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Climate change, air pollution and noise, TA-1831/2001

Estimating the net emission of CO_2 from harvested wood products – A comparison between different approaches

Climate change, air pollution and noise

Estimating the net emission of CO_2 from harvested wood products

1831
2001

A comparison between different approaches

Preface

Through the sequestration of carbon in photosynthesis, forestry is an important part of the anthropogenic carbon cycle. All harvested carbon is eventually oxidised to CO_2, but the carbon may be stored for a short or long period of time before oxidation. The carbon stored in harvested wood products is not presently accounted for under the Framework convention on climate change (UNFCCC). Furthermore, harvested wood and wood products are traded between countries.

How to account for such storage and trade in a CO_2 emission inventory must be decided by the Conference of the Parties. In the current reporting guidelines for greenhouse gas inventories, emissions from forestry are reported separately from the national total, assuming that emissions occur at the time of harvest in the country of harvesting. This implies that no carbon goes into long term storage.

The aim of this report is to test and compare four different proposed approaches for allocating carbon storage and CO_2 emissions from wood products to countries, using Norway as an example. Furthermore, different estimation methods for the storage are compared and discussed from the point of view of accuracy and availability of data.

This report has been prepared by Ketil Flugsrud, Britta Hoem, Eli Kvingedal and Kristin Rypdal at Statistics Norway and is published by the Norwegian Pollution Control Authority.

Per Sander Døvle

The Norwegian Pollution Control Authority

Oslo, October 2001

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1. Summary

The issue of accounting for carbon in harvested wood products needs further attention to ensure verifiable and consistent reporting. In the current IPCC (Intergovernmental Panel on Climate Change) reporting guidelines, it is assumed that carbon in wood is emitted at the time of harvest in the country of harvest. However, carbon may be stored in harvested wood products for a long time and wood products are often traded between countries.

In this report, we analyse the different approaches and estimation methods that have been proposed, and investigate how they affect the outcome with respect to changes in the wood product stock in Norway. We have not aimed at improving the methodology for estimating the forest stock change, but go into detail with respect to approaches to, and estimation methods of, harvested wood product stock change. The analyses are made on Norwegian forest and wood products data, and not all conclusions may be applicable to the circumstances of other countries.

1.1. Approaches and estimation methods

It is important to distinguish between approaches (how emissions are allocated to countries) and estimation methods (how emissions and stocks are estimated). Several *approaches* have been suggested for estimating CO_2 emission sources or sinks within land use, land-use change and forestry: 1) the IPCC Guideline approach, 2) the stock-change approach, 3) the production approach and 4) the atmospheric flow approach. These approaches differ in the way which national emissions and removals are allocated to a country, and will usually give different output with respect to level and trend. In this report we compare the approaches as outlined in Brown *et al*. (1998) for Norway, taking into account different estimation methods for carbon stock change. Within each approach, there may be more than one possible estimation method, as shown in table 1.

Table 1. Approaches versus methods for estimating stock change in harvested wood products

Approaches	Estimation methodology	
	Stock data method	Flux data method
Stock change approach	x	x
Production approach	x	x
Atmospheric flow approach	x	x

The approaches do not differ in the accounting of changes in the forest stocks. The main differences between the approaches relate to how the product stocks and foreign trade in wood products are treated. This aspect will give different incentives to national policies with respect to import and export of wood products.

1.1.1. The stock change approach and the atmospheric flow approach

To a large extent the same methods (and data), see chapter 1.3, can be used for the atmospheric flow and stock change approach. The atmospheric flow approach requires the addition of a term concerning net import, but this is an area where data are easily available from the national external trade statistics. With respect to transparency, however, the atmospheric flow approach can be considered as less intuitive than the stock change approach.

The stock change approach resembles most closely the estimation methods used for other sources, and it is consistent with how LULUCF is treated in the Kyoto protocol and in the 1996 IPCC guidelines. Accounting of emissions after export does not appear in any of the higher tiered methodologies. The stock change approach can also be scaled down to smaller geographical areas, even to a project level.

In general, the atmospheric flow approach gives incentives to producing countries to increase their export, and not necessarily the stock of wood products. This can promote deforestation, because if wood from deforestation is exported, the products are accounted as removal. With respect to fuel switching, it does not give incentives to switch from fossil fuels if biofuels are imported. The reason is that CO_2 emissions from biofuels are accounted for in the country of import and not the producing country. For the other approaches the net carbon source is accounted for in the country where deforestation occurs (Brown *et al.* 1998).

1.1.2. The production approach

The production approach requires data on storage of wood products 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 production approach counts the accumulation of long-lived products in the country where the wood was grown, while the stock change approach counts the accumulation in the country where the wood products are in use. This gives less incentive to import and more incentive to export long-lived wood products for the production approach than for the stock change approach. Also, the production approach may not provide incentives for the importing countries to increase the lifetime of imported wood, or reduce emissions in other ways, such as through better waste management, since emissions are accounted for in the producing country (Brown *et al.* 1998).

1.1.3. Data availability and estimation methods

Within each approach, there may be more than one possible estimation method. All approaches treat the carbon balance of forests in the same manner (as forest stock change), and thus it is the treatment of the product stock change that gives rise to differences between the approaches. Two main estimation methods have been suggested for calculating the stock change of products: the flux method and the stock method.

Flux-based methods requires estimation of carbon release from biomass going out of storage and factors for the rate of oxidation of different product groups. This can be done through an inflow-outflow analysis or as a lifetime analysis. The flux method based on a lifetime analysis is sensitive to the assumptions about lifetimes of the different products, while an inflow-outflow analysis requires accurate waste data. For some product groups it is a good option, either because flux data are readily available or because stock data are unavailable (e.g. for paper, stocks are difficult to estimate because of the short life cycle of many paper products).

With estimation made by stock data, the amount of carbon in a product pool is estimated by calculating the standing stock of product times the carbon content of the product in question.

The net accumulation of carbon is estimated from changes in total storage. A major advantage of stock methods over flux methods is that the accumulated stock change over longer periods can be estimated with less uncertainty. With the flux methods, there is usually no gain in precision from longer periods.

In a total balance of harvested carbon it is difficult to account for all carbon, both due to inaccuracies in the figures on production and foreign trade, and uncertainties in the estimates of emissions and storage. Whether these 'missing sinks' are accounted as emissions or stock change may influence the results significantly.

The report presents results from a pure flux method and a "combined" method which estimates the stock for each type of product based on considerations of what is the best available data; stock-based or flux-based. Stock data are used for buildings and furniture, while flux data are used for paper and waste. This leads to an overall higher accuracy than using the pure flux method in a country with high quality statistics. However, the general uncertainty is high even for the preferred estimation method. This combined approach to data estimation is not possible for the production approach, as it is unable to track the origin of wood and estimate the storage abroad of domestically grown wood.

The approaches require to a large extent the same types of data. Data on production, import and export of basic and intermediate wood products are of good quality and available in official statistics in Norway. From a statistical point of view the atmospheric flow and stock change approaches are approximately equally feasible. The production approach, however, requires data on storage of products produced from domestically grown wood, which is not straightforward to estimate accurately. In particular, the fate (and consequently lifetime) of exported products is often not known accurately.

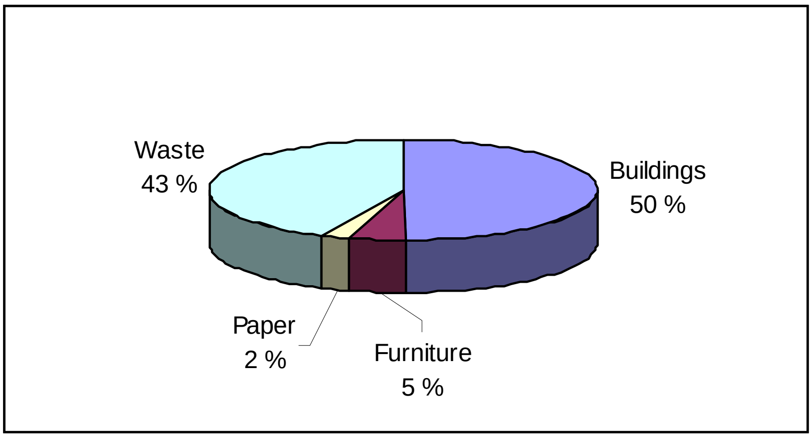
For the combined method, data for calculating the total carbon stock in wood products are found in different statistical sources for the different carbon stocks. Many different sources make the data collection more expensive and difficult. But as long as the needed data already are produced for other purposes, the cost and time uses for the collection are reasonable as the combined method can give a more accurate overall stock change estimate. In general all methods and approaches will need a detailed documentation in order to be transparent.

1.2. Main results, Norwegian wood products stock change

The stock change in products is small compared to the stock change in forest, but it is increasing. The net growth rate in the product stock is lower than the net growth in the forest stock. The product stock change is only about 3.5 % of the total wood carbon stock change. The wood product stock, though, is about 6 % of the total carbon stock in Norway.

Storage in buildings (50 %) and landfills (43 %) are most important for the total wood product carbon reservoir in Norway. Furniture and paper/paper products are of minor importance (Figure 1). With respect to estimation errors, the stock data estimation methods used for buildings and furniture are particularly sensitive to the assumptions made on wood content pr m^2, whereas estimations made with flux data are sensitive to assumptions about product lifetime.

Figure 1. Carbon stock in wood products. Norway 1998, per cent.



The wood product stock has increased from 1990 to 1998 (10 %), and projections indicate further growth (14 % from 1998 to 2010). This corresponds to about 0.7 million tonnes CO_2 annually, compared to the annual emissions of about 55 million tonnes CO_2 equivalents.

Calculating the Norwegian sink by the atmospheric flow and the stock change approach using the "combined" method shows that both approaches give an increase in the CO_2 sink from 1993 to 1998. However, since Norway between 1993 and 1998 has changed from being a net exporter to a net importer of wood and wood products, the atmospheric flow approach gives a smaller increase. Calculated with the stock change and atmospheric flow approaches, the flux method gives a similar result as the combined method considering the change in sink between the two years, but the CO_2 sink values are lower. The production approach ends up with a sink that is intermediate between the two other approaches for both years.

Table 2. Stock change of products and total net carbon removals for the different approaches using different estimation methods. Norway 1993 and 1998, 1000 tonnes C

	1993			1998		
	Stock change approach	Production approach	Atmospheric flow approach	Stock change approach	Production approach	Atmospheric flow approach
Combined estimation method	162	n.a.	587	183	n.a.	- 129
Flux estimation method	-4	62	421	166	81	-146
Total net removal, combined method (forest + forest products)	3 847	n.a.	4 272	4 979	n.a.	4 668
Total net removal, flux method (forest + forest products)	3 681	3 747	4 106	4 962	4 877	4 651

1.3. Accuracy of approaches

The rule is that the greater the number of assumptions, the larger the uncertainty of the emission estimate. For the atmospheric flow approach the net export is an extra term in the calculation of the sink compared to the other approaches, and causes in principle higher uncertainty. As the additional term is quite well known, we would, however, rank these two approaches to have approximately the same uncertainty. For the production approach the way that domestic wood products is calculated contributes to quite high additional uncertainty. To reduce this uncertainty would require an international reporting system tracking flows of wood products.

The uncertainty in the forest stock change used in all the approaches lies mainly in the growth per cent, unregistered felling and the expansion factor. The error-limit for the net carbon stored in trunk, cortex excluded, is maximum 30%. The uncertainty in the expansion factor for calculation from trunk volume to total biomass is probably higher. The overall uncertainty can be of the order 5-10 million tonnes of CO_2 (including soil carbon, the uncertainty would increase). This calls for further work to increase accuracy in the estimation of forest stock change.

When it comes to the stock change of products and the two different estimation methods presented there, both methods include a number of assumed parameters. Parameters in the flux method with a high uncertainty are the assumptions of the lifetimes for the different products, particularly as the time in landfills is to be included, and these time estimations are clearly very rough at this level of detail.

The uncertainty in the combined method is mainly found in the factor for calculating the wood amount per building, and in the calculations of the stock change in waste. The estimation error is probably not exceeding a factor 2 up or down, and is probably much smaller. This gives an uncertainty in the stock change on maximum 0.6-0.7 million tonnes CO_2.

The uncertainty of CO_2 estimates in typical high quality inventories is less than 5 %, and the overall uncertainty in GWP weighted emissions are 15-20 % (Rypdal and Winiwarter 2001). Adding LUCF will clearly increase this uncertainty. All approaches for estimating storage in wood products will add uncertainty to the current IPCC approach, but only marginally compared to LUCF itself. All the approaches are consistent by themselves. However, consistency can be a problem with respect to inter-country comparisons and between sources if different methodologies are in use.

2. Introduction

Forest management and the use of wood products affect the balance of CO_2 removals and emissions in the global carbon cycle. To act as a sink, the amount of CO_2 sequestered in growing forests and the pool of long-lived wood products must be larger than the amount of CO_2 released by decomposition and combustion.

The IPCC has identified several possible approaches for estimating the emissions and removals of CO_2 from forest harvesting and wood products. These approaches, presented in Chapter 3 of this report, differ in the way in which national emissions and removals are allocated to a country, and will usually give different output with respect to level and trend. In this section we will compare the approaches, using Norwegian data. The comparison is based on the approaches as described by Brown *et al.* (1998). The policy relevance of the approaches is not discussed.

It is important to distinguish between the terms *approach* and *method*. *Approach* is a conceptual framework for estimating emissions and removals of greenhouse gases in inventories. In practice that means how emissions are allocated to countries. Within each approach, there may be more than one possible estimation method. *Method* is the calculation framework within an approach for estimating emissions and removals of changes in stocks of greenhouse gases in inventories. Some methods may be relevant to several approaches.

Various methods can be used to estimate the storage in general and within a certain product group. A flux method and a "combined" method are in this report used for estimating the stock change of products in Norway. These estimation methods are described in Chapter 4.

The results (Chapter 5) reveal that the various approaches to some extent give different conclusions. This is due to complex changes in production and import. Some scenarios are shown in Chapter 6 where the effect of changes in single parameters are displayed (*e.g.* production and import).

Finally, in Chapter 7, the approaches are systematically evaluated from a statistical point of view.

3. Approaches

3.1. Description of the approaches

Four approaches for the estimation are discussed. The first one is the current approach in the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 1997). The others are outlined by Brown *et al.* (1998):

IPCC Guideline approach: Only emissions and removals related to forest stock change are considered. Changes in wood product stocks are not accounted for. Emissions from harvested wood are attributed to the year of production and the country of harvest, (harvest = roundwood production).

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

Stock-change approach: Net changes in carbon stocks in the forest and wood-products pool are estimated. *Stock changes* in forests and in wood products are accounted for in the *consuming* country where and when they occur.

Stock change = Stock change forest + stock change products
= (Forest growth – slash – roundwood production)
+ (Wood consumption – decomposition/combustion of wood consumed)

Production approach: *Stock changes* in forests and in wood products are accounted for in the *producing* country when they occur.

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

Atmospheric flow approach: *Emissions and removals* are accounted for where and when they occur. Emissions associated with carbon stocks that cross a boundary are transferred from one country's inventory to another's.

Atmospheric flow sink = Forest growth – slash – decomposition/combustion of wood consumed

3.2. Differences between the approaches

Although the atmospheric flow approach refers to *flow* (net emissions) and the others refer to *stock change*, the purpose of all definitions is to assign a *net removal/emission* of CO_2 from forests and forest products to each country. At the most advanced tiers (complexity levels), all approaches assign these removals when they really occur. Using the default methods, all approaches assign removals at the time of harvest. The difference between the approaches is rather *where* the removals are assigned, *i.e.*, to which country.

To identify the intrinsic differences, we note that the wood consumption in a country is given by the roundwood production and the import and export of wood products. The import and export should be summed over all product groups[1].

Wood consumption	*= Roundwood production + Import – Export*
	= Roundwood production – Net export

Inserting into the definition of the *stock change* sink and rearranging the terms, we can make the definitions easier to compare:

IPCC Guidelines	*Sink = Forest growth – slash – roundwood production*
Stock change	*Sink = Forest growth – slash – net export – decomposition/combustion of wood consumed*[2]
Production	*Sink = Forest growth – slash – decomposition/combustion of wood grown in country*
Atmospheric flow	*Sink = Forest growth – slash – decomposition/combustion of wood consumed*

or

IPCC Guidelines	*Sink = Stock change forest*
Stock change	*Sink = Stock change forest + stock change products*
Production	*Sink = Stock change forest + stock change domestic grown products*
Atmospheric flow	*Sink = Stock change forest + stock change products + net export*

The last set of definitions shows that the treatment of the stock change in the forests is similar in all approaches. The differences lie in the treatment of product stocks and of foreign trade in wood products. In particular, the difference between the stock change approach and the atmospheric flow approach is solely the treatment of the net export. The atmospheric flow sink equals the stock change sink *plus* the net export. Thus, countries with net export of wood products will be assigned a higher CO_2 sink with the atmospheric flow method than with the stock change method. In Norway, the stock change in forest and products is increasing (more carbon is stored), and is also expected to increase in the future. The net export may, however, have variable sign according to conjunctures and policies.

In the definition of the atmospheric flow approach it might look as if all the import is counted as emission. But it is important to notice that if part of the import goes to the product stock, for example import of building materials, this part will end up in the term "stock change products". See also the discussion in section 4.2.1.1 **Atmospheric flow approach**.

[1] If the product stock change is estimated at the level of primary products, then it is conceivable that the net export also should be calculated at this level. See section 4.2.1.1 **Atmospheric flow approach**.

[2] Stock change = Stock change forest + stock change products
= (Forest growth – slash – roundwood production)
+ (Wood consumption – decomposition/combustion of wood consumed)
= (Forest growth – slash – roundwood production)
+ (Roundwood production – net export – decomposition/combustion of wood consumed)
= Forest growth – slash – net export – decomposition/combustion of wood consumed)

The two sets of definitions show that in all approaches, the sink can be estimated using either an *emission* angle or a *stock change* angle. The two angles are complementary as all wood consumed goes either to stocks or emission. Some differences in results are intrinsic to the approaches as defined above. Other differences may occur because, among the approaches, different methods are used for estimating the quantities that appear in the definitions. Thus, we have to distinguish between the *approaches*, which focus on either stocks or emissions in order to assign sinks to countries, and the actual *estimation methods*, which can be based on either stocks or emissions depending on the availability of data (see Chapter 4). If all the quantities that appear in the definitions were estimated with the same methods, then the latter differences in results would disappear.

4. Estimation methods

4.1. Forest stock change

The forest stock change may be estimated in several ways, depending on which parts of the carbon stock to include: Only the trunk volume, or bark, branches, roots, soil carbon etc. However, the definition of the approaches shows that all approaches treat the forest stock change in the same manner. Thus, the method of estimation is irrelevant to the comparison of the approaches. The data for forest stock change used in this report are those reported by Norway to the UNFCCC. They use a biomass expansion factor to include bark and branches, but exclude soil carbon. The forest stock change is calculated by the following definition:

Stock change forest = Forest growth - slash - roundwood production

Data for forest growth are given in the forest inventory of the Norwegian Institute of Land Inventory (NIJOS). Slash data comes from the forest inventory (natural decay) and harvest statistics (silvicultural waste). Data for roundwood production comes from harvest statistics, supplemented with data on non-commercial harvest. Key estimation parameters are shown in Table 3.

Table 3. Parameters for estimating carbon stored in forest

	Unit	Spruce	Pine	Deciduous	Source
Natural decay	% of gross growth	6	6	10	Schøning (1992)
Harvest slash	% of reported harvest[1]	6	6	10	Schøning (1992)
Dry mass content[2]	tonnes/m^3	0.38	0.44	0.503	Lunnan *et al.* (1991)
Carbon content	% of dry mass	50	50	50	IPCC (1997)
Expansion factor[3]		1.9	1.9	1.9	IPCC (1997)

[1] Trunk volume only
[2] Before 1995 a dry mass content on 0.4367 tonnes/m^3 was used as a standard factor.
[3] To account for bark and branches

This report has not aimed at improving the estimation methodology for forest stock change.

4.2. Product stock change

For the estimation of the stock change of wood products different methods are possible. The final choice of method will depend on the data available in a particular country and the characteristics of a particular point of storage. The two main 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. In the stock method no flux data are used. The two methods give the same results if all data sources are complete, exact and consistent.

All the estimation methods can be of different complexity, from the simplest method used in the IPCC default approach, where the change in the wood-products pool is ignored, and to methods with higher complexity, higher tiers. In this report the flux estimation method is supposed to correspond with the tier 2 mentioned in Brown *et al.* (1998, Annex 2) (Section 4.2.1). It is also possible to combine the use of clux based and stock based estimation methods. This can be advantageous with respect to fully exploiting the availability of national data, as overall accuracy can be improved compared with using only stock or only flux based methods (Section 4.2.2). We present the result of using such a combined approach.

The flux method
In general the flux may be estimated as an inflow-outflow analysis or as a lifetime analysis. This may be done at the end-product level or at the intermediate product level. What is here called "the flux method" is based on Brown *et al.* (1998) in order to increase the comparability with other countries and be able to use the production approach[3]. Note that flux data also partly are applied in the combined method at a higher level of detail and using more exact data available at the national level.

The flux method used here is based on data from UN Food and Agriculture Organisation (FAO 2000) and factors for the rate of oxidation. It is a further development of the standard method recommended by IPCC (IPCC 1997). The methodology includes the four semi-products sawn wood, woodbased panels, other industrial roundwood and paper and paperboard. These four groups are considered to be a good estimation for all the woodbased products at this level in the production chain. Secondary products like furniture and books are not included. The reason is that the risk for double counting of the domestic woodbased product stock is too big if you try to count on all the different levels in the production chain.

To find the stock change sink within a country, the carbon stored in products and the carbon release from biomass going out of storage (assumed fraction retired annually) are calculated for all product groups. The annual carbon release is calculated from the total amount of biomass going out of storage and the carbon fraction. The stock change of products for one year is defined as the difference between the consumption in ktonnes C and the carbon release this year.

The first step for calculating the amount of biomass oxidised every year is to calculate the consumption, on the basis of production, import and export of the four wood-based product groups. The consumption for the four product groups is determined by the definition:

[3] The production approach cannot be estimated using the combined method.

Consumption (m^3) = Production (m^3) + Import (m^3) - Export (m^3)

The amount of biomass oxidised is then calculated from the consumption and fractions of storage and oxidation for the different products. Some of the commodities are oxidised in the inventory year, while others will be stored for shorter or longer periods. The methodology distinguishes between storage of less and more than 5 years. There is no distinction between different forms of oxidation.

In the second step we multiply with the fraction in use over 5 years and a biomass conversion factor to get the result in tonnes dry matter (for factors used, see Table 4). Finally we estimate the biomass retired annually for each product group by multiplying with the assumed fraction retired annually:

*Biomass retired annually = (consumption * fraction in use over 5 years * biomass conversion factor) * fraction retired annually*

This factor is the inverted lifetime assumption. Lifetimes used in the calculations are 1.2 years for paper and paperboard and 50 years for the other product groups. These assumptions of lifetimes should also include the time when the wood products are defined as waste, i. e. the total time until the carbon becomes oxidised. There were no such lifetime assumptions available, and the lifetimes used may be a bit too low considering that the waste period is included in the assumptions.

To calculate the total amount of biomass going out of storage in one year we add all the biomass oxidised in this actual year and in every single year throughout the product's lifetime, for all the four product groups. Annual FAO statistics on forest products are only available from 1961, and for earlier years we have used the 1961 value for the amount of biomass oxidised.

The annual carbon release is calculated from the total amount of biomass going out of storage and the carbon fraction, which is defined as 0.5. The stock change of products for one year is then calculated as the difference between the consumption in ktonnes C and the carbon release this year.

For the production approach the methodology differs from the two other approaches in how to count the consumption for a year. Here only the consumption of the commodities with domestic wood origin shall be included. The calculations are made with the assumption that the domestic part is the same for semi-processed products as for roundwood, which is 62%. The domestic part has been calculated by using the FAO data for 1998 (FAO 2000) for production and net import of roundwood in Norway.

Table 4. Factors used for calculating the biomass retired

	Sawn wood		Woodbased panels	Other industrial roundwood		Paper and paperboard
	Coniferous	Non-coniferous	Aggregate	Coniferous	Non-coniferous	Aggregate
Fraction in use over 5 years	0.8	0.8	0.9	0.7	0.7	1[4]
Fraction retired annually	0.02	0.02	0.02	0.02	0.02	0.83
Biomass conversion factor	0.42	0.47	0.52	0.56	0.64	0.95

Data choice

The accounting can focus on various parts of the production chain. Timber is harvested and traded, converted to building materials and pulp and finally processed to end products. In principle, this makes no difference as long as all products are counted as production, export and import. The advantage of counting unprocessed products is that the statistics are easily available and of high quality and that the risk of double counting is small. The disadvantage is that the fate of the product is less precisely known. The method suggested by Brown *et al.* (1998) is not clear at this point; our interpretation of the term *stock change products* is that it counts semi-processed products: paper and paper board, sawn wood, wood-based panels and other industrial roundwood. Export and import are also counted at this level. This, however, gives a misleading picture if products are exported as final processed products (e.g. furniture).

One example: The stock is counted at the level of woodbased panels. It is assumed that carbon in such panels is stored for a long time. Import and export of wood panels is accounted for according to the approach considered. However, these wood panels may be used in producing furniture or prefabricated houses that are exported. This export will not be counted in any of the approaches if the estimation is based on the flux method. Products exported at this level are apparently stored in the producing country.

These types of products make up only a small part of Norwegian foreign trade, but may contribute to the storage estimate. Net import of furniture and prefabricated buildings was 23.3 ktonnes carbon in 1993, printing products was 14 ktonnes. Countries trade products at different levels, consequently, this question may be important to resolve. The consequences of this way of counting export and import will be different for the different approaches as described below.

Stock change approach

The sink is defined as the stock change forest and stock change products. If the stock change of products is estimated at the level of intermediate products, the stock (or sink) will not

[4] This may look strange, but multiplied by the fraction retired annually it gives an estimate of the biomass going out of the paper stock each year, with the estimated lifetime 1.2 years.

resemble the "real". For example, as Norway is a net importer of secondary products, the sink will be too low using the flux method only considering intermediate products.

Production approach
This approach explicitly only includes domestic grown products. This means that in this approach we do not take import and export into the account, we only count the amount of produced semi-products with domestic wood origin. Products exported at all levels are therefore accounted for in the producing country, and there will be no false counting.

Atmospheric flow approach
This sink is dependent on the decomposition of the wood consumed (which again is equal to stock change of products + net export). The term stock change of products is the same as in the stock change approach and will have the same potential errors. If the net export is calculated using product groups at all production levels, then the total sink estimate will also have these errors. That is, import of secondary products such as books or furniture will be accounted as 100% emissions in the year of import.

In our estimation of the net export term commodities at all levels are counted. For the atmospheric flow default method, Brown *et al.* (1998) suggests that *only* data on roundwood, fuelwood and charcoal production should be used. It is unclear whether this also applies to foreign trade. It is our opinion that for consistency, *all* foreign trade should be included in order to account correctly. Norway is a net importer at the level of roundwood etc., and at this level, the atmospheric flow default sink for 1993 is only 3539 ktonnes C. This value can be compared with the value 4109 ktonnes C in Table 6, when net export is estimated using commodities at all levels.

Note that in our way of counting in the atmospheric flow approach, all the trade of wood based products at all levels is included in the *net export* term, and counted as 100% emission in the year of import. But the import and export of semi-processed products (sawn wood etc.) are also accounted for in the estimation of the term *product stock change,* and here the lifetime for the product in the product stock is taken into consideration for the calculation of when the emission takes place.

The combined method
The combined method is developed at Statistics Norway (Gjesdal *et al.* 1996). This method uses both flux data and stock data, depending on the availability of adequate data. We have mainly used the same estimation methods as in earlier estimations in Gjesdal *et al.* (1996).

The methodology and factors used are presented in detail in Appendix 1, but we will here make a short description of the methods used for estimating the carbon stored in the four main product groups paper and paper products, furniture, buildings and wood and paper disposed of in landfills.

Carbon storage in *paper and paper products* is calculated with a flux method based on consumption and lifetime data.

*Accumulated = Consumption * Average lifetime*

The method for estimating the amount of carbon in the stock of *buildings* is based on stock data, using direct estimates of the total building pool. The reason for choosing stock data here is that due to uncertainty in the fluxes and the very long lifetimes of buildings, the stock data are considered more reliable.

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

Furniture is also estimated with a stock data method. The carbon stock is estimated by the expression:

*C stock = Total utility floor space * furniture, kg/m^2 * C content in wood*

For both buildings and furniture we infer the net accumulation from changes in the total storage.

The calculation of carbon stored in *waste* are estimated with a flux data method, using data from the methane emission model (Frøiland Jensen *et al.* 1999).

Yearly accumulation of C = C in waste disposed of - C in emissions from decomposition (CO_2 + CH_4)

The total carbon stored in waste is found by adding yearly accumulation from the year 1945.

Data choice

The combined method calculates the actual, physical emissions and storage within the borders of a country, regardless of country of production or type of product. The combined method is intended to use the available national statistics as much as possible for estimating the stock of carbon in products and waste.

This method includes data on both stocks and flows. Estimation method is chosen for each product group depending on the best and most reliable data available. By choosing the best available estimation method for each actual product group, the combined method will end up with the best estimation for the carbon content in wood products in Norway.

The storage sources included in the study are paper and paper products, furniture, buildings and wood and paper disposed of in landfills. In earlier studies (Gjesdal *et al.* 1996, Flugsrud *et al.* 1998), all the commodity groups in the national external trade statistics (Statistics Norway, annual report) and manufacturing statistics (Statistics Norway, annual report) were reviewed, and it was concluded that all the main wood products are included in these four categories. Waste is here seen as an own stock, which means that the mentioned lifetimes for the products only include the time from production until the product is defined as waste, and not the whole time until the carbon is oxidised. The methodology counts the actual end products.

The combined method is not suitable in the production approach, as it is unable to track the origin of wood and estimate the storage abroad of domestically grown wood.

The results of the combined method are given in Appendix 1, where the carbon stock for 1990 and 1998 have been estimated. The total carbon stock is estimated to nearly 17 million tonnes in 1998. Compared to 1990 the stock has increased with about 10 per cent. Waste in landfills and wood materials in buildings are the main storage sources, contributing to respectively 43 and 50 per cent of the 1998 reservoir. The total stock change is estimated to 231 ktonnes in 1990, and respectively 162 and 183 ktonnes in 1993 and 1998.

A comparison of the methods

In the combined method, we used flux methods for paper and waste, and stock methods for buildings and furniture. In this section we will discuss the reasoning behind these choices. In general, data on the inflow were available for all stocks. Lifetime data were also available, but of variable quality. Outflow and stock data were available only for some stocks.

Paper. No data on the paper product stock were available. This stock does not seem suitable for stock methods. Firstly, it is very difficult to obtain reliable data on the paper stock. Secondly, for stocks with short lifetimes the stock changes are large relative to the stock, and the stock may change rapidly.

The stock change was estimated by two alternative methods: an ordinary inflow-outflow analysis using production and waste data, and a lifetime analysis (Gjesdal *et al.*1996). In the inflow-outflow analysis, the stock change is a relatively small difference between large inflows and outflows. In this situation, the stock change is very vulnerable to even small errors in the flux data. 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 the lifetime analysis was selected for the combined method (section 0, appendix 1). A lifetime analysis was also used in the flux method (section 0). In this case, the lifetime included a period as waste.

Buildings. For the building stock, both inflow data at several levels, outflow data, stock data and lifetimes were available. However, all input data had some shortcomings.

- Inflow at the level of sawn wood and other input materials: Total material input well known, but the losses before entering the stock is poorly known.
- Inflow at the level of construction: Construction (number of dwellings, floor space etc.) well known, but amount of wood per unit is uncertain. Materials for rehabilitation poorly known.
- Outflow: Demolition statistics has been improved, but is still uncertain.
- Total stock: Total amount of buildings (number of dwellings, floor space etc.) well known, but amount of wood per unit is uncertain.
- Lifetime: Suggested values from the literature vary widely (<50 – 200 years).

In the flux method, a lifetime analysis was used. However, the lifetime value is highly uncertain. With longer lifetimes, we also get increasing uncertainty from estimating the amount of wood in old buildings.

The new demolition statistics (Rønningen 2000) improves the basis for performing an inflow-outflow analysis. These data were not available to Gjesdal *et al.*(1996). However, more work is needed to determine exactly the inflow that corresponds to the demolition outflow. For example, we need to know the losses between reported production and the materials that eventually are used in the buildings.

A major advantage of stock methods over flux methods is that the accumulated stock change over longer periods can be estimated with less uncertainty. With the flux methods, there is usually no gain in precision from longer periods. For these reasons, we chose a stock method for buildings.

Furniture. This is a minor stock with very uncertain data. It is closely related to the building stock. For simplicity, we chose a stock method with a single conversion factor from the building stock data.

Waste. Waste landfills can be treated as a separate stock, or it can be included in the other stocks. In the latter case one has to use a flux method with inflow data and lifetime values for the other stocks. The lifetimes have to incorporate the period as waste. This approach was used in the flux method described in section 0.

If the other stocks are handled with stock methods or with inflow-outflow flux methods, then waste has to be treated as a separate stock. If the stocks are estimated with a lifetime analysis, the lifetime may or may not include the time in landfills. A lifetime including landfills is supposed to be more uncertain. Direct measurements of the total stock of wood carbon in landfills are not available, and are not likely to be so in the future. Nor are direct measurements of the outflow of CO_2 and CH_4 from landfills likely to be available. Both the emissions and the stock change of waste in the combined method were calculated basically as a lifetime analysis.

Both approaches, inclusion in lifetimes or separate stock, are highly uncertain. Lifetimes including a period as waste have to be based partly on the same data as are used in the separate analysis of the waste stock. We find it hard to say which method implies most uncertainty. The lifetime approach is feasible even for countries with poorly developed waste statistics. However, when adequate waste statistics are available, we believe that the separate treatment is easier to understand and more easily adapted to national conditions.

Conclusions. In general, we find that inflow-outflow flux methods are sensitive to errors in the input, in particular when the flow is large relative to the stock change. They are also prone to systematic errors that cannot be corrected by long-term controls.

Lifetime flux methods rely heavily on the quality of the lifetime values. However, use of lifetimes makes it possible to use the results from high quality studies in other nations, selected districts etc. Lifetime analyses are more robust with respect to errors in the input than inflow-outflow analyses.

Stock methods are only possible for some of the product stocks. The main uncertainty is in delimitation and conversion factors, which contribute to level uncertainty. However, the quality of trend estimates can be improved by using long-term averages.

For further discussions on the merits of flux and stock methods we refer to the appendix on the stock change approach in Brown *et al.* (1998).

4.3. The emission orientated method

Estimating emissions directly

Stock and flux methods are both used for estimating the *stock change* term in the definition of CO_2 sinks. However, the sinks can also be estimated from an *emission* angle, as shown in section 3.2. For this method we need estimates of all forms of decomposition and combustion of wood materials in a country. The following table shows an estimate of emission sources in Norway.

Table 5. CO_2 emissions from combustion and decomposition of wood materials. Norway 1998, 1000 tonnes C.

Source	Emissions
Total	1 500
Wood materials used for energy consumption	1 115
Charcoal used as feedstock	72
Wood chips used as feedstock	51
Waste incineration	58
Landfill gas	198
Fires in buildings	2
Natural decay of buildings and materials	5

Source: Gjesdal *et al.* (1996, 1998), updated.

Comparison of direct emissions with the combined stock/flux method
In principle, the direct emission method should give the same result for a given approach as the methods using stock changes. In practice some of the estimates will have large uncertainties. Table 5 shows a bottom-up estimate of 1998 emissions at 1500 ktonnes C. However, the emissions may also be estimated indirectly using the definition of the stock change approach in section 3.1 and the first equation in section 3.2:

Decomposition/combustion of wood consumption
= *Wood consumption - Stock change products*
= *Roundwood production - Net export - Stock change products*

Using this method and the data in Table 8, the emission is estimated to be 1952 ktonnes C. The difference between the two estimates, 452 ktonnes C, is carbon inflow which could not be accounted for as either emission or stock change.

Handling of discrepancies between the methods
It is likely that both emissions and stock change are underestimated. We have not been able to identify all likely sources of errors (Flugsrud *et al.* 1998). As such discrepancies are likely to occur in most countries, it is important to realise how this situation is handled by the different methods.

The important point here is that when the CO_2 sink is estimated with an emission angle (first set of sink definitions in section 3.2), the stock change is implicitly determined as *Roundwood production – Net export – emissions*. When the CO_2 sink is estimated with a stock change angle (second set of sink definitions in section 3.2), the emissions are implicitly determined as *Roundwood production – Net export – Stock change products.* If the directly estimated term is too low, then the implicitly determined term gets too high. This means that if the direct estimates of both emissions and stock change are too low, as seems to be the case for Norway, then CO_2 sinks will be higher when using the emission angle.

When estimates for both angles are available one can make more well-founded assumptions about the uncertainties. In the Norwegian data, the unexplained discrepancy is more than three times the estimated stock change (183 ktonnes C). We find it very unlikely that our estimate of the stock change contains errors of this order. The estimated emissions (1500 ktonnes C) are much larger than the stock change. We find it more likely that the emissions were underestimated, although we have not been able to find such “missing emissions”.

Our conclusion is 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.

5. Results for Norway

5.1. Results based on the default methods

The main aim with this report is to present the results for the approaches estimated with the combined and the flux method. At this early stage of the development of the different estimation methods, also the results of the default method can be of interest, as a base for comparisons with other countries. It is also illustrative for highlighting the gain by moving to higher tier methods. The IPCC Guideline approach treats wood products as emissions in the year of harvest and thus sets the product stock equal to zero.

In the default method of all approaches, product stock changes are ignored. In this case the differences between the stock change, production, and IPCC Guidelines approaches vanish. Only the atmospheric flow approach differs, due to the net export term.

Table 6. Carbon balance sheet for forests and forest products, default methods. Norway 1993 and 1998, 1000 tonnes C

	1993	**1998**	**Change**	
Forest stock:			**Absolute**	Relative
Forest growth	8 852	9 133	281	3 %
Slash (incl. Natural decay)[5]	2 915	2 513	-401	-14 %
Roundwood production	2 254	1 823	-431	-19 %
Stock change forest	**3 685**	**4 797**	**1 112**	**30 %**
Net export	425	-312	-737	-173 %
Forest products	**0**	**0**	**-**	**-**
Sinks:				
IPCC guidelines/stock change/production approach	3 685	4 797	1 112	30 %
Athmospheric flow, default	4 109	4 485	375	9%

The major change in the balance from 1993 to 1998 is that the domestic roundwood production has declined, but this has been more than offset by an increased roundwood import, especially to the pulp and paper industry. When the imported pulpwood is re-exported as pulp or paper, there is a considerable loss of carbon, consisting of waste products and emissions from the production process.

The four approaches give conflicting accounts of this situation, with respect to both level and trend. The first three approaches only regard the increase in the forest stock change, and Norway is credited with an increased sink. In the atmospheric flow approach, the net export of wood and wood products in 1993 results in a higher net sink than in the other approaches. However, the large change in net export makes the increase in the sink lower in the atmospheric flow approach than in the other approaches over the period.

[5] The allocation of a scaling factor to account for biomass in addition to the actual timber is done by including the estimation of all biomass originating from bark, roots and branches in the term for slash. Roundwood production thus only includes commercial timber. This is done throughout the report. In the national reporting to the UNFCCC, the scaling factor is included in the overall figure for felling.

5.2. Results based on the combined method

As the combined method is considered to be the most reliable, this can be seen as the most accurate result for Norway. A disadvantage with the combined method, though, is that there are problems getting a result for the production approach. The reason is lack of data for calculating the stock change for all domestic grown products in Norway. The stock changes for the main product groups are shown in Table 7. Carbon balance sheets for forest stocks and forest products stocks are shown in Table 8 for the stock change approach and the atmospheric flow approach. For the IPCC guidelines approach, results will be the same as those presented in Table 6.

Table 7. Stock change of products. Norway 1993 and 1998. 1000 tonnes C.

	Stock change of products	
	1993	1998
Total	162	183
Buildings	65	88
Furniture	5	10
Paper	9	-14
Waste	83	100

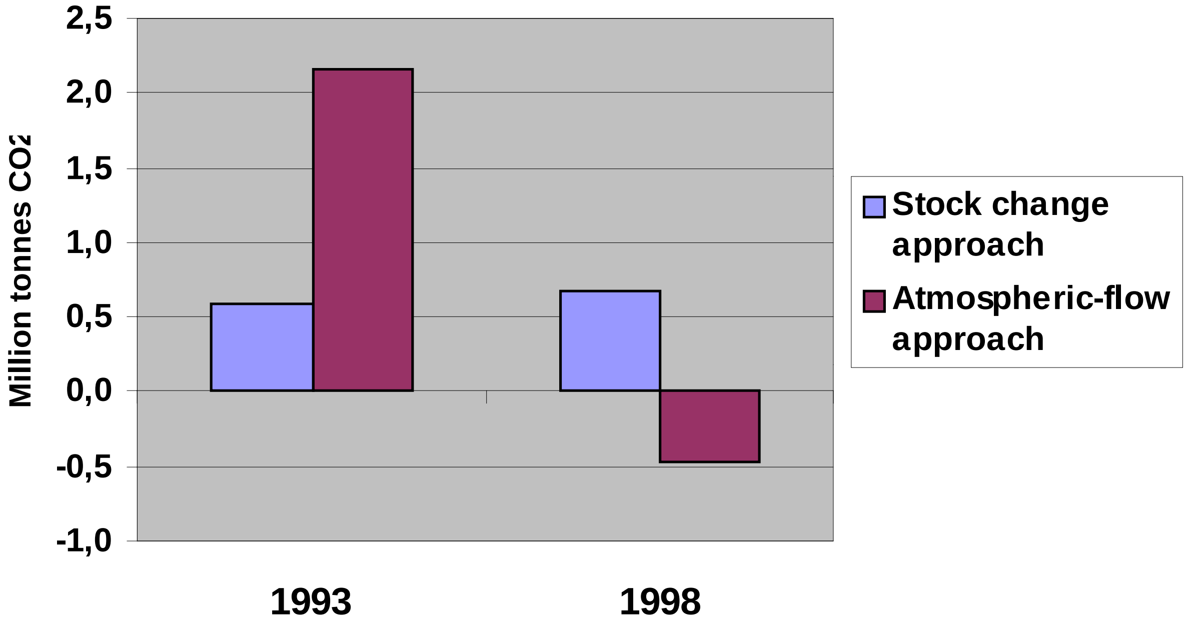
Table 8. Carbon balance sheet for forests and forest products, combined method. Norway 1993 and 1998, 1000 tonnes C

	1993		1998		Change
	Stock change approach	Atmospheric flow approach	Stock change approach	Atmospheric flow approach	Relative
Forest stock:					
Forest growth	8 852	8 852	9 133	9 133	3%
Slash incl. Natural decay	2 915	2 915	2 513	2 513	-14%
Roundwood production	2 254	2 254	1 823	1 823	-19%
Net removal in forest	**3 685**	**3 685**	**4 797**	**4 797**	**30%**
Forest products:					
Export of wood products		1 311		1 445	
Import of wood products		886		1 757	
Stock change products	162	162	183	183	13%
Net removal, forest products	**162**	**587**	**183**	**- 129**	
Total net removal	**3 847**	**4 272**	**4 979**	**4 668**	

The results in Table 8 show that which approach that gives the highest sink to Norway has changed during these five years. In 1993 the atmospheric flow approach gave the highest CO_2 sink, but in 1998 it was surpassed by the stock change approach, due to the change in net export. The term *stock change of products* is small compared to the other parameters and the trends between the approaches have not changed from the results in the default method.

We also see that the inclusion of the net export in the atmospheric flow approach makes estimation of the wood products sinks sensitive to variations in export or import of wood products (see figure 2).

Figure 2. CO_2 stored in wood products in Norway in 1993 and 1998. Combined stock/flux data method



The combined method is assumed to give the best estimate of the stock change for Norway, if yearly data are available. In some parts of the calculations we have used the mean value over some years, and with this technique we cannot catch the fluctuation for one single year. Despite this insensitivity to fluctuations this method is still considered to be the most reliable in calculating the stock change of products.

5.3. Results based on the flux method

An advantage of the flux method is that it is in line with the method description in Brown *et al.* (1998). In this method it is also possible to make an estimate for the stock change of domestic grown products, mainly because here we are only looking on the flows of semi-processed products.

Table 9. Stock change of products and stock change of domestic grown products. Norway 1993 and 1998. 1000 tonnes C.

	Stock change of products		Stock change of domestic grown products	
	1993	1998	1993	1998
Total	-4	166	62	81
Sawn wood	4	138	41	57
Woodbased panels	-10	25	2	17
Other industrial roundwood	-6	-5	-3	-3
Paper and paperboard	8	8	23	10

Table 10. Carbon balance sheets for forests and forest products, flux method. Norway 1993 and 1998, 1000 tonnes C

	1993			1998		
	Stock change approach	Production approach	Atmosph. flow approach	Stock change approach	Production approach	Atmosph. flow approach
Forest stock:						
Forest growth	8 852	8 852	8 852	9 133	9 133	9 133
Slash incl. natural decay	2 915	2 915	2 915	2 513	2 513	2 513
Roundwood production	2 254	2 254	2 254	1 823	1 823	1 823
Net removal in forest	**3 685**	**3 685**	**3 685**	**4 797**	**4 797**	**4 797**
Forest products:						
Export of wood products			1 311			1 445
Import of wood products			886			1 757
Stock change:						
All products	-4	-4	-4	166	166	166
Domestig grown	62	62	62	81	81	81
Net removal, forest products	**-4**	**62**	**421**	**166**	**81**	**-146**
Total net removal	**3 681**	**3 747**	**4 106**	**4 962**	**4 877**	**4 651**

The flux method gives similar trend results as the combined method considering the change in the sink between the two years calculated with the stock change and atmospheric flow approach, but the CO_2 sink values are slightly lower for both approaches. The production approach ends up with a sink that is intermediate between the two other approaches for both years. If we look at the calculated stock change of products we can see that it differs from the results in the combined method. One explanation for this is that we have used mean values for the calculations in the combined method. The difference was bigger in 1993 because the use of wood products was unusually low this year, which is perceptible in the result for the flux method.

As mentioned before, the lifetime assumption used for wood based products in the calculations is 50 years. This might be a too low assumption, considering the fact that the period that the wood products are defined as waste shall be included in the flux method. Also for paper and paperboard the lifetime assumption on 1.2 years might be too low, when the waste period for paper is included. For 1993 the sink is also calculated with a lifetime assumption on 100 years for wood based products, and the results are shown in Table 11. When the lifetime was doubled the increase in the sink did not exceed 1.5% for any of the approaches, which can be interpreted as that the lifetime assumption is of minor priority for the end result.

Table 11. Sinks with different estimates of the lifetimes for the wood based products, 1993.

	Lifetime	
	50 years	100 years
Sinks:		
IPCC guidelines	3 685	3 685
Stock change	3 681	3 736
Production	3 747	3 775
Atmospheric flow	4 106	4 160

5.4. Result summary

Table 12 shows a summary of the main results in this report. The sink is increasing when the estimation methods of higher tiers are used. The results for the stock change and the atmospheric flow approaches have good agreements for the combined method and the flux method in 1998, but in 1993 there is a variation on 0.166 million tonnes between the methods. Explanations for this difference are to be found in the calculation of the stock change of products, as mentioned in section 5.3.

Table 12. Stock change of products for the different approaches using different estimation methods. Norway 1993 and 1998, 1000 tonnes C

	1993			1998		
	Stock change approach	Production approach	Atmospheric flow approach	Stock change approach	Production approach	Atmospheric flow approach
Stock change in harvested wood products:						
Combined method	162	n.a.	587	183	n.a.	- 129
Flux method	-4	62	421	166	81	-146
Total net removal:						
Combined method	3 847	n.a.	4 272	4 979	n.a.	4 668
Flux method	3 681	3 747	4 106	4 962	4 877	4 651

6. Scenarios for changes in harvest and net export

The change from 1993 to 1998 in Table 6, Table 8 and Table 10 is a result of several trends, some independent and some interconnected. This makes it difficult to illustrate the effects of a single trend. In the following examples, we do some simulated changes to the 1998 data for the combined method in order to make the effects more evident.

In the *first* example, we assume that 100 000 tonnes of domestic roundwood production is replaced by imports, with no changes in production, consumption, or export.

Table 13. Carbon balance sheet for forests and forest products. Sample change 1: Domestic harvest replaced by imports. 1000 tonnes C

	1998	Sample	Change	
			Absolute	Relative
Forest growth	9 133	9 133	-	0 %
Slash (incl. natural decay)	2 513	2 423	-90	-4 %
Roundwood production	1 823	1 723	-100	-5 %
Stock change forest	4 797	4 987	190	4 %
Net export	-312	-412	-100	-32 %
Stock change products	183	183	-	0 %
Sinks:				
IPCC guidelines	4 797	4 987	190	4 %
Stock change	4 979	5 169	190	4 %
Production	n.a.	n.a.	n.a.	n.a.
Atmospheric flow	4 668	4 758	90	2 %

The forest stock change increases due to the reduced harvest. This leads to an increase in the sink estimate for the IPCC guideline, the stock change and the production approaches. In the atmospheric flow approach, the reduced harvest is partly compensated by the increase in import, giving a smaller increase in the sink estimate. The slash is reduced when the harvest is reduced. The effect is larger forest stock growth and smaller total emissions.

In the *second* example, we again assume that the import is increased by 100 000 tonnes, but now without reduction in domestic roundwood production. Furthermore, we assume that the increase goes to domestic emissions and product stock change, *i.e.*, no re-export.

Table 14. Carbon balance sheet for forests and forest products. Sample change 2: Increased import. 1000 tonnes C

	1998	Sample	Change	
			Absolute	Relative
Forest growth	9 133	9 133	-	0 %
Slash (incl. natural decay)	2 513	2 513	-	0 %
Roundwood production	1 823	1 823	-	0 %
Stock change forest	4 797	4 797	-	0 %
Net export	-312	-412	-100	-32 %
Stock change products	183	193	10	5 %
Sinks:				
IPCC guidelines	4 797	4 797	-	0 %
Stock change	4 979	4 989	10	0 %
Production	n.a.	n.a.	n.a.	n.a.
Atmospheric flow	4 668	4 578	-90	-2 %

In this case, there is no change in the forest stock change. The stock change approach gives a minor increase in the sink because of the increase in the product stock change. The atmospheric flow approach, on the other hand, gives a reduction in the sink because of the increased import. In this approach, the increased inflow of wood is assumed to give increased emissions.

The production approach sink would not change because the increase in product stock change would be accounted for in the exporting country.

In the *third* example, we assume that the harvest is increased by 100 000 tonnes, with no change in import. As in example 2, we assume that the increase goes to domestic emissions and product stock change, *i.e.* no change in export.

Table 15. Carbon balance sheet for forests and forest products. Sample change 3: Increased harvest. 1000 tonnes C

	1998	Sample	Change	
			Absolute	Relative
Forest growth	9 133	9 133	-	0 %
Slash (incl. natural decay)	2 513	2 603	90	4 %
Roundwood production	1 823	1 923	100	5 %
Stock change forest	4 797	4 607	-190	-4 %
Net export	-312	-312	-	0 %
Stock change products	183	193	10	5 %
Sinks:				
IPCC guidelines	4 797	4 607	-190	-4 %
Stock change	4 979	4 799	-180	-4 %
Production	n.a.	n.a.	n.a.	n.a.
Atmospheric flow	4 668	4 488	-180	-4 %

In this example there is no change in the foreign trade. All changes occur within the country. This situation is handled in the same manner for both the stock change approach and the atmospheric flow approach. Whether one looks at the reduction in forest stock change or the increase in emissions, the result is the same.

7. Evaluation of the approaches

The criteria used for evaluating the usage of different approaches and methods for estimating the net emission of CO_2 from harvested wood products in Norway are the criteria outlined in Brown *et al.* (1998): Feasibility, accuracy and policy relevance. We will here focus on an evaluation from a statistical point of view.

7.1. Feasibility

Feasibility implies that all data are available and we also interpret that the methods are transparent.

As described, to a large extent the same methods (and data) can be used for the atmospheric flow and stock change approach. The atmospheric flow approach requires addition of a term concerning net import. This, however is an area where data are easily available from the national external trade statistics. With respect to transparency, however, the atmospheric flow approach can be considered as less intuitive than the stock change approach.

The production approach, on the other hand, requires data on storage of wood products 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.

Data needed for the flux method in all approaches are easily available in FAO (United Nations Food and Agriculture Organisation) statistics, where data for production, export and import of semi-processed wood products from 1961 are given. For the production approach only FAO data for the production of semi-processed products are being used. For this approach stock data are required for all countries to which products are exported. This data would be very difficult and expensive to collect, and in our calculations we avoided this problem by assuming that the part of the produced semi-processed wood products with wood origin in Norway are the same as the part of roundwood in Norway that is harvested in Norwegian forests.

For the combined method the data for calculating the total carbon stock in wood products are found in different statistical sources for the different carbon stocks. Many different sources make the data collection more expensive and difficult. But as long as the needed data already are produced for other purposes, the cost and time uses for the collection are reasonable. For the combined method the calculations for the production approach become impossible due to the problems with calculating the changes in the stocks of all the exported wood products in different countries.

In general all methods and approaches will need a detailed documentation in order to be transparent.

7.2. Accuracy of approaches

The rule is that the greater the number of assumptions, the larger the uncertainty of the emission estimate. A higher complexity often gives an increase in the number of assumptions. For the atmospheric flow approach the net export is an extra term in the calculation of the sink compared to the other approaches, and causes in principle higher uncertainty. As the additional term is quite well known, we would, however, rank these two approaches to have approximately the same uncertainty. For the production approach the way that domestic wood products is calculated is a source of quite high additional uncertainty. To reduce this uncertainty would require an international reporting system tracking flows of wood products.

The uncertainty in the forest stock change used in all the approaches lies mainly in the growth per cent, unregistered felling and the expansion factor. The error-limit for the net carbon stored in trunk, cortex excluded, is maximum 30%. The uncertainty in the expansion factor for calculation from trunk volume to total biomass is probably higher. The overall uncertainty can be of the order 5-10 million tonnes of CO_2[6].

When it comes to the stock change of products and the two different estimation methods there, both methods include a number of assumed parameters. Parameters in the flux method with a high uncertainty are the assumptions of the lifetimes for the different products, particularly as the time in landfills is to be included, and these time estimations are clearly very rough at this level of detail. The fact that FAO data are given only from 1961 is also a source of uncertainty, especially for the calculations of the yearly carbon-output from the building stock, where the consumption rate in 1961 is used for all the previous years too, which is a questionable assumption. The error bar around these data is about ± 10-15 % for OECD countries (Brown *et al.* 1998), but the lifetime uncertainty will dominate.

The uncertainty in the combined method is mainly found in the factor for calculating the wood amount per building, and in the calculations of the stock change in waste. The estimation error is probably not exceeding a factor 2 up or down, and is probably much smaller. This gives an uncertainty in the stock change on maximum 0.6-0.7 million tonnes CO_2. As mentioned in section 4.3.2 the gap between consumption and estimated sink and emissions are 452 ktonnes carbon. This can be regarded as an upper limit for the uncertainty, but we believe that much of this uncertainty lies in the CO_2 estimation.

The uncertainty of CO_2 estimates in typical high quality inventories is less than 5 %, and the overall uncertainty in GWP weighted emissions are 15-20 % (Rypdal and Winiwarter 2001). Adding LUCF will clearly increase this uncertainty. All approaches for estimating storage in wood products will add uncertainty to the current IPCC approach, but only marginally compared to LUCF itself.

7.3. Relevance to the reporting needs of the UNFCCC and the Kyoto protocol

The final decision on approaches and inclusion in national total emissions when reporting to the Kyoto protocol is finally a political question. In general, inventories should be accurate, consistent, comparable and transparent. Accuracy and transparency have been discussed

[6] Including soil carbon, the uncertainty would increase.

above. All the approaches are consistent by themselves. However, consistency can be a problem with respect to inter-country comparisons and between sources.

In general the stock change approach mostly resembles the estimation method used for other sources. It says that the national responsibility is the emissions from the national territory. Accounting of emissions after export does not appear in any of the higher tiered methodologies. This approach can also be scaled down to smaller geographical areas (even to a project level).

The mentioned methodological problems with the production approach can be a problem both for consistency and comparability. In general, however, the large number of assumptions required for all approaches can cause problems with both consistency and comparability.

7.4. Relevance to the national policies

As illustrated in Chapter 6, the various approaches will give different incentives to national policies with respect to import and export. It is finally a political decision what is most appropriate.

Most illustrative is perhaps how the different approaches react on the use 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 the 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.

The atmospheric flow approach can promote deforestation, because if wood from deforestation is exported, the products are accounted as removal. For the other approaches the net carbon source is accounted for in the country where deforestation occurs (Brown *et al.* 1998).

The approaches differ in the allocation of imports and exports of wood products, which leads to a difference in incentives for trade. The atmospheric flow approach would give incentives to producing countries to enhance their export of wood products. For the production approach there are less incentives to import and more incentives to export long-lived sustainably grown wood products than for the stock change approach. That is because the production approach counts the accumulation of long-lived products in the country where the wood was grown, and the stock change approach in the country where the wood products are in use.

The production approach may not provide an incentive to a consuming 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.* 1998).

Appendix 1. Carbon stored in wood products in Norway, estimated with the combined method

Summary

In the calculation of carbon stock, four main carbon storage sources are considered: 1) paper and paper products, 2) buildings, 3) furniture and 4) paper and wood products in landfills. We have mainly used the same estimation methods as in earlier estimations in Gjesdal *et al*. (1996).

The total carbon stock is estimated to nearly 17 million tonnes in 1998. Compared to 1990 the stock has increased with about 10 per cent. Waste in landfills and wood materials in buildings are the main storage sources, contributing to respectively 43 and 50 per cent of the 1998 stock. The total stock change is estimated to 231 ktonnes in 1990, and respectively 162 and 183 ktonnes in 1993 and 1998.

Compared to previous calculations (Gjesdal *et al*. 1996), the estimated storage in landfills is about seven times higher. This is mainly due to lower estimates of emissions from decomposition given by the new methane emission model. But also higher estimates of waste disposed of before 1990 and accumulations of waste back to 1945 contribute to larger total carbon reservoir in landfills compared to the previous results. The estimates of carbon accumulation and storage in landfills are rather sensitive to the assumption of how large fraction of the deposited carbon that is decomposed. Both the estimates of carbon disposed of on landfills and the fraction of decomposed carbon should be investigated further to improve the quality of estimations.

Projections based on the economic development and data from the methane emission model give further increase of the carbon stock. In 2010 the stock is expected to be 2.3 million tonnes or almost 14 per cent higher than in 1998.

Introduction

According to the Kyoto protocol, carbon stored in wood products might be included in the national accounts of sources and sinks of CO_2 emissions. In this work we estimate the total stock of carbon stored in wood products in 1990 and 1998. The calculations are mainly based on the preferred approaches in previous calculations given in Gjesdal *et al*. (1996), partly due to time constraints. The storage sources included are paper and paper products, furniture, buildings and wood and paper disposed of in landfills. Textiles, leather etc. which were included in previous calculations (Gjesdal *et al*. 1996) are not considered. Projections of the carbon stock for the period 2000 - 2020 based on the assumptions given in Gjesdal *et al*. (1998) and the methane emission model (Frøiland Jensen *et al*.1999) are also presented.

Methodology and results

Paper

Methodology

The paper storage is calculated based on consumption and lifetime data similar to previous calculations (Gjesdal *et al*. 1996). Consumption of paper is given by the formula:

Consumption = Import - Export + Production - Feedstock

To avoid double counting of production, only production of primary paper is counted. For import and export all paper and paper products are counted.

A simplified estimation of paper storage is given by:

Accumulated = Consumption · Average lifetime

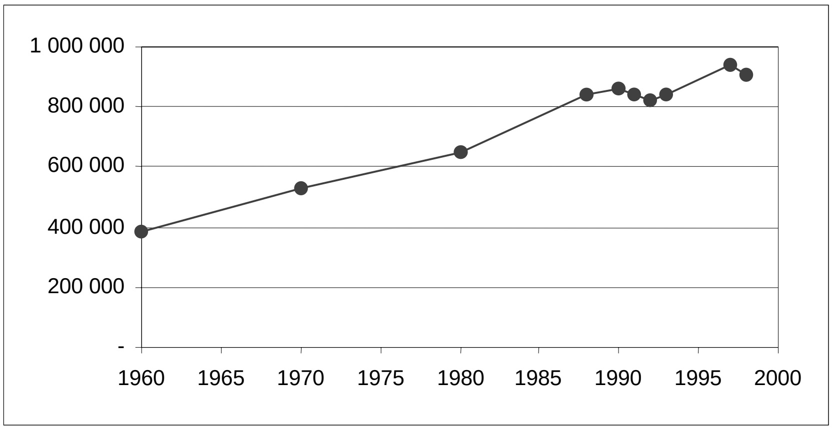
The lifetime for different paper products is based on data from Pingoud *et al*. (1996). In the period from 1960 to 1993 the average lifetimes were found to be in the range 1.16 - 1.27. For 1997 and 1998 the average lifetimes were approximately 1.28 and 1.31. However, the distribution of primary products as feedstock for secondary products is uncertain, so we still choose to use an average lifetime of 1.2 for all years.

Production data are obtained from Statistics Norway's annual industry survey, while the annual external trade statistics gives data on import and export. For a few products in the industry survey the production is given by value only and not by weight. In those cases the production volume is estimated from the production value and the relationship between export and value for the same products given in the external trade statistics.

Results

The consumption of paper in Norway was rather stable from 1988 to 1993 (Gjesdal *et al*. 1996), but increased in the period from 1993 to 1998 (Figure 3).

Figure 3. Consumption of paper in Norway 1960-1998. tonnes



Source: Gjesdal *et al.* (1996) for the years 1960 -1993, updated to 1998.

Table 16 gives the paper storage for 1990 and 1998 for an average lifetime of 1.2. Also shown are the results with lower and higher lifetime estimates.

Table 16. Paper storage based on different lifetime data. 1000 tonnes C.

	Average lifetime	1990	1998	Change 1990 - 1998	
				Absolute	Relative
	0.75	238	252	14	6%
Paper storage	1.2	381	404	23	6%
	2	635	673	38	6%

Buildings

The method for estimating the amount of carbon in the stock of buildings was developed by Gjesdal *et al*. (1996). The method has been revised to include dwellings with no inhabitants. The method is based on *stock* data, using direct estimates of the total building pool. The data for *fluxes* have been improved since 1996, especially with the new demolition statistics (Rønningen 2000). However, due to the uncertainty in the fluxes and the very long lifetimes of buildings, we still find the stock approach more reliable for the present purpose.

The stocks in residential and nonresidential buildings are estimated separately. The basic method for estimation is:

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

More detailed:

*C-residential = number of houses * average utility floor space m^2 * wood% * tonnes wood/m^2 in wood buildings * C-content*

Number of houses: Data from the Population and Housing census for 1990 (Statistics Norway 1999), supplied with data from Norwegian Building Research Institute (Byggforsk)[7] for 1999. The 1998 value was interpolated. The data from Byggforsk included separate estimates of

[7] Pers. comm. Norwegian Building Research Institute (2000).

inhabited and non-inhabited dwellings. These values were used to estimate the amount of non-inhabited dwellings in 1990.

Average utility floor space per dwelling: For 1990, this value is given in the Building census. The utility floor space in dwellings built in the period 1991-1998 was taken from the annual Building statistics. For this calculation, it was assumed that all 1990 dwellings were still in the building pool in 1998, *i.e.*, demolition was ignored.

Total utility floor space, non-residential buildings was obtained from the Norwegian Association of General Contractors (Norwegian Association of General Contractors 1990).

Wood %: Fraction of houses built with wood. The fraction is first calculated for houses completed (1960-1980) or started (1988-1993) in a given year. The fraction is based on data from Building statistics giving the number of houses by materials used in vertical supporting structures, horizontal supporting structures and outside walls. To get the average fraction for the building pool in a given year fractions for year of construction were weighted by the number of buildings dating from each period (Statistics Norway 1999).

Tonnes wood per m^2 in wood buildings: Standard values were assumed to be 150 kg/m^2 in the case of one- and two-family houses and 15 kg/m^2 in multi-family houses. The values were obtained from Norwegian Building Research Institute. Average values for the building pool were calculated using the proportion of dwellings for 1-2 and more than 2 families. For non-residential buildings a factor of 0.035 m^3/m^2 was used, corresponding to 17.5 kg/m^2

Alternative values: Rønningen (2000) gives the following factors for the wood content in waste from demolition:
- Small buildings (1-4 dwellings) 98.5 kg/m^2.
- Large buildings (5 or more dwellings, buildings for service industries) 77.7 kg/m^2.
- Other buildings (primary and secondary industries) 23.6 kg/m^2.

The demolition data probably refer to older buildings than the average building population. It is expected that older buildings have a higher wood content, and the population average should be lower than the demolition values. However, these results are based on a limited material, and we concluded to use the values from the 1996 carbon balance.

C-content: The proportion of carbon in wood materials in buildings was assumed to be 39% by weight (Det norske Veritas 1996). In the forest balances, a value for forest products of 50% of dry matter weight has been used. In practice, wood materials have a certain water content. Thus, the carbon fraction by weight including water is lower. If the water content is 22%, the two values are in fact the same. This water content is on the high side, but the value of 39% seems reasonable.

Using the data, we obtain the following table showing the amount of carbon in buildings.

Table 17. Carbon stocks in buildings.

	1990	1998	Per cent change
Residential buildings			
Number of dwellings, 1000	1 835	1 936	5.5 %
Average utility floor area, m^2	103	106	3.0 %
Total utility floor area, 1000 m^2	189 363	205 766	8.7 %
Wood percentage	78.2 %	77.5 %	-0.7 %
Wood content kg/m^2, small houses	150	150	
Wood content kg/m^2, large houses	15	15	
Proportion of large houses	13.6 %	13.6 %	
Average wood content, kg/m^2	132	132	
Carbon content in wood	39 %	39 %	
Carbon stock, tonnes	7 606 383	8 190 542	7.7 %
Non-residential buildings			
Total utility floor area, 1000 m^2	95 483	108 150	13.3 %
Wood percentage	20 %	20 %	
Average wood content, m^3/m^2	0.035	0.035	
Dry matter conversion factor	50 %	50 %	
Carbon content in wood	39 %	39 %	
Carbon stock, tonnes	130 335	147 625	13.3 %
Total building carbon stock, tonnes	7 736 718	8 338 167	7.8 %

The estimate of the carbon stock in 1993 is 2% higher than in Gjesdal *et al.* (1996), due to the inclusion of non-inhabited dwellings.

Furniture

Gjesdal *et al.* (1996) estimated the carbon stock in furniture by the expression

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

A factor of 10 kg furniture per m^2 was used. Non-residential buildings were excluded from the calculation. New estimates for the carbon stock are given in Table 18, using the revised data for total utility floor space from Table 17.

Table 18. Carbon stocks in furniture

	1990	1998
Total utility floor area, 1000 m^2	189 363	205 766
Furniture, kg/m^2	10	10
Carbon content in wood	39 %	39 %
Total furniture carbon stock, tonnes	738 517	802 489

In accordance with the building stock estimate, the estimate of the 1993 stock is 2% higher than in Gjesdal *et al.* (1996), due to the inclusion of non-inhabited dwellings.

Within the framework of waste accounts, Frøyen and Skullerud (2000) gives data for the generation of waste from furniture and building materials. The data for furniture include inflow data used for a life cycle analysis. The inflow in a given year is expected to remain unchanged in the pool for 10 years and then decrease linearly from 10 to 20 years. Reliable inflow data have been prepared only for the years up to 1987. For this year, the life cycle analysis gives a total furniture pool of wood at 1.76 million tonnes. The corresponding carbon stock is 685 000 tonnes, which is very similar to the 1990 estimate in Table 18. Thus, the two approaches seem to corroborate each other.

Waste

Methodology

Yearly accumulation of carbon in waste is found through an inflow-outflow analysis:

Yearly accumulation of C = C in waste disposed of - C in emissions from decomposition (CO_2 + CH_4)

The amount of waste disposed of in landfills for a specific year is given by:

Waste disposed of = Waste production - Waste recycled - Waste burned

The total carbon stored in waste is found by adding yearly accumulation from the year 1945. Only paper and wood products are considered. The factors of carbon content used in the calculations are given in Table 19.

Emissions of methane and carbon dioxide from decomposition are calculated by assuming half-lifetimes ($t_{1/2}$) given in Table 20. This differs from the previous calculations (Gjesdal *et al.* 1996) where emissions were assumed to occur in the year of deposition. Total emissions of both gases (Q) in tonnes methane equivalents for a given year T from waste disposed of in year x are given by the formula:

$$Q_{T,x} = k * M_x * L_0 * e^{-k*(T-x)} * v/1000$$

Here L_0 (m^3/tonne) is the gas potential that is calculated from the carbon content and proportion of carbon decomposed. The proportion of carbon decomposed is estimated to 0.7, based on the assumption of a mean temperature of 30 ^oC in the anaerobe zone (Frøiland Jensen *et al*. 1999).
Further is M_x (tonnes) the amount of waste disposed of in year x, and v is the weight of methane (0,7168 kg/m^3). The factor k is given by:

$$k = ln(2)/t_{1/2}$$

Emissions in year T from all waste disposed of in preceding years are then given by:

$$Q_T = \Sigma Q_{T,x}$$

Table 19. Weights used for calculating the wood percentage from Building statistics

	Proportion of total materials		Wood fraction	Total weight
In vertical supporting structures	50 %	wood	100 %	0.500
		wood/light weight concrete	50 %	0.250
		wood/concrete	50 %	0.250
		wood/light weight concrete/concrete	33 %	0.167
In horizontal supporting structures	25 %	wood	100 %	0.250
		wood/light weight concrete	50 %	0.125
		wood/concrete	50 %	0.125
		wood/light weight concrete/concrete	33 %	0.083
In outside walls	25 %	wood	100 %	0.250
		wood/light weight concrete	50 %	0.125
		wood/concrete	50 %	0.125
		wood/light weight concrete/concrete	33 %	0.083

Table 20. Carbon content and half-life of different waste products

	Carbon content (tonnes/tonnes)	Half-life (years)
Municipal waste		
Paper	0.385	8.4
Wood	0.400	10.5
Organic fraction of industrial waste[1]	0.350	11.0

[1] Mainly wood and bark.

Waste data

The calculation of carbon stored in waste is based on the same background data as used in estimation of methane emissions from landfills (Frøiland Jensen *et al*. 1999). Three categories of waste are considered: Household and industrial waste included in municipal waste and industrial waste treated outside the municipal refuse disposal service. We will here make a short description of the background data, but for closer description we refer to the model documentation (Frøiland Jensen *et al*. 1999).

There are good data on municipal waste from 1992. For household waste there are data on amounts of waste per capita back to 1974. For the years from 1945 to 1973 the amount of waste from households is projected based on the trend for the period 1974-1985.

In addition to household waste, municipal waste includes some of the industrial waste. There are statistics on amounts of industrial waste in municipal refuse disposal systems from 1991 and for some years earlier on. For the years where data are missing the amount of industrial waste is calculated based on the relative distribution of household and industrial waste for the years where statistics exist and the time series of household waste.

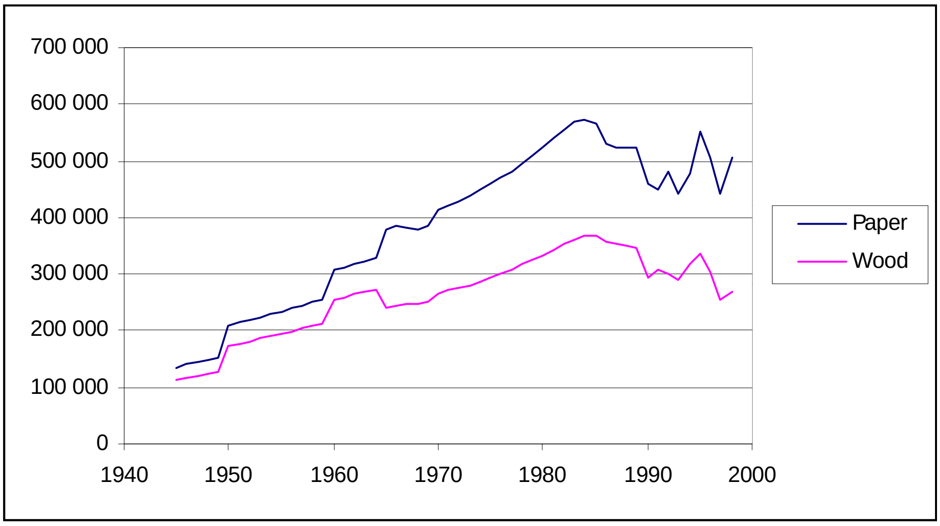
Factors for the composition of household and industrial waste in municipal waste are based on examinations for single years. However, especially for the industrial waste, the factors are uncertain. The waste products included in this analysis are paper and wood.

For industrial waste treated outside the municipal waste system, only the organic fraction of waste disposed of is considered. The data are based on statistics on industrial waste for 1993 and 1996. It is assumed that the organic fraction mainly consists of treated wood, as bark, splinter, wood fibres, paper etc. In the methane emission model mud from the wood-processing and graphic industry is added to the other organic fraction. These amounts are not included in our estimates, because we assume that the matters have short decomposal rates compared to bark and wood etc. However, as the amount is considerable, this exclusion might be questionable.

The methane emission model does not consider waste used as filling, because it is assumed that the organic fraction is small and under aerobic decomposition. This fraction is neither included in this work. The methane model's figures on wood waste disposed of are similar to the figures found by the waste accounts for wood (Statistics Norway 2000). This might indicate that the volume of wood products stored as filling is insignificant or that the methane model overestimates the figures. In either of the cases, we do not find it reasonable to make any additions to the figures from the methane emission model.

Figure 4 shows the disposal of paper and wood from 1945 to 1998. For 1998 new data on municipal waste (Statistics Norway 2000) are used, but for industrial waste outside the municipal system deposition is assumed to be equal to 1997.

Figure 4. Disposal of waste in landfills from 1945 to 1998. Tonnes.



Source: Frøiland Jensen *et al*. (1999) for 1945-1997 and Statistics Norway for 1998.

Results

The carbon accumulated in landfills has increased steadily from 1945 to 1998 (Figure 5). However, the growth has been less during the 1990s, due to increased level of recycling and combustion.

Figure 5. Accumulation of carbon from wood and wood products in landfills. 1945 - 1998. 1000 tonnes C.

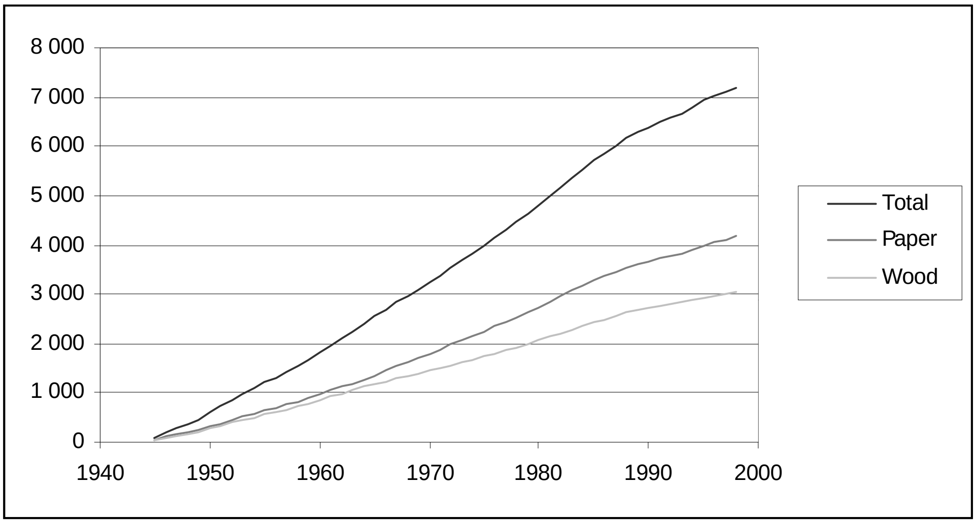


Table 6 gives the contribution from different waste products to the carbon stored in landfills from 1990-1998.

Table 21. Contribution of different waste products to carbon storage in landfills. 1000 tonnes C

	1990	1991	1992	1993	1994	1995	1996	1997	1998
In total	6 393	6 488	6 593	6 676	6 783	6 927	7 040	7 108	7 208
Paper, paperboard etc.	3 673	3 724	3 789	3 837	3 900	3 991	4 062	4 109	4 180
Wood, bark etc	2 720	2 763	2 804	2 839	2 883	2 936	2 978	2 999	3 027

Compared to earlier results (Gjesdal *et al*. 1996) the biotic carbon storage in landfills is much higher (about 7 times higher in 1993), even though textiles were included in the previous analysis[8]. One reason for this is that the accumulation starts from 1945, compared to 1960 in the previous calculation. But even if we make an accumulation from 1960, the total carbon storage in 1993 is about 6 times higher. In the previous calculations it was assumed instant emissions from decomposition, while in this model emissions are exponential decaying. Hence, the waste disposed of will impact on the future carbon storage for a longer time.

Discussion

If we compare the yearly accumulation found in this work[9] with previous results (Table 22), we see that the data set and emissions given by the methane emission model give higher accumulation for all years. The difference in accumulation is mainly due to different estimates of emissions from decomposition, but also due to different estimates of deposition. These factors are however not independent, as higher estimates of waste disposed of will give higher emissions in subsequent years.

[8] Including textiles in this work increases the carbon reservoir in landfills with 4.5 per cent in 1990 and 5 per cent in 1998.
[9] Here, textiles are included to make the results comparable.

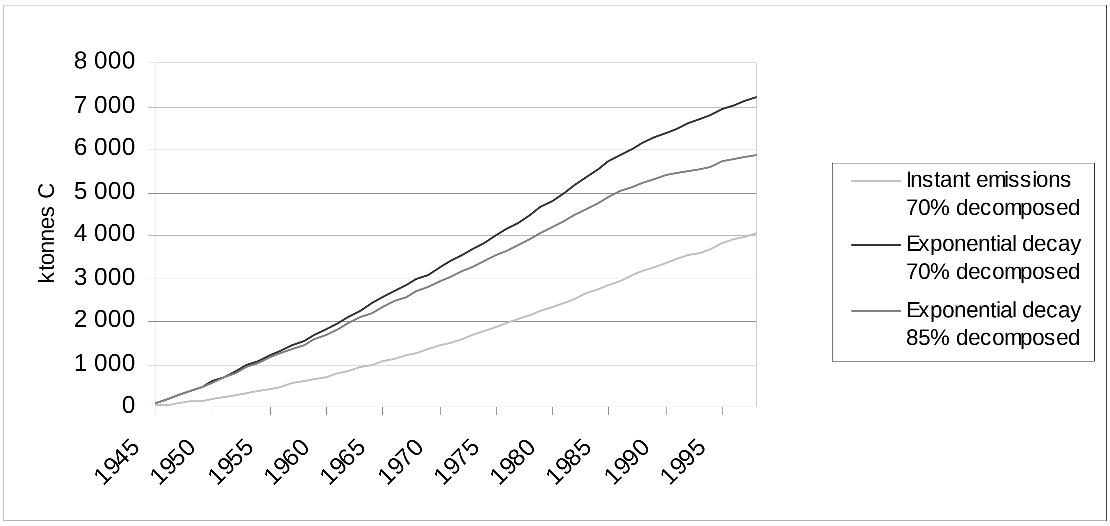
Table 22. Differences in the results of accumulation of carbon in waste. 1000 tonnes.

	1960	1970	1980	1988	1990	1991	1992	1993
Yearly accumulation								
In this work	155	153	179	149	103	104	114	92
Previous work[1]	1	31	14	42	52	49	46	22
Difference in accumulation	154	123	165	107	51	55	68	69
Caused by emissions	132	111	94	81	79	77	77	72
Caused by deposition	22	12	71	26	-28	-23	-9	-3

[1] In Gjesdal *et al*. (1996) mean yearly accumulations were given in tables and used in calculations of storage.

In the methane emission model it is assumed that only 70 per cent of the carbon on landfills are decomposed. This assumption is however questionable, as this means that accumulation on landfills will last forever. Figure 6 shows the estimated accumulation of carbon in landfills when we assume that emissions are instant. Hence, just by accumulating 30 per cent of the carbon in waste disposed of, the carbon reservoir gets considerable. The increase from 1960 to 1993 is approximately 2000 ktonnes carbon, which is twice the reservoir size given in the previous work.

Figure 6. Accumulation of carbon in landfills from 1945 to 1998. 1000 tonnes C.



By assuming that 85 per cent of the carbon is decomposed, the accumulated storage in 1998 is reduced by nearly 20 per cent. Of higher importance is that this gives a much smaller increment in the landfill storage of carbon from 1990 to 1998. With 85 per cent decomposable carbon this change is 530 000 tonnes carbon, compared to 887 000 tonnes carbon with 70 per cent decomposed.

Hence, both the data set of waste disposal and the emission estimates from decomposition are rather uncertain and have considerable impact on total carbon storage in landfills.

Total carbon stock and stock changes

The total stock of carbon in 1998 is estimated to almost 17 million tonnes (Table 23). Compared to 1990 the stock has increased with 1500 ktonnes or 10 per cent. Storage of carbon in buildings and waste is the most important source both to the total stock and the accumulation from 1990 to 1998.

Compared to previous calculations the carbon storage in buildings and furniture in 1990 is approximately the same. The methane emission model gives a carbon stock in landfills that is almost 8 times higher (see Section 0 for discussion).

Table 23. Stock of carbon 1990 and 1998. 1000 tonnes C

	1990	1998	Change	Annual Average Change, %
Total	15 249	16 752	10 %	1.20
Wood products	8 475	9 141	8 %	0.97
Buildings	7 737	8 338	8 %	0.97
Furniture	739	802	9 %	1.08
Paper	381	404	6 %	0.73
Waste	6 393	7 208	13 %	1.54

The total stock changes of the studied product groups are given in Table 9 for 1990, 1993 and 1998.

Table 24. Stock change of carbon 1990, 1993 and 1998. 1000 tonnes C

	Change 1990	Change 1993	Change 1998
Total	231	162	183
Wood products	160	70	98
Buildings	145	65	88
Furniture	15	5	10
Paper	4	9	-14
Waste	52	83	100

Projections of stored carbon in wood products

Projections of the carbon storage in buildings, products and furniture are based on the growth rates estimated in Gjesdal *et al*. (1998). For carbon in landfills the same projections of waste deposition as used in the methane emission model (Frøiland Jensen *et al*. 1999) are used. We will here only give a short description of the methodology, but more detailed information is found in Gjesdal *et al*. (1998) and Frøiland Jensen *et al*. (1999).

Methodology

In the previous projections (Gjesdal *et al*. 1998) the trend in use of different products was estimated by the economic model MSG-6 (Bye 1996). Based on these trends the reservoir of wood products, paper and textiles for 2005, 2010 and 2020 was estimated. The base year for the projections was 1992. In this work we use the same growth rates for paper and wood products as in the previous work for the period 2005-2010 and 2010-2020. For the period 1998 to 2005 we apply the growth rate estimated for 1992-2005.

Figure 7 shows the projections of biotic carbon based on the MSG-6 model from the base year 1992. The updated estimates of carbon storage in paper and wood products in 1998 are about

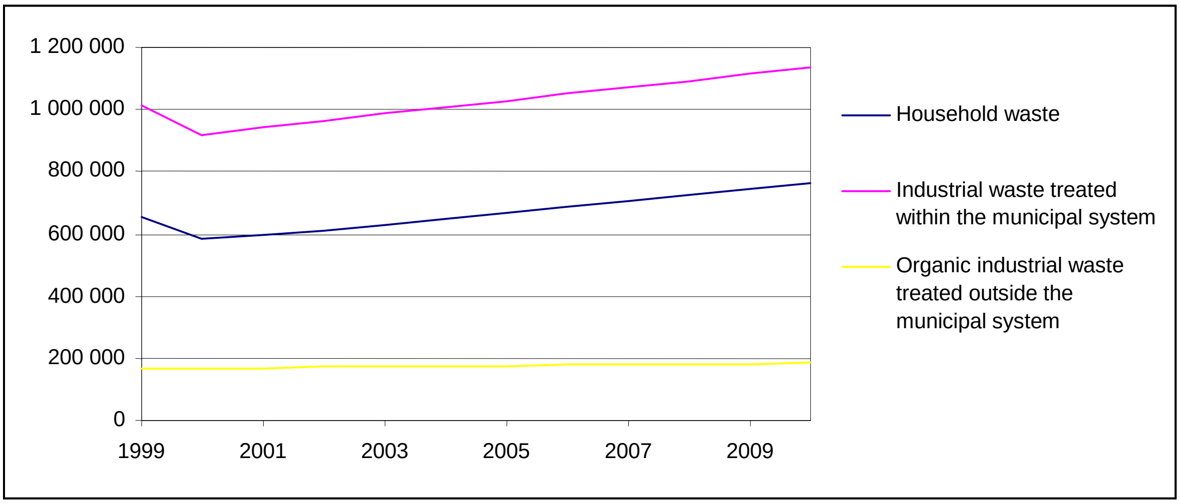
5 and 3.5 per cent higher than expected, based on the projections from the earlier 1992 estimates. By using the same yearly growth, the absolute differences given in 1998 will be maintained in subsequent years.

Figure 7. Projections of carbon reservoir in different products. Values in 1992 = 1.

Projections of carbon stored in landfills are based on the projections included in the methane emission model. The emission model has three different scenarios, one 'status quo' where about the same proportion of waste is disposed of and two scenarios with higher environmental efforts. In this work we use the data set based on the 'status quo' scenario.

Figure 8 gives the future deposition of waste from households, industrial waste within and outside the municipal removal of refuse. For the household waste about 30 per cent is paper and 3 per cent is wood. For the industrial waste within the municipal system the similar figures are about 35 per cent paper and 20 per cent wood. The industrial waste treated outside the municipal system only considers wood/bark and organic mud from wood-processing and graphic industry. In our projections we exclude the organic mud, which is assumed to be constant at about 70 ktonnes.

Figure 8. Projections of waste disposed of in landfills. Tonnes.



The projections included in the methane emission model only range to 2010. In our estimations we use the same yearly growth of carbon stored in waste for the period from 2010 to 2020 as from 2005 to 2010.

Results

The total reservoir of carbon is expected to increase with about 2.3 million tonnes or almost 14 per cent from 1998 to 2010. Carbon storage in waste contributes with 7 percentage points and storage in buildings with 6 percentage points of this growth.

Table 25. Projection of the reservoir of carbon 2000-2020. 1000 tonnes C.

	1998	2000	2005	2010	2020	Change 1998 -2010		Annual average change, %	Change 2009-2010
						Absolute	Relative		
Total	16 752	17 098	18 024	19 038	20 940	2 286	14 %	1.10	206.75
Wood products	9 141	9 336	9 825	10 241	10 981	1 100	12 %	0.95	96.26
Buildings	8 338	8 516	8 961	9 334	10 033	996	12 %	0.95	87.74
Furniture	802	820	864	907	948	104	13 %	1.02	9.19
Paper	404	411	428	437	421	33	8 %	0.64	2.79
Waste	7 208	7 352	7 771	8 360	9 538	1 152	16 %	1.24	102.76

Even though the waste disposed of only increases with about 10 per cent between 1998 and 2010, the reservoir increases with 16 per cent. This is because the emissions from decomposition are almost constant in the same period. Since emissions depend on the historic deposition, it does not always follow the current trend of deposition. High deposition of waste during the 1980s and low deposition in the 1990s explain the results.

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Title Estimating the net emissions of CO2 from harvested wood products - A comparison of different approaches
Summary The report presents results analyses of carbon storage in harvested wood products and forest in Norway. In the current reporting guidelines for greenhouse gas inventories, emissions from forestry are reported separately from the national total, assuming that emissions occur at the time of harvest in the country of harvesting. This implies that no carbon goes into long term storage. The aim of this report is to test and compare four different proposed approaches for allocating carbon storage and CO_2 emissions from wood products to countries, using Norway as an example. Different estimation methods for the storage are compared and discussed from the point of view of accuracy and availability of data. The approaches do not differ in the accounting of changes in the forest stocks. The main differences between the approaches relate to how the product stocks and foreign trade in wood products are treated. This aspect will give different incentives to national policies with respect to import and export of wood products.

Subject words Carbon sinks Wood products Carbon accounting	Karbonsluk Treprodukter Karbonregnskap