospheric flow approach be adopted for HWP, while the stock-change approach is retained for forests (because it is inscribed into the Kyoto Protocol, Marrakech Accords and 2003 GPG LULUCF), then country A would report a zero balance, and country B would report an atmospheric flow of one unit. In total, the countries would report a release to the atmosphere of one unit, which does not occur in reality: Conservation of mass is violated. Thus, one would have to adopt either the atmospheric flow or the stock-change approach for both forests and HWP, in order to maintain a constant mass balance.

State of the art in Italy – Carbon Stock Evaluation Model (CSEM)

First estimations on carbon stocks and stock-changes for harvested wood products in Italy were made in the Carbon Stock Evaluation Model (CSEM) by Anderle *et al*. 2002.

The calculation is based on FAO statistics on production and trade of semifinished forest products excluding fuelwood.

Two different approaches were applied: Flow consumption and flow production approach.

The model recalculates the input of roundwood for the semifinished products using roundwood equivalents. The semifinished products were subdivided in different end use categories (“paper”, “furniture”, “construction”, “packaging” and “other”, see Table 1). For each end use category a lifetime was defined. Both the subdivision in end use categories and the lifetimes of the products are based on expert judgement.

Table 1: Partitioning of semi-finished products into end-use categories according to CSEM (Anderle et al. 2002)

	Paper	**Furniture**	**Construction**	**Packaging**	**Other**
Sawnwood (C)	4%	5%	80%	8%	3%
Sawnwood (NC)	5%	50%	15%	15%	15%
Veneer Sheets	0%	75%	5%	15%	5%
Plywood	0%	85%	5%	0%	10%
Particle Board	0%	85%	10%	0%	5%
Fibreboard	0%	80%	10%	5%	5%
Paper	90%	0%	0%	10%	0%

The calculation of the carbon flow (in tonnes of carbon, tC) in the year (i) into the wood products pool with the flow consumption method is based on the estimated consumption of wood products (C_{WP} in cubic meters) and the percentages of end use categories (pu in percent) like described in the following formula:

$C_i = C_{WP\ final\ i} \cdot D \cdot 0.5$

$C_{WP\ final\ i} = C_{WP\ total\ i} - \Sigma\ (pu_{\ end\ use\ i}) \cdot (1/\text{medium life span})$

$C_{WP\ total\ i} = P_i + I_i - E_i$

D – basic density = 0.65

0.5 – fraction of wood carbon content
P – Production, I – Import, E – Export

For the estimation after the flow production method the same formulas were used, but instead of C_{WP} (production + import – export) only the domestic production was taken into account.

The following Figure 1and Figure 2 show the results of that updated model. The existing CSEM was updated with data from 2001 to 2003 and the period from 1960 to 1969 was added. Some FAO data differ from the first model because of actualization. (FAO data are periodically revised and corrected.)

The model includes a valuation of different lifetime hypotheses for the applied end use categories. Different lifecycle hypotheses were adapted and refer to the end uses “furniture” and “construction”(see Table 2):

Table 2: Hypotheses of average lifetime of different end uses (yr)

End use category	Medium lifetime (yr)		
	1. Hypotheses	**2. Hypotheses**	**3. Hypotheses**
Paper	2	2	2
Furniture	**10**	**20**	**30**
Construction	**15**	**25**	**35**
Packaging	3	3	3
Other	3	3	3

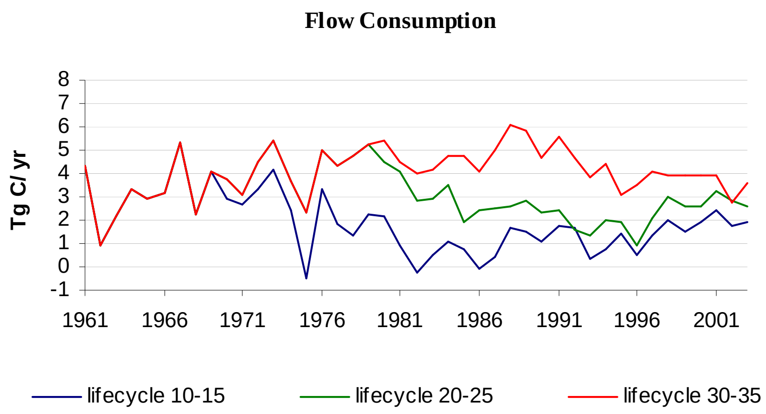

Figure 1: Flow Consumption (CSEM)

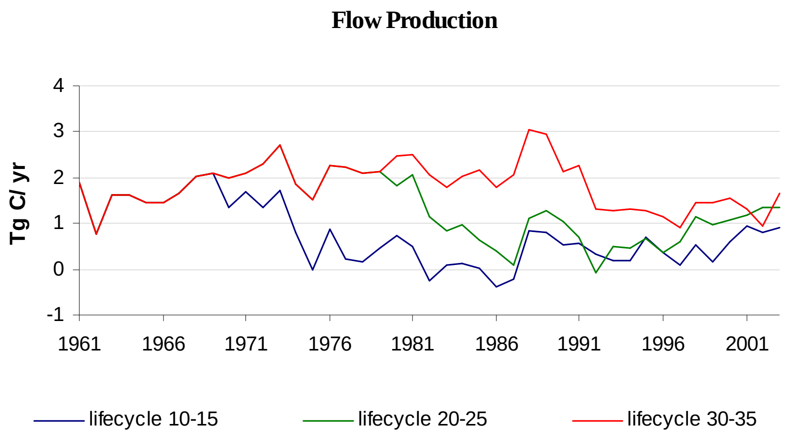

Figure 2: Flow Production (CSEM)

1.3 Objective of the paper

This report provides comparative information about carbon sequestration in harvested wood products in Italy, including solid waste disposal sites. The calculation of carbon stock and emissions/ removals of carbon shall apply the three alternative approaches described in the Annex 3.a.1 of IPCC GPG for LULUCF.

Chapter 2 gives an overview about wood resources and utilization of wood in Italy and shall provide some background information. Chapter 3 describes the applied methodology. The results of the calculation of carbon stocks and sinks are listed in chapter 4, including some considerations about the inclusion of trade of end products. In the discussion in chapter 5 the effects of different values for some basic input parameters illustrated and compared. Chapter 6 gives an outlook on the possible future development of carbon sequestration in wood products and solid waste disposal sides.

2 Resources and wood utilization in Italy

2.1 Forest resources and wood supply in Italy

Total forest area amounts to 8,7 million hectares (Mha). According to the first national forest inventory carried out in 1985, 25% of these forests are high forests, 42% are coppice or coppice with standards, 26% shrubland (maquis) (MAF 1988).

Italian forests are used in a limited way. Only 36% of annual increment of high forests is used. Coppices are of limited importance for production of long-lived wood products like for construction, they are mainly used for fuel-wood (MAF, 1988).

Important for domestic wood production are plantations on 280 000 ha. 70% of domestic wood supply comes from poplar plantations in the river Po valley (Pettenella et al. 2005).

The annual harvest is about 8 million m^3. A high proportion of domestic wood production is used as fuelwood (around 60%) – in terms of carbon this means immediate emissions in the same year, but substitution benefits. The CO_2 emissions of wood fuel are already accounted in the carbon losses in forests due to harvesting.

Italy is strongly dependent on imports of raw material and semifinished wood products (see Table 3):

Table 3: Trade activities (Baudin *et al.*, 2005)

Assortment	Import/ export	Remarks
Coniferous industrial roundwood:	net importer	- considerable net importer with 2/3 of apparent consumption from external sources
Non-coniferous industrial roundwood:	net importer	- importing half its consumption
Coniferous sawnwood:	net importer	- 90% of apparent consumption annually around 6-7 million m^3 is imported
Non-coniferous sawnwood:	net importer	- tropical sawnwood imports accounting for 10% to 15% of the imported NC sawnwood.
Veneer:	net importer	- self-sufficiency rate about 70%
Plywood:	net importer	- self-sufficiency rate about 30%.
Builders' joinery (excluding windows and doors):	net importer	- imports are slightly higher than the exports
Windows:	net importer	- net importer of windows that account for about 15% of total imports
Doors:	-	exports and imports are balancing each other
Flooring:	net importer	- imports 2/3 of the consumption
Mouldings:	net exporter.	- positive trade balance tends to weaken
Millwork	net importer	
Wooden furniture:	net exporter.	- the leading producer and exporter of furniture in the world - almost 50% of the production is exported

The average current wood consumption in Italy is around 0.11 m^3 *per capita* (Kreitner, 2002). In the last 3 years, the consumption of wood in Italy has increased of about +16% (www.promolegno.com)

2.2 Wood utilization in Italy

2.2.1 Construction sector

There are very few studies about the wood utilisation in final products and the lifespan of wood products in Italy.

In Italy occur large regional differences in wood utilization. It differs between rural and urban areas and by kind of buildings (CNEL, 2001). The construction sector can be subdivided in residential construction and non-residential construction, civil engineering and other construction (including do-it-yourself). Most wood in constructions is used in the northern part, especially in the alpine regions.

Traditionally wood is used mainly as material for roof constructions, stairs, shutters of windows etc. In some seismic active areas of Italy wood is used for melioration of constructions in case of earthquakes. Wood is important for restoration of historic buildings. In mountain areas of North Italy wood is used in residential houses of rural areas as construction material for walls of the second floors (CNEL 2001). But there are still many possibilities for using more wood.

In comparison to other European countries little wood is used for long-lived products, like in the construction sector. 35% of new roof constructions and 42% of reconstructed roof constructions are of wood, 25% of window frames and 50 – 60% of flooring material (Gardino 2001, American softwoods 1999, Bass e Besozzi, 2003).

According to a survey of Gardino (2001) most important for wood utilization is the renovation sector of residential houses. In 2000 wood consumption for roofs was estimated to be 1.4 million m^3, for flooring, etc. around 0.6 million m^3 and for structural elements and wooden houses 0.05 million m^3.

A questionnaire about the use of wood in civil constructions at carpentries and other wood consumers of the construction sector demonstrate for which components wood is used in civil constructions (Table 4).

Table 4: Wood utilization in construction elements (%) (CNEL 2001)

	Roof	Structural Elements	Frames outside	Frames inside	Flooring	Stairs	Other
New construction residential building	14	10	21	24	10	10	11
Restoration of residential building	14	9	24	26	11	8	8
Restoration urban area	14	18	35			18	15
Restoration after earthquakes	24	14	28		14	10	10
Restoration of buildings with historic, artistic or cultural value	19	12	23	25	7		23

2.2.2 Furniture industry

The furniture industry in general is utilizing a great variety of materials.

7% of the total softwood consumption and large amounts of imports and domestic production of hardwood are used in the furniture industry (Besozzi 2003). On the European level around 55% of the particle board production, 20% of sawn wood production and 90% of MDF production are utilized in the furniture sector (www.ueanet.com).

There are no official statistical data available about the volumes of wooden materials used in the Italian furniture industry.

3 Methodology

3.1 Carbon in wood products in use

Since HWP are not included in the first commitment period of the Kyoto Protocol, the methodology in the GPG LULUCF is still under preparation. The methods of the GPG LULUCF were fully applied for the wood products in use.

The subdivision of semi-finished products in end use classes (in percent) like in the CSEM model was kept and partly updated to increase accuracy since it reflects country specific conditions.

Stock-change approach

Carbon emissions/ removals are calculated as annual change in carbon stored in HWP in use in the country ($\Delta C_{HWP\ IU\ SCA}$):

$\Delta C_{HWP\ IU\ SCA}(t) = C_{HWP\ IU\ SCA}(t) – C_{HWP\ IU\ SCA}(t – 1)$

The carbon stock for each year was calculated in the following way:

$C_{HWP\ IU\ SCA}(j) = (1 / (1 + f_{D\ i}) \cdot (P_{Aj} + C_{HWP\ IU\ SCA}(j – 1))$

For the initial year, e.g. *j* = 1900, the value of $C_{HWP\ IU\ SCA} = 0$

t – current year
j – year of data, starting in 1900
f_D – Decay rate = ln2/ half life

P_A = current year additions to HWP carbon in use from domestic consumption (production + import – export), tonnes C/ yr

For solidwood and for pulp and paper:

$P_A\ (solidwood)_i = [P_{DP}\ (solidwood) + P_{IM}\ (solidwood) – P_{EX}\ (solidwood)] \cdot CF \cdot pu_i$

$P_A\ (paper)_i = [P_{DP}\ (paper) + P_{IM}\ (paper) – P_{EX}\ (paper)] \cdot WP_{ratio} \cdot CF \cdot pu_i$

CF – Conversion factor to carbon

pu – Percentage of end use category

i – End use category

DP – Domestic production, IM – Import, EX – Export

WP_{ratio} is the fraction of all pulp that is wood pulp (WP) and excludes other fiber pulp (OFP):

WP_{ratio} = [(WP + IM (WP) – EX (WP))/ ((WP + IM (WP) – EX (WP)) + (OFP + IM (OFP) – EX (OFP))]

Production approach

Similar for the production approach was calculated:

$\Delta C_{HWP\ IU\ PA}(t) = C_{HWP\ IU\ PA}(t) – C_{HWP\ IU\ PA}(t – 1)$

$\Delta C_{HWP\ IU\ PA}$ = annual change in carbon stored in HWP in use from wood harvested in the country (includes carbon in exports and excludes carbon in imports), tonnes C/ yr

$C_{HWP\ IU\ PA}$ (j) = (1 / 1 + $f_{D\ i}$)· (PH_{Aj} + $C_{HWP\ IU\ PA}$ (j – 1))

For the initial year, e.g. *j* = 1900, the value of $C_{HWP\ IU\ PA}$ = 0

PH_A = current year additions to HWP carbon from wood harvested in the country calculated on the basis of primary products carbon flux, tonnes C/ yr

PH_A (solidwood)$_i$ = P_{DP} (solidwood) · IRW_D · CF · pu_i

PH_A (paper)$_i$ = P_{DP} (paper) · IRW_D · CF · pu_i · WP_{ratio}

IRW_D is the fraction of industrial roundwood (IRW) from domestic origin:

IRW_D = IRW/ (IRW + IM (IRW) – EX (IRW))

Atmospheric flow approach

E = – $\Delta C_{HWP\ IU\ SCA}$ – P_{EX} + P_{IM}

E = carbon flux from HWP into the atmosphere within the borders of the reporting country, tonnes C/ yr

P_{EX} = exports of wood and paper products including roundwood, chips, residue, pulp, and recovered (recycled) paper, tonnes C/ yr

P_{IM} = imports of wood and paper products including roundwood, chips, residue, pulp, and recovered (recycled) paper, tonnes C/ yr

3.2 Carbon in wood products in SWDS

The estimation of carbon stocks and emissions on solid waste disposal sides (SWDS) follows the methodology used in the EXP.HWP model of Pingoud (2002).

The input flow to SWDS was estimated using the output flow from HWP in use and a percentage (ps) of the amount of HWP which is entering the SWDS. The input flow to SWDS is further subdivided in a fraction of degradable waste and a permanent stock of non degradable (permanent) waste (e.g. lignin in anaerobic conditions).

Stock-change approach

Output (solidwood)$_i$ = $C_{HWP\ IU\ SCA\ i}$ · $f_{D\ i}$
Output (paper)$_i$ = $C_{HWP\ IU\ SCA\ i}$ · $f_{D\ i}$

Input flow to SWDS (solidwood) = Σ Output (solidwood) · ps (solidwood)
Input flow to SWDS (paper) = Σ Output (paper) · ps (paper)

Input to permanent stock (solidwood) = (1- DOC solidwood) · Input flow to SWDS (solidwood)
Permanent stock (solidwood) = Input to permanent stock (solidwood)$_j$ + Permanent stock (solidwood) (j – 1)

For the initial year, e.g. j = 1900, the value of permanent stock (solidwood) = 0

DOC – Degradable organic carbon: 0.5 solidwood
0.6 paper

Input to degradable stock (solidwood) = (DOC solidwood) · Input flow to SWDS (solidwood)

Degradable stock (solidwood) = $(1/(1+ f_{D\,W}))\cdot$ (Input to degradable stock (solidwood)$_j$ + degradable stock (solidwood) (j – 1))

Output degradable stock (solidwood) = $f_{D\,W}$ · degradable stock (solidwood)

Stock-change degradable (solidwood) = degradable stock (solidwood)j - degradable stock (solidwood) (j-1)

Total stock-change (solidwood) = Input to permanent stock (solidwood) + stock-change degradable (solidwood)

$f_{D\,W}$ – decay rate for the waste sector: solidwood: 0.01
paper: 0.03

Input to permanent stock (paper) = (1- DOC paper) · Input flow to SWDS (paper)

Permanent stock (paper) = Input to permanent stock (paper)$_j$ + Permanent stock (paper) (j – 1)

For the initial year, e.g. j = 1900, the value of permanent stock (paper) = 0

Input to degradable stock (paper) = (DOC paper) · Input flow to SWDS (paper)

Degradable stock (paper) = $(1/(1+ f_{D\,W}))\cdot$ (Input to degradable stock (paper)$_j$ + degradable stock (paper) (j – 1))

Output degradable stock (paper) = $f_{D\,W}$ · degradable stock (paper)

Stock-change degradable (paper) = degradable stock (paper) j - degradable stock (paper) (j-1)

Total stock-change (paper) = Input to permanent stock (paper) + stock-change degradable (paper)

Total stock (SWDS) = Permanent stock (solidwood) + Degradable stock (solidwood) + Permanent stock (paper) + Degradable stock (paper)

Total stock-change (SWDS) = Total stock-change (solidwood) + Total stock-change (paper)

Production Approach

For the calculation after the production approach only the flows of wood grown in the country are considered:

Output (solidwood) $_i = C_{HWP\ IU\ PA\ i} \cdot f_{D\ i}$

Output (paper) $_i = C_{HWP\ IU\ PA\ i} \cdot f_{D\ i}$

The further calculations of input and output flows of SWDS are similar to those of stock-change method.

Atmospheric- flow approach

The flow corresponds to the calculation of total C stock-change of the stock-change approach.

3.3 Input data

FAO data

Basic input data (FAO) are the production and trade of the following products:

- Roundwood (Coniferous and Non-Coniferous)
- Solidwood products:

- Sawn wood (Coniferous and Non-Coniferous)
  - Veneer sheets
  - Plywood
  - Particle board
  - Fibreboard (Fibreboard compressed, Hardboard, MDF, Insulating board)
- Pulp, paper and paperboard data:
  - Paper and paperboard
  - Recovered paper (RP)
  - Recovered fibre pulp (RFP)
  - Other fibre pulp (OFP)
- Industrial Roundwood (Coniferous and Non-Coniferous)

Historic consumption

Model simulations are performed for a time period ranging from 1900 to 2003. Since FAO statistics start in year 1961 - for estimation of data prior 1961 a trend in growth back to 1900 was calculated according to the IPCC GPG for LULUCF. A discount rate of 2% was chosen. Instead of using only one reference year the average of 1961 – 1963 was used.

Wood density

In the CSEM model a density of 0.4 Mg/m³ for coniferous and 0.6 Mg/m³ for non-coniferous species were used. For the harvested wood product module a general density of 0.65 Mg/m³ was applied.
Since the major part of wood in Italy is imported, national values for wood density seem not to reflect the real situation. For this reason the data on wood density suggested in the IPCC GPG for LULUCF are used: For coniferous 0.45 Gg/m³ and non-coniferous wood 0.56 Mg/m³ roundwood and sawnwood.

Veneer sheets: 0.59 Mg/m³
Plywood: 0.48 Mg/m³
Particle Board: 0.26 Mg/m³
Fibre Board: 1.02 Mg/m³
Hardboard: 1.02 Mg/m³
MDF: 0.50 Mg/m³
Pulp, paper and paperboard: 0.9 Mg/ Mg

The carbon content of wood was calculated assuming a 50% carbon concentration of the dry weight.

3.4 Lifetimes of the end use categories

Carbon remains stored in wood products until the end of their lifetime. The lifetime differs by end use of the wood. For calculation of carbon stocks and fluxes in the methodology of the IPCC GPG for LULUCF the half life of the products is used. It is defined as “the number of years until one-half of the products have gone out of use. The average life is the average number of years a product is in use”:

Average life in years = 1/ ln2/ half life in years

The annual decay rate is estimated using the average lifetime:

Decay rate = 1/ average lifetime = ln2/ half life

Tables Table 5 - Table 10 show an overview of different lifetimes of wood products used in other models for calculation of carbon stocks in wood products.

The list is not complete and shows a large range of half lifes for the same or similar products. More data can be found in Pingoud et al. (2005) or in the IPCC GPG for LULUCF (Penman et al. 2003). The latter one proposes 35 years for sawn wood, 30 years for veneer, plywood and structural panels, 20 years for non-structural panels and 2 years for paper. Except the assumptions from the CSEM Model no data for Italy exist. Many of the listed data are based on expert judgement. Only few studies about lifetimes of wood products exist (e.g. Scharai Rad and Fruehwald 2002). Summarising it seems that for CSEM the lifetimes were underestimated, so for this study new lifetimes were assumed. They are listed in the line “assumption for this study”.

Table 5: Half lifes of different wood products. Construction Sector

Product	*Half life (years)*	*Country*	*Source*
Construction	65	Germany	Burschel et al.,1993
Construction	80	UK	Thompson/ Matthews,1989
Non residential construction and homes	67 – 100	USA	Skog/ Nicholson 1998
Construction wood	30	Netherlands	Sikkema/ Nabuurs 1994
Building sector	30 - 50*	France	Lochu in Pingoud et al. 2005
Construction material	80	Norway	Hoen and Solberg 1994
Construction	75**	Germany	Scharai Rad/ Frühwald 2002
Products made of sawn timber, plywood / veneer, or particleboard used for construction work in buildings, civil engineering and other long-life construction work	50	Europe (EFISCEN)	Eggers 2001
Construction	15 (25, 35)*	Italy (CSEM)	Anderle et al. 2002
Assumption for this study	50		

* Lifespan[2], **Average lifetime

Table 6: Average half lifes of different wood products. Windows, doors, interior work

Product	*Half life (years)*	*Country*	*Source*
Windows	50	Italy	Rilegno 2000
Windows	20 – 25	Germany	Binz et al. 2000
Stairs/ Doors/ Parquet	25 – 65	Germany	Binz et al. 2000
Interior	30	Germany	Scharai Rad and Frühwald 2002
Window frames	30	Netherlands	Nabuurs and Sikkema 1994
Parquet	30	Netherlands	Nabuursand Sikkema 1994
Parquet, doors, windows, stairs	30*	France	Lochu 2005
Products made of sawn timber, plywood / veneer, or particleboard used for maintaining in houses or civil engineering, commodities, fences, window frames, panels, wooden floors and doors	16	Europe (EFISCEN)	Eggers 2001
Inside walls, Sliding doors, shutter	20*	France	Lochu 2005
Assumption for this study	20		

* Lifespan, ** Average lifetime

Table 7: Average half lifes of different wood products. Furniture

Product	*Half life (years)*	*Country*	*Source*
Furniture	30	USA	Skog and Nicholson 1998

[2] The lifespan is defined by Pingoud et al., 2005 as “the time needed that the majority of the HWP pool has decayed, e.g. 90% or 95%”.

Furniture	15	Germany	Burschel et al.,1993
Furniture	10 – 30	Germany**	Scharai Rad/ Frühwald 2002
Furniture (Kitchen, Bedroom)	13-17	Germany	Naumann 1992
Bedroom furniture	25	Germany	Binz et al. 2000
Furniture	10 – 12	Europe	www.ueanet.com
Furniture	15	Netherlands	Nabuurs/ Sikkema 1994
Furniture	12*	France	Lochu in Pingoud et al. 2005
Furniture and interiors	20	Norway	Hoen/ Solberg 1994
Furniture	7 (10, 20, 30)*	Italy (CSEM)	Anderle et al. 2002
Assumption for this study	12		

* Lifespan, ** Average lifetime

Table 8: Average half lifes of different wood products. Packaging

Product	*Half life (years)*	*Country*	*Source*
Packaging	1 – 6	USA	Skog and Nicholson 1998
Packaging	2	UK	Thompson/ Matthews 1989
Packaging	2	Germany**	Scharai Rad and Frühwald 2002
Pallets	5	Italy	Rilegno 2002
Pallets	2	Netherlands	Nabuurs and Sikkema 1994
Packing	1*	France	Lochu 2005
Pallets	2	Norway	Hoen and Solberg 1994
Packaging	3*	Italy (CSEM)	Anderle et al. 2002
Assumption for this study	3		

* Lifespan, ** Average lifetime

Table 9: Average half lifes of different wood products. Paper

Product	*Half life (years)*	*Country*	*Source*
Paper	1 – 6	USA	Skog/ Nicholson 1998
Newspaper	2	UK	Thompson/ Matthews 1989
Paper	1	Germany	Burschel et al. 1993
Books	25	Germany**	Scharai Rad/ Frühwald 2002
Newspaper/ Journals	0.2 – 0.5	Germany**	Scharai Rad/ Frühwald 2002
Pulp & paper	1	Norway	Hoen and Solberg 1994
Newsprint, shares of packing paper, paperboard, and printing and writing paper	1*	Europe (EFISCEN)	Eggers 2001
packing paper, paperboard, and printing and writing paper	4*	Europe (EFISCEN)	Eggers 2001
Average for paper	1.8	Finland	Pingoud et al. 1996
Paper	2*	Italy (CSEM)	Anderle et al. 2002
Assumption for this study	2		

* Lifespan, ** Average lifetime

Table 10: Average half lifes of different wood products. Other

Product	*Half life (years)*	*Country*	*Source*
Sleepers	30	USA	Skog/ Nicholson 1998
Fences	20	UK	Thompson andMatthews 1989
Other industrial branches	10*	France*	Lochu 2005
Garden	15	Germany**	Scharai Rad and Frühwald, 2002
Other	3*	Italy (CSEM)	Anderle et al. 2002
Assumption for this study	5		

* Lifespan, ** Average lifetime

The tables show a large difference in lifetime between “construction” and “interior work” (e.g. windows versus roof construction), which were unified in the CSEM. Interior work is also an important sector in Italian wood utilization (see chapter 2.2.1). It was decided to introduce another category: “Interior”.
Therefore the distribution of semi-finished products was manipulated like in the following Table 11.

For “Furniture”, “Packaging”, “Paper” and “Other” the distribution data of CSEM were used.

Table 11: Partitioning of semi-finished products into end-use categories and their lifetimes used in the model

	Paper	**Furniture**	**Interior**	**Construction**	**Packaging**	**Other**
Years	**2**	**12**	**20**	**50**	**3**	**5**
Sawnwood – C	4%	5%	40%	40%	8%	3%
Sawnwood – NC	5%	50%	10%	5%	15%	15%
Plywood	0%	75%	5%	0%	15%	5%
Veneer	0%	85%	5%	0%	0%	10%
Particleboard	0%	85%	10%	0%	0%	5%
Fibreboard	0%	80%	10%	0%	5%	0%
Pulp and Paper	90%	0%	0%	0%	10%	0%

For the SWDS an average lifetime of 30 years for paper and 100 years for solid wood products were adapted from Pingoud, 2002.

3.5 HWP in Solid waste disposal sides (SWDS)

After the end of the lifetime of wood products there are three possibilities:

1) Recycling
2) Burning (with generation of energy)
3) Disposal on landfills - SWDS

Data for wood and paper waste are coming from the stock of HWP in use (Table 12). The direct flows of wood waste and residues from production processes are neglected. Methane and other emissions of the landfills are reported under the waste sector. The modelling of HWP in solid waste disposal sites is compatible with the Good Practice Guidance for the Waste sector (Pingoud, 2005).

Table 12: Flow of wood products into landfills (SWDS – Percentages, ps) (Pingoud, 2002)

Year	*Flow of Solid wood products into landfill*	*Flow of paper products into landfill*
1900 - 1950	5%	10%
1960	11%	30%
1970 - 1990	21%	50%
2000	21%	45%
2010	21%	40%

Large uncertainties occur for the flow of wood products into the landfills, especially historical flows and lifetimes (depending on conditions – aerobic/ anaerobic) (Pingoud *et al*., 2005).

Since the beginning of the 1980-ies Italy is one of the leading countries in Europe using secondary wood materials for the production of new panels and boards but also paper. Necessary precondition for recycling is the separate waste collection. The long experience in utilizing waste wood as raw material contrasts with poor facilities for separate collection, especially in middle and southern Italy. Thus Italy is an importing country also for waste wood and paper to cover the demand.

In 1996 74.4% and in 1997 68.4% of biodegradable municipal waste[3] was disposed in landfills (Crowe, 2002).

After the release of the Law n. 22/1997 the situation started to change. The law has the aim to increase the reuse and recycling of materials and pushed forward the selective collection of waste, especially in the Centre and the South of the country. The collection and recycling rate in Italy is continuously increasing (see Table 13).

Statistics exist only for the last years for the packaging sector. Wood from construction and demolition as well as wood for furniture is not included.

Table 13: Collection and recycling of waste wood and paper in Italy

	1998	1999	2000	2001	2002	2003
Collection of waste wood relative to the wood consumption (%)	42.9	38.0	35.0	53.9	60.6	
Collection of paper relative to the wood consumption (%)	39.9	44.0	47.8	55.3	59.0	65.9[1]
Recycling rate paper (%)[1]	37.0	40.7	45.9	50.7	56.2	57.8

[1] Farotto, 2004

In 2004, about 60% of the waste wood was recycled and a small fraction (1.2%) was used for generating energy (Rilegno,2005). Vice versa about 35% of the wood is still disposed in landfills. 16% of the recyclable paper and paperboard have their destination in landfills or in other uses, 25% are not recyclable or recoverable and remain too at the disposal sides (Comieco, 2004).

In conclusion, the flow of waste wood and paper into landfills in Italy seems to be higher than the parameters (of) the model suggests. The parameters of the EXP.HWP model were changed for the period from 1970 - 2000 in the following way, using the data described above (Table 14):

Table 14: Flow of wood products into landfills - Changes

Year	*Flow of Solid wood products into landfill*		*Flow of paper products into landfill*	
	EXP.HWP model	Changes	EXP.HWP model	Changes
1900-1950	5%	5%	10%	10%
1960	11%	11%	30%	30%
1970-1990	21%	35%	50%	60%
2000	21%	35%	45%	55%
2010	21%	21%	40%	40%

4 Results

4.1 C – Sink of HWP

Table 15 shows the results for the annual flows of carbon. Stock-change and production approach provide a net sink of carbon. The production approach shows much lower results like to be expected for net wood importing countries like Italy. After the atmospheric flow approach, HWPs are always a source of carbon (see also Figure 3 - Figure 5).

The carbon flow into landfills is of high importance. It amounts to 64% of the total sink effect of HWP under stock-change approach and 86% under the production approach.

[3] Food, garden, paper and paperboard, textiles, wood and other miscellaneous biodegradable content of the waste

Table 15: C – Sink of the different approaches in 2003

	Sink (Gg C/yr)	%
Stock-change Approach		
HWP in use	1451	36%
SWDS	2628	64%
Total	4080	100%
Production Approach		
HWP in use	126	14%
SWDS	768	86%
Total	895	100%
Atmospheric Flow Approach		
Total	-1523	100%

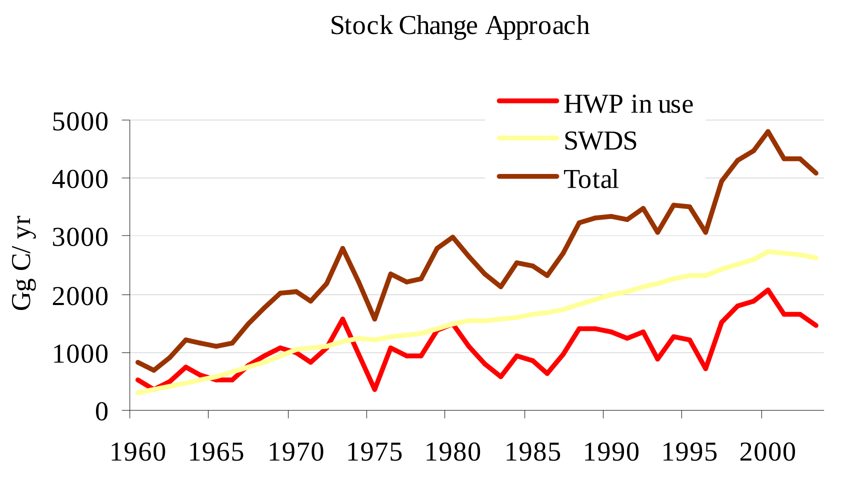

Figure 3: Stock-change Approach – Stock-changes (Gg C/ yr)

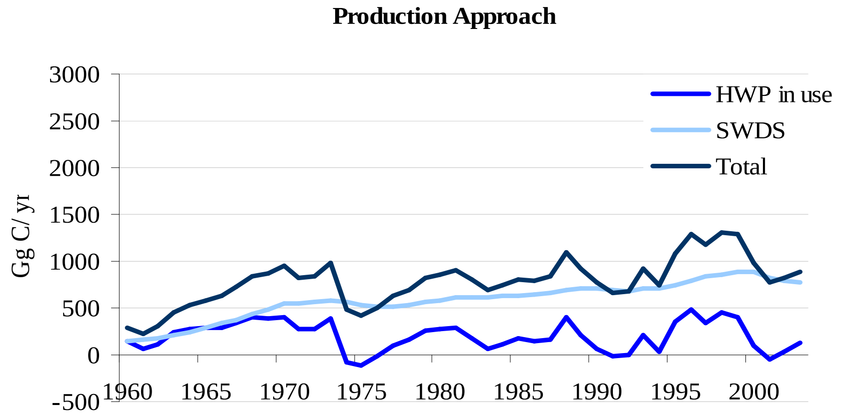

Figure 4: Production Approach – Stock-changes (Gg C/ yr)

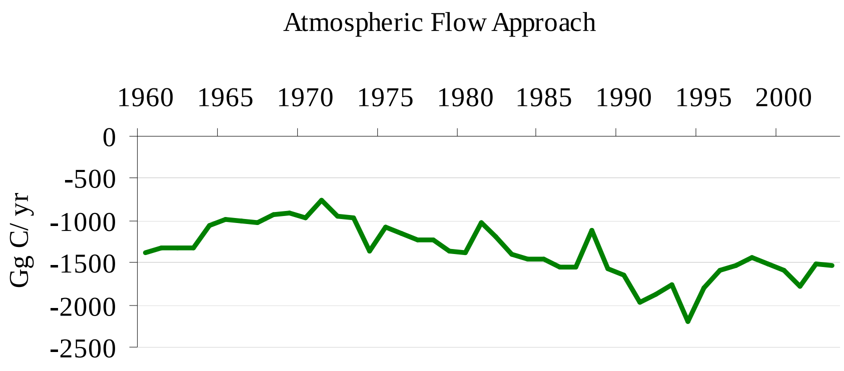

Figure 5: Atmospheric Flow Approach – C-sink (Gg C/ yr)

4.2 C – Stocks of HWP

The following Table 16 shows the results of the stock-change and production approach for the C stock in HWP in Italy. The stock-change approach provides the higher results. After both approaches the carbon stock in landfills exceeds the values of the carbon stock of products in use.

Table 16: C – Stock of the different approaches in 2003

	Stock (Tg C)	**%**
Stock-change Approach		
HWP in use	58.2	45%
SWDS	72.5	55%
Total	130.6	100%
Production Approach		
HWP in use	12.2	30%
SWDS	27.7	70%
Total	39.9	100%

The pools of HWP in use as well as in landfills are continuously increasing (Figure 6 and Figure 7).

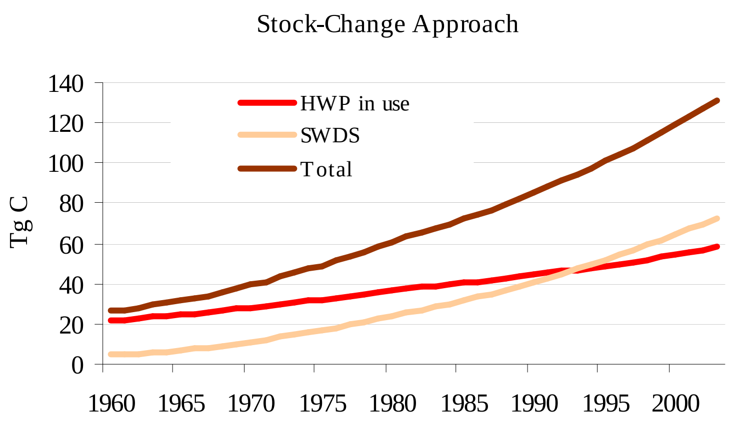

Figure 6: Stock-change Approach – C Stock (Tg C)

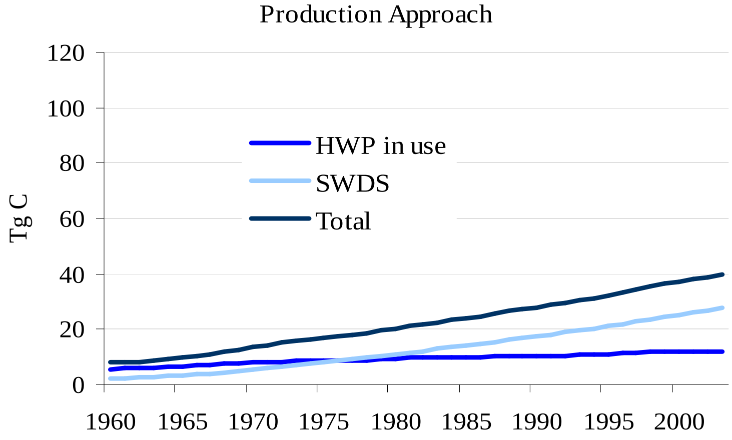

Figure 7: Production Approach – C Stock (Tg C)

4.3 Trade of end products

As said before, Italy is a wood importing country but large volumes of produced end products, mainly furniture, do not remain in the HWP pool of the country, they are exported. There are only view data about the trade of end products available.

In the *Stock-change Approach* changes in the products pool are accounted for in the country where the products are used (consuming country). Any export is leading to reduced stock and emissions for the producing country. In the *Production Approach* any stock of carbon that crosses national boundaries is not transferred to the inventory of the importing country. The carbon exported is accounted for in the inventory of the producing country. In the *Atmospheric Flow Approach* instead net exports of wood products lead to removals of carbon for the exporting country (FCCC/TP/2003/7).

Table 17 shows the results, if trade of end products are included.

Table 17: Import and export of wooden end-products (included: Builders Joinery, Flooring, Mouldings, Millwork, Wooden furniture) Source: ISTAT, Federlegno in Baudin et al., 2005

	1999	2000	2001	2002	2003
Export (1000 t)	1350	1533	1574	1534	1435
Import (1000 t)	890	1100	1115	1164	1236
Net export (1000 t dry weight)	405	381	404	326	175
Net export (Gg C)	203	191	202	163	87

The inclusion of exports of end products leads to fewer removals in the Stock-change Approach and to higher emissions under the Atmospheric Flow approach. It would lead to higher C stocks and sinks under the Production approach, but it has to be taken into account how much of the wood of these end products was grown in the own country.

5 Discussion

5.1 Input parameters

Since some of the input parameters are based on assumptions the following calculations show possible alternatives. May be for future work could be decided which values to use. Comparisons of the alternative values shall show the consequences of the results for C stock and emissions/ removals.

5.1.1 Historic consumption rate

FAO databases about production and trade of wood products are starting in the year 1961. For calculation of carbon in wood products historic stocks and emissions have to be taken into account. The IPCC GPG for LULUCF give the possibility to choose between two different historic consumption rates to estimate historic consumption of industrial round-wood (0.02 or 0.0119), depending on development before 1950. Statistics provided by the National Institute of Statistics (ISTAT) about wood production are available from 1948/49 on, and earliest numbers for wood trade can be found for 1950. Thus, no estimations about wood production and trade before 1950 are available. (ISTAT, 1950-2005).

The following Figure 8 - Figure 10 show C Stock and C Stock-changes of the different applied approaches with different historic consumption rates.

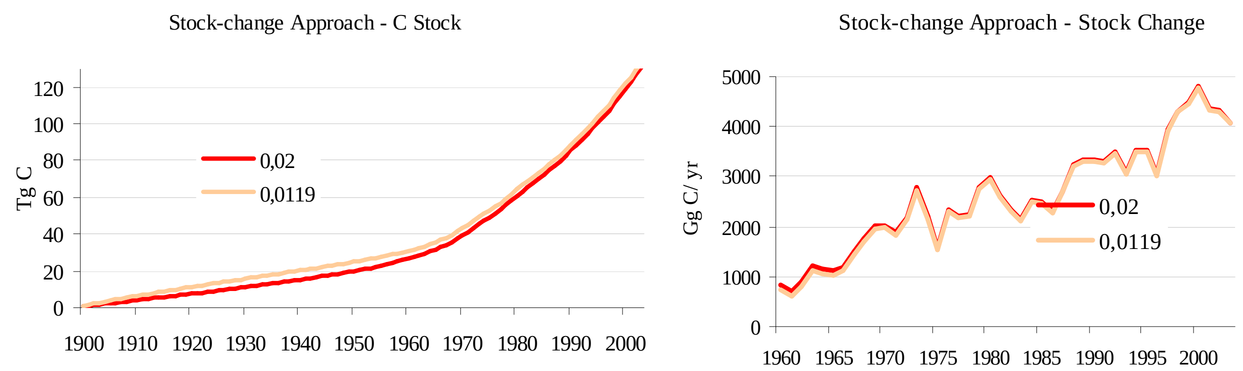

Figure 8: C Stock and C Stock-changes of the Stock-change Approach with different historic consumption rates

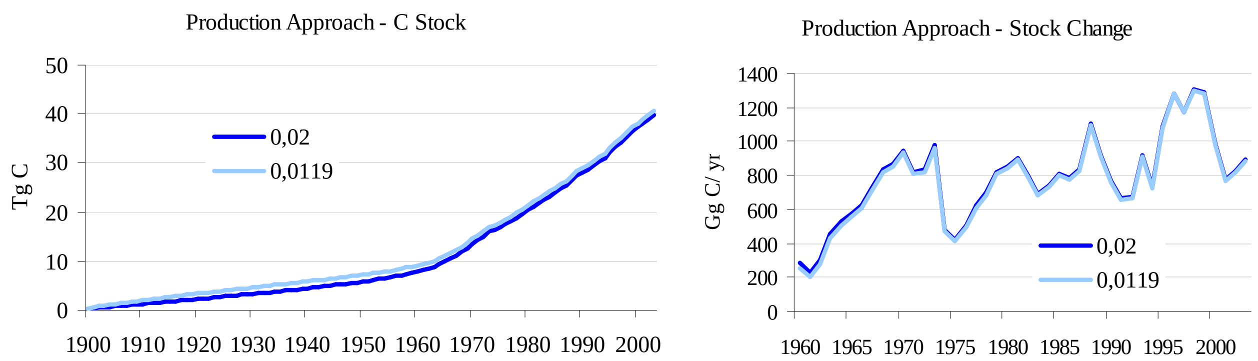

Figure 9: C Stock and C Stock-changes of the Production Approach with different historic consumption rates

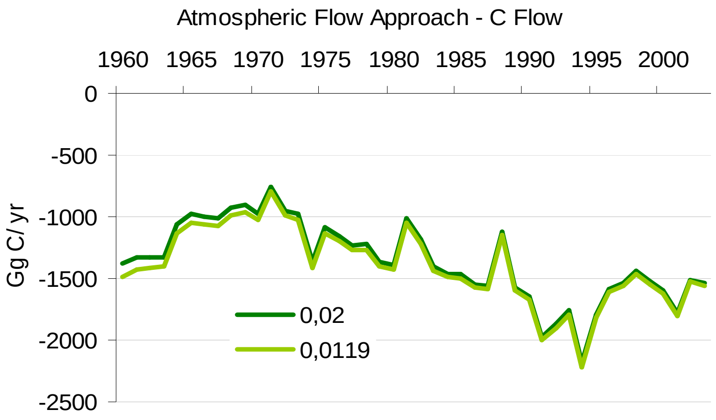

Figure 10: C Sink of the Atmospheric Flow Approach with different consumption rates

The different parameters have only an influence on earlier consumptions, the curves for C-stocks as well as for C-flows inside the HWP pool become closer to each other over time. For all approaches the difference of the results is less than 1%.

5.1.2 Lifetimes

To estimate consequences of prolongation of half lives the following scenarios were used (Table 18). Scenario 2 represents the parameters used in the model. For scenario 1 shorter lifetimes for furniture, interior and construction were applied, similar to the CSEM. For scenario 3 longer lifetimes for these categories were chosen and represent higher values used in other studies (Table 5 - Table 10).

Table 18: Lifetime scenarios

	Paper	Furniture	Interior	Construction	Packaging	Other
Scenario 1	2	7	16	30	3	5
Scenario 2	**2**	**12**	**20**	**50**	**3**	**5**
Scenario 3	2	20	30	80	3	5

Longer lifetimes lead to higher values of C-stocks and C-sinks for the wood products in use and lower values for solid waste disposal sides. A change in lifetimes has higher influence for the carbon sequestration in wood products in use than for SWDS. The results are illustrated in the following figures (Figure 11- Figure 13).

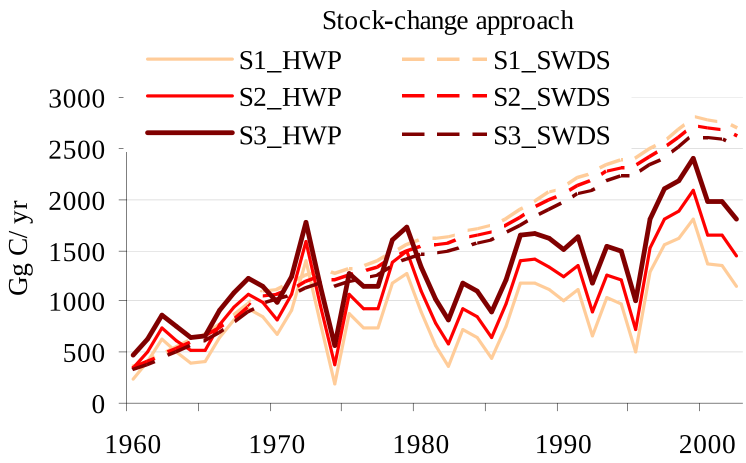

Figure 11: Stock-change Approach – Lifetime scenarios (Gg C/ yr)

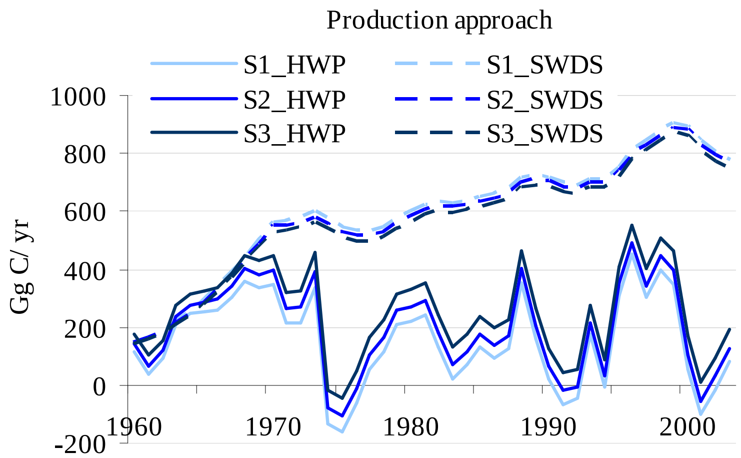

Figure 12: Production Approach – Lifetime scenarios (Gg C/ yr)

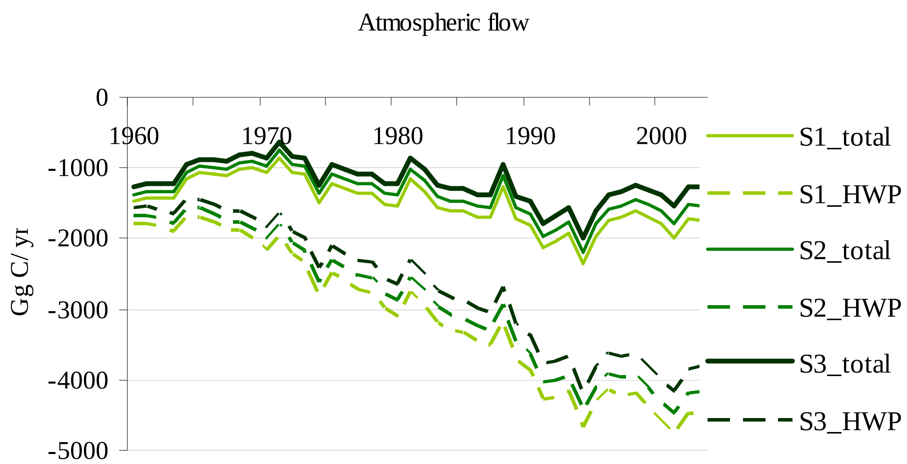

Figure 13: Atmospheric Flow Approach – Lifetime scenarios (Gg C/yr)

In general longer lifetimes provide higher removals of carbon for the stock-change and production approach and lower emissions for the atmospheric flow approach.

The differences between the applied lifetimes are rather low for stock-change and production approach – since losses in wood products in use are compensated by higher values in the solid waste disposal sides. Large differences occur for the atmospheric flow approach (see Table 19).

Table 19: Results of the scenarios of different lifetimes in 2003, Carbon flows [Tg C/ yr]

	S 1		**S 2**	S 3	
	[Gg C/ yr]	Difference S1/ S2 [%]	**[Gg C/ yr]**	[Gg C/ yr]	Difference S2/ S3 [%]
Stock-change Approach	3860	-5%	**4080**	4336	+6%
Production Approach	860	-4%	**895**	943	+5%
Atmospheric Flow Approach	-1751	-14%	**-1532**	1276	+17%

5.1.3 Flow into SWDS

If the flow of wood products into landfills is increasing like described in chapter 3.2 (Table 14), the total carbon stock and stock-change are increasing to a large extent. Table 20 shows the differences between the applied input parameters. Concretization of this data would have a large influence on accuracy of the calculation.

Table 20: Effect of changes in the flow of wood products in landfills (2003)

	Total Stock [Tg C]		**Difference**	**Stock-change [Gg C/ yr]**		**Difference**
	EXP.HWP	**EXP.HWP modified**		**EXP.HWP**	**EXP.HWP modified**	
Stock-change Approach	114.7	130.7	+12.2%	3603	4080	+11.8%
Production Approach	34.4	39.9	+13.8%	766	895	+14.4%
Atmospheric Flow Approach				-2008	-1532	+35.6%

5.2 Comparison with other studies

CSEM

Flow Consumption and Stock-change both are based on calculations of the wood products consumed (Production + Import - Export) meanwhile Flow Production includes only the domestic produced wood without trade.

The treatment of historic emissions is different. For two reasons: 1) Period of time 2) way of decay of wood products in the model. The CSEM assumes that the entire products are emitted at the end of their lifespan. No considerations for landfills were made in the model (Table 21).

Table 21: Results of CSEM for year 2000, results depending on lifetimes (10-15 yr, 20-25 yr, 30-35 yr)

	C-Stock (Tg C)	C-Sink (Tg C/ yr)
Flow consumption	1.9 - 2.6 - 3.9	1.9 - 2.6 - 3.9
Flow production	0.6 - 1.1 - 1.4	0.6 - 1.1 - 1.4

EXP.HWP

The EXP.HWP model of Pingoud (2002) provides lower values for the stock-change approach and the atmospheric flow approach for carbon stock and carbon sink and slightly higher values for the production approach as this study (Table 22). The new version of the model doesn't include SWDS up till now.

Table 22: Comparison EXP.HWP model and this study (year 2000)

	EXP.HWP (Pingoud, 2002)		**EXP.HWP (Pingoud, 2005)**		**This study**	
	C - Stock (Tg C)	C - Sink (Tg C/ yr)	C - Stock (Tg C)	C - Sink (Tg C/ yr)	C - Stock (Tg C)	C – Sink (Tg C/ yr)
Stock-change, total	111.6	3.58			119.0	4.81
Stock-change, only HWP	64.0	1.78	84.2	2.61	54.5	2.08
Production, total	44.6	1.27			37.3	1.0
Production, only HWP	20.5	0.36	30.7	0.75	12.0	0.1
Atmospheric flow, total		-1.94				
Atmospheric flow, without landfill		-3.64		-3.44		

Different input parameters and a slightly different methodology lead to the differences in the results of the models which are all based on the same FAO databases. In the EXP.HWP model only 2 lifetimes for wood products are used: 1 year for paper products and 30 years for solid wood products. The distribution of semi-finished products in end-use categories lead to lower lifetimes in this study and therefore have provided lower results for all approaches for the wood products in use. Besides that the estimated growth rate of HWP consumption prior to 1961 and values of dry weight for solid wood products differ.

Furthermore for the methodology of the stock-change and production approach of the IPCC GPG for LULUCF include for calculation of current year addition of Pulp and Paper (P_A(paper) and PH_A (paper)) an additional factor – the WP ratio (fraction of all pulp that is wood pulp and excludes fibre pulp) which further diminishes the results.

Since the atmospheric flow approach is based on results of the stock-change approach differences occur also here.

For the production approach the domestic roundwood production for current year additions to HWP (P_{HA} (solidwood) and PH_A (paper)) is calculated with all roundwood in the EXP.HWP. The IPCC GPG for LULUCF instead uses only the domestic production of industrial roundwood. If total roundwood would be used, than the results would be almost double and similar to those of EXP.HWP.

Other studies

Karjalainen et al., 2003 estimated 21.3 Tg C stock in wood products in 1990 in Italy and an annual carbon uptake of 172 Gg C/ yr in wood products for the period 1995-2000.
Hashimoto et al., 2002 calculated an annual carbon sequestration of wood commodities of 2.4 Tg C/ yr in 1990 and of 3.0 Tg C/ yr in 1999.

Alternative calculation method to the three approaches would be for example a direct stock inventory of wood products in two points of time (see e.g. Pingoud, 2000). However this method request good statistical data about main end uses of wood products e.g. the building sector and the amount of wood used for these products. Statistics are available only in a limited way and no information exists about the utilized wood per wood product.

6 Future trend

6.1 Utilization of HWP

Like in the CSEM, the future trend was modelled using a polynomial trend line. The stock-change approach yields a trend towards increasing carbon sink for wood products. The production approach remains nearly on the same level meanwhile the atmospheric flow approach produces slightly decreasing values.

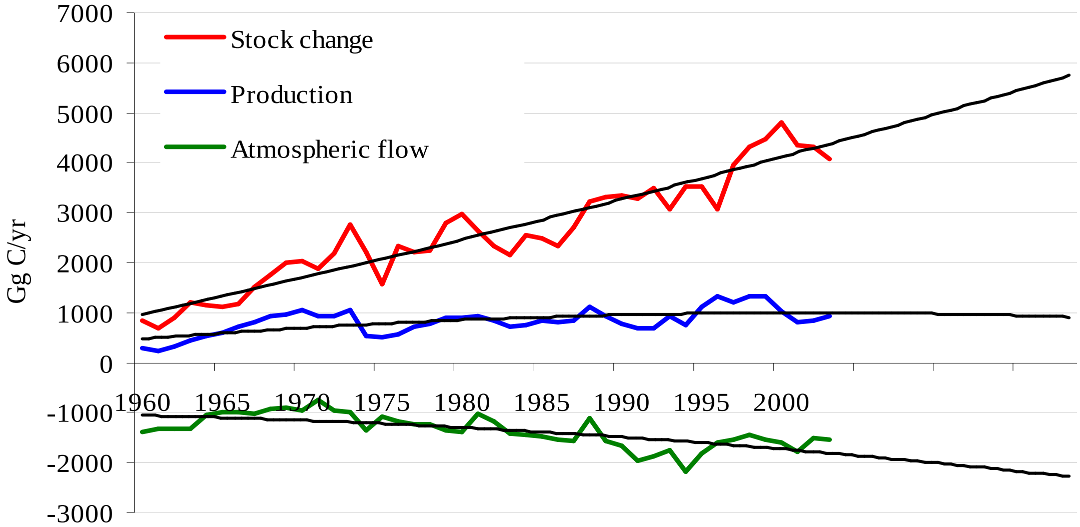

Figure 14: Future trend in carbon flows (GgC/ yr)

The demand of many wood products like in the construction and interior sector as well as for furniture is determined by the socio-economic situation, like e.g. population development and the number of households. In Italy we can find the following processes:

- increasing number of families and decreasing family size
- increasing number of single households (ISTAT, 2003)
- aging of the population, and after 2012 decreasing number of population (ISTAT, 2005)

The building activities, especially for residential buildings were permanently increasing over the last years due to a "baby boom" that created an increased demand for new housing in the 1990. It was estimated that these trend will stop after 2004.

Gardenio (2001) mentioned that wood came into fashion in the last period, especially for new roof constructions and mansards. Furthermore it is expected that the renovation market will further increase within the next years.

The furniture sector expects a slightly growing demand in the near future (CSIL, 2005).

All facts together lead to the conclusion, that the pool of carbon in wood products might continue to increase in the future, but in a very limited way.

6.2 Waste sector

The flow of wood products into landfill will decrease due to better recycling systems in the country and a higher rate of energetic use. After the directive n. 99/31/CE all materials with a calorific value of more than 13 000 kJ/ kg may not be stored on landfills anymore.

Studies have shown that the recycling of 1 kg waste wood prevents the emissions of 1.03 kg CO_2 eq., especially thanks to avoided methane emissions on landfills (www.rilegno.it). For paper was calculated, that with each kg of recycled paper 1.3 kg CO_2 can be avoided (Farotto, 2004).

6.3 Future work

Scenarios for

1) Production outside the country (China)
2) Capacity of recycling
3) Energetic use of wood
4) Plantation for wood production in context with policy of European Union

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