REPORT

Carbon Footprint of Cartons in Europe

– Carbon Footprint methodology and biogenic carbon sequestration

Elin Eriksson, Per-Erik Karlsson,
Lisa Hallberg & Kristian Jelse

B1924
May2010

This report approved
2010-04-29-

John Munthe
Scientific Director

IVL Swedish Environmental Research Institute

Organization IVL Swedish Environmental Research Institute Ltd.	**Report Summary** A method for Carbon Footprints of cartons in Europe has been developed and applied. The average carbon footprint of converted cartons sold in Europe has been calculated and summarised.
Address P.O. Box 5302 SE-400 14 Göteborg	**Project title** Carbon Footprint of Cartons in Europe **Project sponsor** The European Carton Makers Association (ECMA), financed the project together with SIVL. ECMA and Pro Carton members have been deeply involved in the study.
Telephone +46 (0)31-725 62 00	

Author

Elin Eriksson, Per-Erik Karlsson, Lisa Hallberg and Kristian Jelse

Title and subtitle of the report

Carbon Footprint of Cartons in Europe – Carbon Footprint methodology and biogenic carbon sequestration

Summary

A methodology for estimating the carbon sequestration in forests associated with the roundwood supply for carton production has been developed and applied. The average Carbon Footprint of converted cartons sold in Europe has been calculated and summarised. A methodology for a EU-27 scenario based assessment of end of life treatment has been developed and applied. The average Carbon Footprint represents the total Greenhouse Gas emissions from one average tonne of virgin based fibres and recycled fibres produced, converted and printed in Europe.

Keywords

carbon footprint, cartons, carbon sequestration, CEPI Carbon Footprint Framework, avoided emissions, greenhouse gas emissions, waste treatment

Bibliographic data

IVL Report B1924

The report can be ordered via

Homepage: www.ivl.se, e-mail: publicationservice@ivl.se, fax+46 (0)8-598 563 90, or via IVL, P.O. Box 21060, SE-100 31 Stockholm Sweden

Preface

This study has been performed with financing from ECMA Carbon Footprint and the Foundation of the Swedish Environmental Research Institute (SIVL).

The project team thanks the industry and Swedish Environmental Protection Agency reference group for their valuable input and for interesting discussions. We would like to thank also Reid Miner at the National Council for Air and Stream Improvement (NCASI) for performing critical review of the study.

Summary

In this study, a methodology for assessment of the Carbon Footprint of cartons has been developed, based on the CEPI Carbon Footprint framework. The methodology includes an assessment method for the net sequestration (removal from the atmosphere) of biogenic CO_2 in the forests where roundwood used for carton production is harvested. The study shows the link between carton consumption and net carbon sequestration in sustainably managed forests. A methodology for inclusion of end of life and avoided emissions in the carbon footprint has also been developed. This is based on average statistics for waste treatment and avoided emissions. The developed methodology is applied to the ECMA carton product pool in Europe, and the average Carbon Footprint of one ton produced, converted and printed carton board in Europe has been calculated, see Table 1. The Carbon Footprint gives important information to customers, and can serve as a base for further improvements.

Table 1. The resulting Carbon Footprint presenting the net flows as CO_2e. The delay of emissions according to PAS 2050 at use and in landfills are not included.

Description of the Carbon Footprint ten toes given as GWP100	GHG emission (kg CO2/tonne carton)	Biogenic CO2 (kg CO2/tonne carton)
Toe 1: Biogenic CO2 net sequestration in managed forests		-730
Toe 2: Carbon stored in products as biogenic CO2		
Toe 3-7: GHG emission from production and transport of the converted cartons	964	
Summary Cradle to gate or Cradle to customer gate	***964***	***-730***
Toe 8: Emissions associated with product use		
Toe 9: Emissions associated with end of life	308	
Summary Cradle to grave	***1 272***	
Toe 10: Avoided emissions from the production phase and from end of life	-145	
Summary Cradle to grave including avoided emissions	***1 127***	***-730***

The greenhouse gas (GHG) emissions from the whole supply chain of converted cartons from forestry and production of fuels and chemicals, through the mill, converting and printing to end of life have been calculated and added. The cradle to gate Carbon Footprint is presented in the table above, as well as the full cradle to grave Carbon Footprint, including end of life treatment at the average European (EU-27) market. The biogenic CO_2 is presented separately from fossil CO_2 and other GHG. The carbon stored in the product is not presented in this summarised table, but is included in the report.

Based on this study, the following recommendations are given:

- The Carbon Footprint study shows that forest management is a prerequisite for high net removals of CO_2 from the atmosphere. The study shows that the net removals of CO_2, that can be associated with the roundwood supply for carton production, are significant.

- The Carbon Footprint shows the average GHG emissions and removals per average tonne of converted cartons. This average information can be used by individual companies to continue the work on improvements and GHG emission reductions in the own supply chain. Especially substitution of fossil fuels at production and transportation, and purchase of electricity from renewable sources according to contracts are interesting improvements.
- Ask for Carbon Footprint, Environmental Product Declarations or other third party verified life cycle information to stimulate environmental improvements of packaging. When comparisons are made, consider the functional unit.
- Use the information with care since Carbon Footprints from different frameworks, Product Category Rules, Environmental Product Declarations or Carbon Footprint programmes may not be comparable.
- Promote systems where landfill of packaging with energy content is avoided and systems where, after recycling, the energy of waste at waste incineration is utilised as heat and power that may be used in other applications.
- Further studies need to be done to study the net removals of CO_2 over longer time periods, covering several decades.

Critical review statement

ECMA and IVL are to be commended for taking on the daunting task of attempting to develop a carbon footprint methodology for carbon stored in forests. The approach described in the IVL report is thoughtful, well researched and thoroughly documented. It provides a much-needed focal point for discussions of this issue.

We acknowledge that IVL has provided written responses to the comments we submitted on 30 November 2009 dealing with the report cited above. Below, we provide some final thoughts on the most important issue addressed in our earlier comments, attributing changes in forest carbon stocks.

The most difficult issue faced by those attempting to develop carbon footprints of forest-derived products is understanding and attributing changes in forest carbon stocks. The topic continues to be the focus of intense discussion in many places, including the deliberations on carbon footprint standards under ISO and under the WRI/WBCSD GHG Protocol. In the absence of agreement on standard approaches, one can only attempt to do what makes sense, which is what IVL has attempted to do.

The carbon footprint of a product is the result of a calculation that describes the life cycle greenhouse gas impacts attributable to a product. One of the most difficult questions related to forest carbon is "What sequestration in the forest can be claimed as being attributable to the forest product?"

On land that is owned or controlled by the entity producing the product, the attribution of changes in carbon stocks is, at least in concept, relatively straight forward. The entity determines whether forest carbon stocks are changing (over scales of area and time appropriate for the analysis) and if they are changing, the changes are allocated to products made from wood taken from these areas (using allocation methods appropriate for the purpose). Although the calculations are simple in concept, there are numerous details that contribute uncertainty to the estimates of carbon impacts allocated to individual products. This does not mean that such calculations are suspect; only that the uncertainties need to be recognized (as they should be recognized in all areas of carbon footprint calculations).

In the parts of Europe supplying wood to ECMA members, the forests are largely owned by entities other than the forest products industry. Some of these forests are used primarily for wood production. Some are protected for preservation or recreation. Many provide wood as well as other goods and services. Importantly, the carbon stocks in Europe's forests, including those in regions supplying most of the wood to ECMA's members, are increasing. Clearly, there is empirical evidence to support the assumption that, at a minimum, wood production in these forests is consistent with the maintenance of stable forest carbon stocks. It is reasonable to conclude, therefore, that at worst, the net impact of the industry's activities on forest carbon stocks is zero loss (or gain) of carbon.

If, for land not owned by ECMA members, a zero impact is the worst case assumption, the "best" case assumption attributes all of the carbon stock increases on these lands to the products made from harvested wood. In our opinion, for wood from land not owned or controlled by the industry, it is best to show the forest carbon impact of the products either as the worst case, or as a range, with one end of the range being the worst case (zero net benefit on forest carbon stocks) and the other being the best case (attributing all of the forest carbon stock increases to forest products). There can be little disagreement that the "true" value is somewhere in this range.

If a value from within this range is used to represent the footprint, it needs to be extensively justified, and, in our opinion, the uncertainty around that value should be shown as being equal to the range discussed above (i.e. best case to worst case).

As we noted above, there is currently no widely accepted standard approach, and no "correct" way, to include forest carbon impacts in the carbon footprints of forest products. The documentation provided by IVL for the calculations on forest carbon for the ECMA footprint study is thorough and transparent. The IVL estimate of forest carbon impacts for the footprint is subject, nonetheless, to considerable uncertainty, and appears to fall closer to the "best" end of the range of possible estimates. As long as the uncertainty bounds around the estimate are transparently stated in the report, however, the reader of the report will have the information needed to interpret the results.

We hope you find these comments helpful.

Best Regards

Reid Miner

Table of contents

1 Introduction

Due to an increased awareness of and concern for climate change, there is need for more knowledge of the removal and emissions of greenhouse gases, such as carbon dioxide (CO_2), methane and nitrous oxide, associated with the use of products and services.

Pro Carton, the Association of European Cartonboard and Carton Manufacturers, has developed a carbon footprint presenting the fossil CO_2 emissions for the average production of cartons in Europe (Pro Carton, 2006 and 2009). One part of the greenhouse gas balance is the biogenic flows; carbon dioxide sequestration in the forests, the balance of the dead biomass material, the flows to and from the ground and the biogenic flows during production of forest products. Another part is the flows in the product pool in society, and a third part is the flows of products after use at recycling and at waste treatment, considering also electricity and heat produced at waste incineration.

ECMA, the European Carton Makers Association, has had preliminary approaches for calculating the biogenic CO_2 flows, but there has been a need for further methodological development and research in this area. IVL has now developed a methodology for Carbon Footprints of carton and paper products, and assessed the average European footprint.

A reference group has been working in the project, consisting of:

Jan Cardon, ECMA
Jennifer Buhaenko, Pro Carton Europe
Silvia Greimel, Mayr Melnhof Karton
Paivi Harju Eloranta, Stora Enso
Mervi Niininen, Stora Enso
Ohto Nuottamo, Stora Enso
Staffan Sjöberg, Iggesund
Sammy Hallgren, A&R Carton
Cecilia Mattsson, Swedish Environmental Protection Agency (only participating in one meeting)

Data have also been provided by:

Bernard Lombard, CEPI
Richard Dalgleish, Pro Carton Europe

The Carbon Footprint should not be regarded as a benchmark for the industry, or as a tool for comparisons between different parts of the industry, since different methodologies and system boundaries may be applied. If specific information on a particular cartonboard grade or carton is required, then this should be requested directly from the manufacturers.

2 Goal

The goal of the study is to develop a methodological approach for how to include the biogenic flows of carton products in a carbon footprint of such products. The main objectives of the study are the following:

1. To develop a methodology for the carbon sequestration and biogenic emissions in the forests. This corresponds to toe 1 in the CEPI Carbon Footprint Framework (CEPI, 2007).
2. Based on the developed methodology decide which data and data source to use for the net carbon sequestration of different forests in Europe used for carton production on e.g. a national level.
3. To define how to account for the carbon tied in the carton product pool in society, e.g. according to the PAS 2050 (BSI, 2008). This is part of toe 2 in the CEPI framework.
4. To develop a methodology suited for use in carbon footprint for recycling and final waste treatment (toe 9), including energy recovery and electricity and heat production, as well as whether system expansion or allocation should be applied, and in that case how (Toe 10).
5. To calculate the carbon footprint of an average converted carton board in Europe

The Carbon Footprint should not be regarded as a tool for comparisons between different parts of the industry, since different methodologies and system boundaries may be applied. If specific information on a particular cartonboard grade or carton is required, then this should be requested directly from the manufacturers.

3 Carbon footprint: general methodology, frameworks and standards

A carbon footprint is a measure of the greenhouse gas emissions associated with e.g. an activity, group of activities or a product. The most important greenhouse gas is carbon dioxide (CO_2) but other gases such as methane (CH_4) and nitrous oxide (N_2O) are also contributing to climate change.

The carbon footprint concept has emerged from the need of a tool to measure and communicate the climate change performance of an activity or a product. A framework methodology for carbon footprint calculations has been developed in e.g. the pulp and paper industry (CEPI, 2007), see Table 2. The methodological description is in the form of a general framework, why the details of the calculations have to be defined by each user of the framework. A new work item on carbon footprint has just started within the International Organization for Standardization (ISO), and is expected to be finished by 2011. Until there is a detailed standard in place for carbon footprint, it is important to describe the details and conditions for the methods used. In this report, the conditions and assumptions for the method used are presented, as well as the results. The detailed data and calculations are also presented in the carbon footprint calculation sheet in Excel.

A carbon footprint is in principle the same as the climate change impact category of a life cycle assessment (LCA); the GWP (Global Warming Potential) profile. There may however be some differences/additions in carbon footprints. Within the working group of ISO 14067, additional issues as compared to the GWP part of an LCA based on ISO 14044 are currently being discussed. One such issue is the biogenic carbon sequestration related to the products. Other issues discussed are also the time frames, carbon storage, carbon capture and storage (CCS), and direct and indirect land use change. A carbon footprint is similar to an environmental product declaration (EPD) presenting just one category indicator, climate change. Therefore, product category rules (PCRs) are relevant also for carbon footprints. In this study, the CEPI Carbon Footprint Framework has been used, as well as the ISO 14044 on LCA. The requirements for EPD e.g. according to the “General Programme Instructions” have not been used extensively. As an example, EPDs do not include waste treatment more than as additional information; however in this study waste treatment is included, as well as a system expansion, in order to show the environmental impact of the whole life cycles of the carton products, from cradle to grave. The avoided emissions are however transparently presented.

Table 2: The ten toes as defined by the CEPI Carbon Footprint Framework (CEPI, 2007).

Description of the CEPI Carbon Footprint ten toes	**Fossil CO_2 emission (GWP 100)**	**Biogenic CO_2**
Toe 1: Biogenic CO_2 net sequestration in managed forests		
Toe 2: Carbon stored in products as biogenic CO_2		
Toe 3: GHG emission from forest product production process		
Toe 4: GHG emission associated with producing the fibre (forestry)		
Toe 5: GHG emission from raw material production		
Toe 6: GHG emissions from purchased and sold electricity and heat		
Toe 7: Transport related GHG emissions		
Summary Cradle to gate or Cradle to customer gate		
Toe 8: Emissions associated with product use		
Toe 9: Emissions associated with end of life		
Summary Cradle to grave		
Toe 10: Avoided emissions from the production phase and from end of life		
Summary Cradle to grave including avoided emissions		

4 Description of carton board and carton products

Folding cartons are small to medium sized “cardboard boxes” made from cartonboard. They are used to package a wide range of products from foodstuffs – such as cereals, frozen and chilled food, confectionary, bakery goods, tea, coffee and other dry foods – to pharmaceuticals, medical and healthcare products, perfumes, cosmetics, toiletries, photographic products, clothing, cigarettes, toys, games, household an electrical, engineering, gardening and DIY (do it yourself) products.

Several different types of cartonboard are manufactured, all of which can be made with different grammage (weight per unit of area) and thickness. The type of cartonboard and the fibre composition depend on the intended use and the specific requirements. Usually paperboard is made up of several plies to make the best possible use of the different types of raw materials and optimise the product performance.

Cartonboard is made from cellulose fibres that are produced either from wood or from recovered paper and board. A combination of the two can be used and there are various types of fibre that produce different characteristics. For example, shorter fibres generally give a better bulk and longer fibres give a greater stiffness and so types of fibre are mixed to produce the desired characteristics.

The fibres can also be treated with various chemicals to improve a variety of properties such as moisture and grease barriers. Additionally they can be coated with a range of coatings to produce cartonboard that can be used in ovens and microwaves and other specialist packaging. They can also have metal foil laminated to them to enhance the appearance of the finished product. The following carton board qualities are used and produced by ECMA and Pro Carton members:

White Lined Chipboard, WLC (also known as GT/GD/UD)
This grade is typically made using predominantly recovered paper or recovered fibres. It is manufactured in a number of layers, each of which uses selected grades of raw materials. It typically has three layers of coating on the top or printing surface and one layer on the reverse. It is used in a range of applications such as frozen and chilled foods, cereals, shoes, tissues and toys.

Folding Boxboard, FBB (also known as GC/UC)
This grade is typically made of mechanical pulp sandwiched between two layers of chemical pulp with up to three layers of coating on the top or printing surface and one layer of coating on the reverse. Typical uses include pharmaceuticals, confectionery, frozen food and chilled food.

Solid Bleached Board, SBB, (also known as SBS/GZ)
This grade is typically made from pure bleached chemical pulp with two or three layers of coating on the top surface and one or more layers on the reverse. There are also uncoated grades. Typical markets include cosmetics, pharmaceuticals, graphics, tobacco and luxury packaging.

Solid Unbleached Board, SUB/SUS
This grade is typically made from pure unbleached chemical pulp with two or three layers of coating on the top surface. In some cases a white reverse surface is applied. It is primarily used as beverage carriers for bottles and cans, as it is very strong and can be made resistant to water. It is used where strength of packaging is important.

The make-up of the total production in Europe is as follows:

- WLC: 59.6%.
- FBB: 32.7%
- SBB/SBS: 7.7%

The average consumption of cartonboard in Europe is approximately 10 kg per capita (Pro Carton, 2009).

5 Scope of this study

This section describes the scope of this study.

5.1 Functional unit

The functional unit of an LCA or of a carbon footprint defines the quantification of the function of the products and serves as a basis of comparison. The functional unit in this study is one average ton of converted carton products put on the European market (EU-27).

5.2 Overall scope of the study

This study has analysed the toes 1, 2, 9 and 10 of the CEPI Carbon Footprint Framework. It covers greenhouse gas (GHG) emissions measured from fossil fuels and from methane in landfill using the GWP 100 (Global Warming Potential 100 years), as well as biogenic carbon dioxide (CO_2) as presented separately.

Toe 1 covers the net sequestration in forests where the wood used for the carton pulp and board is harvested. Toe 2 covers the changes in GWP and biogenic carbon dioxide in the product pool on the market. The toe 9 covers the waste incineration and landfill. The toe 10 includes the avoided emissions of the end of life energy recovery at incineration and at the landfill. The so-called avoided emissions at pulp and board production are already included in the toe 3-7 profile; if considered (e.g. sold electricity or heat at virgin carton production). Figure 1 presents the life cycle of one average ton of carton put on the European market, including toe 1-9.

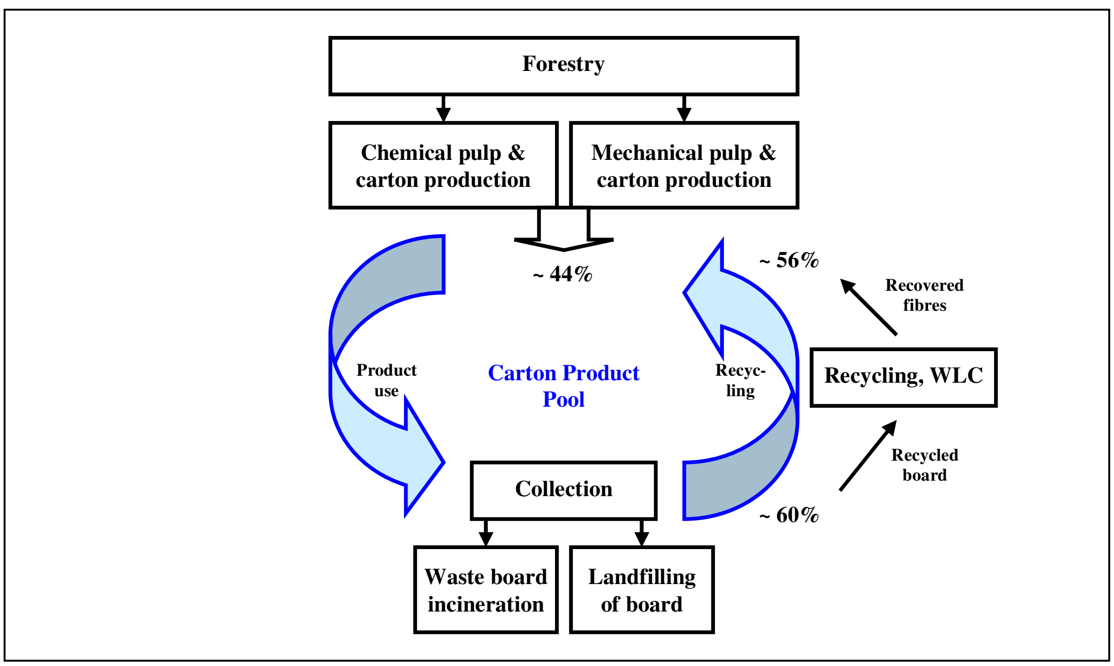


Figure 1: Carton product life cycle including toe 1-9.

Figure 2 presents the life cycle, including the avoided emissions (toe 10) associated with:

- the production of electricity and heat which is assumed to replace the electricity and heat produced at waste incineration of board and
- the combustion and production of the alternative fuel which is assumed to replace the biofuel (from formation of methane) produced at the landfill from the carton products.

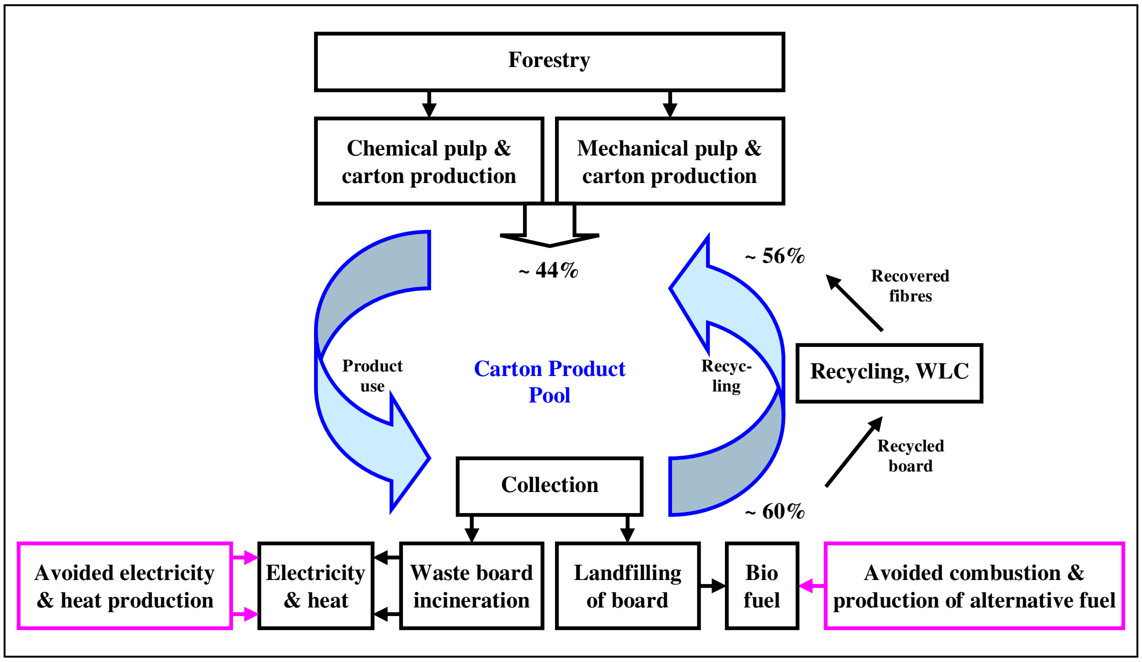


Figure 2: Carton product life cycle including also toe 10, avoided emissions at end of life.

In the base case, a so called attributional system analysis methodology has been used, since marginal LCA would not be relevant for an average European Carbon Footprint (see Section 5.3).

5.3 Type of carbon footprint system analysis

We distinguish between two types of methods for LCA and other system analyses: attributional and consequential studies. An attributional system analysis is defined by its focus on describing the environmentally relevant physical flows to and from a life cycle and its subsystems. A consequential system analysis is defined by its aim to describe how environmentally relevant flows will change in response to possible decisions (Curran et al., 2005). The choice between these two types of system analysis is discussed in detail by Ekvall et al. (2005). However, in that paper, the terms retrospective and prospective LCA are used instead of attributional and consequential LCA.

Attributional methodology is used in this study. This has bearing on the electricity production mix assumed, which has been average national or European, as well as on toe 10 and avoided emissions at energy recovery, also where average data have been used.

5.4 Data collection procedure

For toe 1 and the sequestration in forests, the data on origin of the wood used at pulp and carton production were collected from forest experts in CEPI based on more general statistics and from Pro Carton experts based on capacities of the relevant plants (Lombard, 2009; Dalgleish, 2009). The waste treatment data and flows are based on several literature sources and discussions with experts. For toe 3-7, data from Pro Carton (2009) have been used. For end of life treatment, statistics for the European market have been collected from Eurostat (2009) and other sources. The data sources are further described in each paragraph for each toe.

The collected data were validated by cross-checking several sources, analysing the documentation of the data set and by checking that flows and units were reasonable. The calculations were carried out using Excel.

5.5 System boundaries

5.5.1 Basic criteria

A carbon footprint should include all processes contributing significantly to the environmental impact of the system investigated.

In all LCAs, data collection is restricted by the specific limitations of the project. In this study the net sequestration of timber imported from outside Europe is not included; which means it is considered to zero. This should be a conservative assumption.

5.5.2 Geographical boundaries

The purpose of the study is to reflect conditions on the European market, since most of the cartons converted in Europe are sold on this market. Since recycling rates and other data represent EU-27, we have selected the EU-27 as the geographical area for the production, use phase, recycling and other end of life treatment. However, some of the wood used for the production is originating from outside Europe. In that case, we have selected to assume a net sequestration of zero as mentioned above, since we have not been able to study the circumstances of the forestry outside of Europe.

An important issue is what environmental impact is associated with the electricity use. In an accounting system analysis, the electricity is typically regarded as being produced in a system with a mix of technologies for electricity production. The emissions from the production of 1 kWh electricity are then defined as the average emissions from this mix.

To calculate the average emissions, we need to define the geographical (or organisational) boundaries of the system where the electricity is produced. Several alternative bases for defining system boundaries exist, such as:

- the company from which the electricity is bought,
- the geographical area where an electricity market is effective,
- the geographical area where the transmission capacity is rarely a constraint.

There is no objective way of defining these boundaries; the electricity system is that which is perceived to be the electricity system. Here, since we are looking at the European market, the average electricity mix of the EU-27 countries (520 g CO_2e per kWh) has been used for the toes covered by this study.

For toe 3-7, care should be taken to use similar system boundaries for the electricity system in order for the different results to be possible to add up to calculate the total carbon footprint.

For average avoided heat production in Europe, heat from natural gas corresponding to emissions of 237 g CO_2e per kWh has been used.

5.5.3 Boundaries within the life cycle

Boundaries within the life cycle describe *where* in the life cycle the environmental impact is accounted for as inputs or outputs and *how aggregated* the data presented are. The environmental impact is accounted for in the toe of the ten toes where they are generated.

Since the toes 1, 2, 9 and 10 are supposed to be added up with the production and converting profiles of cartons, the boundaries need to be consistent.

The production, maintenance and after-use treatment of capital goods, such as machines, power stations, activities of the employees, etc., are not included in the studied product systems.

5.5.4 Production of electricity and fuels

Electricity production and the conversion of energy resources into fuels are included in the carbon footprint. This means that the GHG emissions from electricity and fuel production are included (see Figure 3).

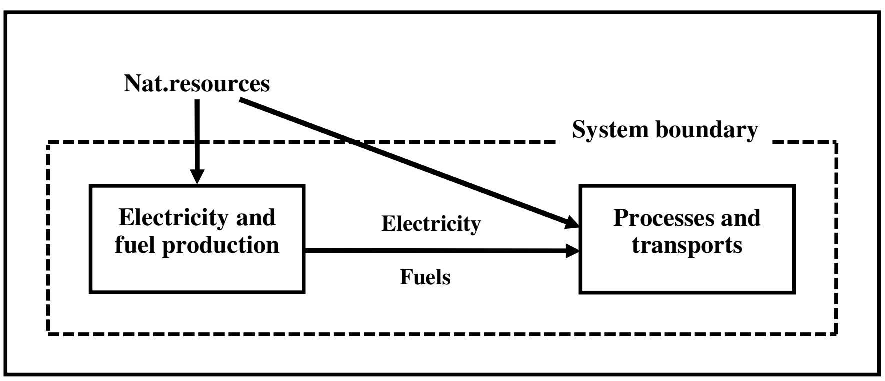


Figure 3: Illustration of system boundary regarding electricity production.

5.5.5 Validation of boundaries

The fact that non-elementary inflows and outflows are not followed to the boundary between technosphere and nature is assumed not to have a significant effect on the total LCA results. The interpretation phase includes a quantitative and semi-quantitative sensitivity analysis with the purpose to validate this assumption. If the sensitivity analysis indicates that the assumption is wrong, the system boundaries are adjusted to include the processes that are significant for the carbon footprint results, and the calculation procedure is reiterated.

5.5.6 Boundaries towards nature

The cradle of the life cycle is nature. The boundary between nature and the product life cycle is crossed when the resources used (e.g. crude oil) are extracted from the ground.

The grave of the life cycle is the soil, the air (e.g. emissions from combustion of fuels) or water (e.g. water emissions from wastewater treatment). At landfill, the time perspective here is chosen to 100 years, and not to after human activity has ceased, and landfill gas emissions and leakage production are minimal, which could be another alternative. The 100 years perspective in this case is because other standards use that perspective, and since data on e.g. decomposition used in most LCA studies are based on the 100 years perspective.

At incineration of waste, the emissions to air and the ashes or waste generated from the incineration process are included. The GHG emissions associated with the landfilling of the ashes however is not included, i.e. the ashes are a non-elementary outflow from the system, i.e. an outflow not followed to the boundary between technosphere and nature (stated as non-elementary waste).

5.6 Recovery of energy at waste incineration and landfill

At incineration, district heat and electricity are produced. These products can be used in other technical systems, avoiding the use of electricity and heat produced from other energy sources; see Figure 4.

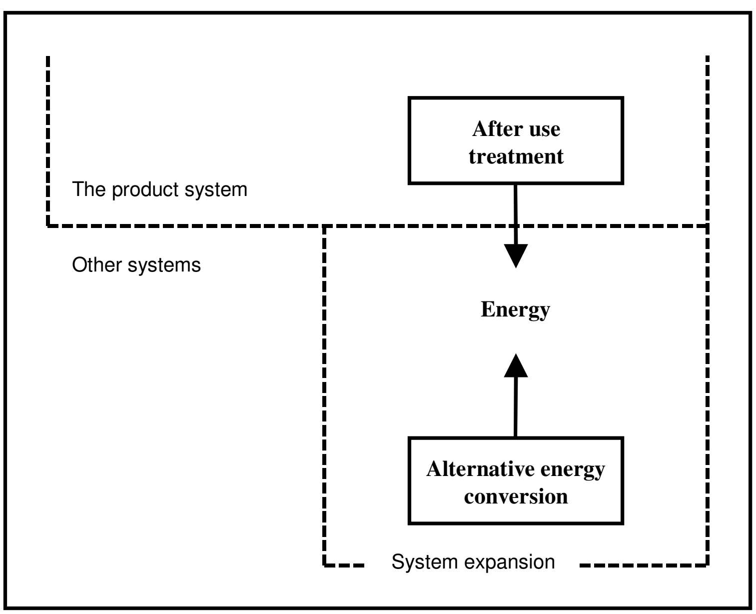


Figure 4: System boundaries are expanded to include the avoided emissions caused by generated electricity and heat from incineration.

5.7 Data quality requirements

This section presents the quality requirements on the data that are used in this study. It covers the quality aspects that are described in ISO 14044 (since ISO 14067 is not yet finished).

5.7.1 Time-related coverage

This study aims at investigating the environmental impacts of the carton product systems we have today, why as recent data as possible has been used, e.g. data from 2008 or 2007.

5.7.2 Geographical coverage

The study concerns the cartons that are produced in Europe. In toe 1, the wood represent the share of the wood used that is harvested in Europe. The data on sequestration of wood from outside Europe is a data gap, and was assumed to be zero. Imported carton board and cartons are included at the recycling stage, but it has not been possible to model the import and export to and from Europe in the model in detail within the scope of the project.

5.7.3 Technology coverage

The study aims at describing the processes used specifically for the cartons in Europe, and thus, the level of technology that these systems currently are using.

5.7.4 Precision

The precision of the data is a measure of the exactness of the data values. The aim is always to obtain as high precision as possible within the framework of the study. In most case studies, however, the uncertainties in the data are large.

5.7.5 Completeness

The completeness of the data concerns the percentage of the total GHG emissions of the cartons that have been covered in the data collection. Since this study aims at assessing the cartons entering the market in Europe, the data that should be used are the specific data for these cartons. Therefore, the ideal situation would have been to collect data from all producing pulp and carton board production plants regarding e.g. the origin of the wood. This has not been possible within the scope of the project. The time limit of this study has not allowed for such a comprehensive data collection procedure, neither has the confidentiality agreement administration needed allowed it within the scope of the project.

5.7.6 Consistency

The consistency concerns the data, the data sources and the methodologies of different parts of the study. These should be used in a consistent way for the different systems studied. This is especially important for studies used for comparative assertions. The consistency also concerns methodological issues such as systems definitions and allocation procedures. The methodology should be applied uniformly to the different parts of the analysis (ISO 14044). Here it is important that the toes 1, 2, 9 and 10 calculated here are consistent with the toes 3-7 calculated in Pro Carton (2009), when they are added up in cradle to gate and cradle to grave carbon footprints.

5.8 Category indicator for climate change

The mandatory elements of life cycle impact assessment (LCIA) according to ISO 14044 consists of selection of impact categories, category indicators and characterization models, assignment of LCI results to the selected impact categories (classification) and calculation of category indicator results (characterisation).

Global climate change is a problem for many reasons. One is that a higher average temperature in the seawater results in flooding of low-lying, often densely populated coastal areas. This effect is aggravated if part of the glacial ice cap in the Antarctic melts. Global warming is likely to result in changes in the weather pattern on a regional scale. These can include increased or reduced precipitation and/or increased frequency of storms. Such changes can have severe effects on natural ecosystems as well as the food production.

Global warming is caused by increases in the atmospheric concentration of chemical substances that absorb infrared radiation. These substances reduce the energy flow from Earth in a way that is similar to the radiative functions of a glass greenhouse. The category indicator is the degree to which the substances emitted from the system investigated contribute to the increased radiative forcing. The characterisation factor stands for the extent to which an emitted mass unit of a given substance can absorb infrared radiation compared to a mass unit of CO_2. As the degree of persistence of these substances is different, their global warming potential (GWP) will depend on the time horizon considered. Thus there exist values for 20, 100 and 500 years. In this study the time horizon 100 years has been chosen. The time scale 100 years is often chosen as a ”surveyable” time period in LCA, policy discussions and international agreements, but one should be aware that the choice may be rather arbitrary.

The total contribution to the global warming potential from the life cycle is calculated as:

$$GWP = \Sigma\ GWP_j * E_j$$

where E_j is the amount of the output j and GWP_j the characterisation factor for this output. The characterisation factor is measured *in kg CO_2-equivalents per kg of the emitted substance*, and thus, the unit of the category indicator is *kg CO2-equivalents*. The characterisation factors used for global warming are GWP100 characterisation factors as published by the International Panel of Climate Change (Forster et al, 2007).

5.9 Sensitivity check

To investigate the sensitivity of the results, a number of sensitivity analyses are performed, covering different aspects, such as the inclusion of sequestration of biogenic CO_2, alternative methodologies on carbon stored in products and in products deposited at landfill and the shares of product that is treated with different waste management options.

6 Carbon sequestration in forests (Toe 1)

6.1 Introduction

The world's annual fossil CO_2 emissions (including cement) correspond to approximately 25 billion tonnes CO_2e. (IPCC, 2007). The vegetation in temperate and boreal ecosystems sequesters in the order of 5 billion tonnes CO_2e annually and most of this goes into the forests (Hyvönen et al., 2007, Royal Society, 2001). This is a considerable amount as compared to the fossil emissions. As a result, the annual increment in atmospheric CO_2 is substantially smaller than the increment in anthropogenic emissions (Canadell et al., 2007). This is described by the so called "Airborne Fraction" (AF), which is the ratio between the annual increase in atmospheric CO_2 and the total anthropogenic emissions of CO_2 (fossil + land-use change) for the same year. This ratio varies considerable between years and range between 0 and 0.8. The AF has increased since 1960, implying that the carbon sequestration to terrestrial ecosystems and oceans have not been able to keep up with increasing anthropogenic CO_2 emissions (Canadell et al., 2007). This highlights the importance of the capacity for carbon sequestration into the forests.

The net exchange of carbon between the terrestrial biosphere and the atmosphere results from the difference between the very large fluxes of carbon uptake by photosynthesis (nCO_2 + nH_2O + light → $(CH_2O)n$ + nO_2) and release by plant and soil respiration. Disturbance processes (fire, windthrow, insect attack and herbivory in unmanaged systems), together with deforestation, afforestation, land management and harvest in managed systems are also important (IPCC, 2007). During the recent 30 years, the net result of all these processes has been an uptake of atmospheric CO_2 by terrestrial ecosystems. It is critical to understand the reasons for this uptake and its likely future course (IPCC, 2007).

The question arises to what extent carbon sequestration to forests can continue into the future? It has been estimated that the capacity for carbon sequestration by the world's forests has currently been used up only to approximately 20% of the full capacity (Kauppi, 2009). This implies that that the forest carbon sequestration can continue to increase for several decades to come.

It is important to note that actions to expand the area of boreal forests in order to mitigate climate change has been criticised, since this can change the local albedo, increase the absorbance of heat radiation and thus cause local warming (Bala et al., 2006). However, this should apply mainly on land-use change (afforestation, reforestation) and not so much for maintaining high growth rates for already existing forest land.

Key conclusion:
The carbon sequestration in forests is substantial in relation to anthropogenic emissions of CO_2.

6.2 The need for forest management for high net carbon sequestration in forests

Actively managed forests in general remove carbon from the atmosphere at much higher rates as compared to non-managed forests (Hyvönen et al., 2007; Grace, 2004). Any measure that increases the productivity of a temperate or boreal forest, such as e.g. fertilization, is likely to increase the rate at which forests remove carbon from the atmosphere. (Hyvönen et al., 2007) Carbon stocks in the forest ecosystems at the regional scale are influenced by rotation lengths, thinning intensity and the resulting age-class distribution of the forests (Nabuurs et al., 2008). Shorter rotation length generally results in lower carbon stocks in the biomass. However, increasing the rotation length might increase the risk for windthrow as well as for insect attacks. Due to vast insect attacks and fires Canadian forests have in recent years been regarded as a source, not a sink, for CO_2 (Kurz et al., 2008). The choice of tree species is important and conifers may in many cases sequester carbon more effectively that deciduous species, since conifers maintain a higher growth rate over longer time periods (Hyvönen et al., 2007).

Nabuurs et al. (2008) make recommendations for management options for how to optimize the carbon sequestration in European regions with already high carbon stock in forests. These regions cover southern Fennoscandia and some parts of central and Eastern Europe (Nabuurs et al., 2008, Figure 5). For these regions it is recommended to apply a careful regeneration regime and to reduce risks for disturbances (e.g. windthrow, insect attacks, fire) in order to preserve and increase existing large carbon stocks. Nabuurs et al. (2008) also provide some evidence that the regions with high carbon stocks are also regions with high biomass production (see Figure 6), not yet in a phase of saturation and still sequester large amounts of carbon due to that increments exceeds losses from harvests and mortality. They conclude that keeping the forest estate at a high stock and at the same time carrying out sustainable harvests is very well possible (see also Karpainen et al., 2004). They also point out, however, that optimal growing stock in relation to long-term carbon sequestration can be quite different under different growing conditions. For regions with lower carbon stocks (blue in Figure 5) it is recommended, from the point of view of carbon sequestration, to decrease harvested amounts or change towards more productive tree species.

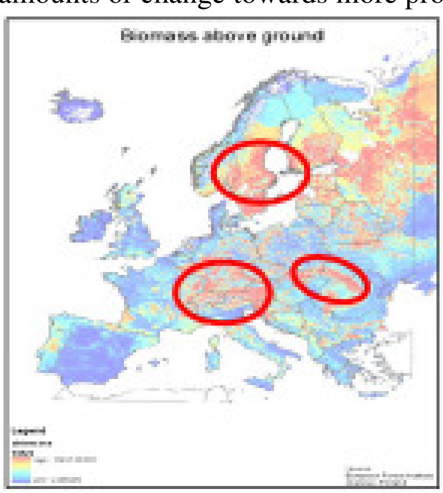


Figure 5: Regions with high aboveground biomass. Red colour; high values, yellow; intermediate, blue; low values.

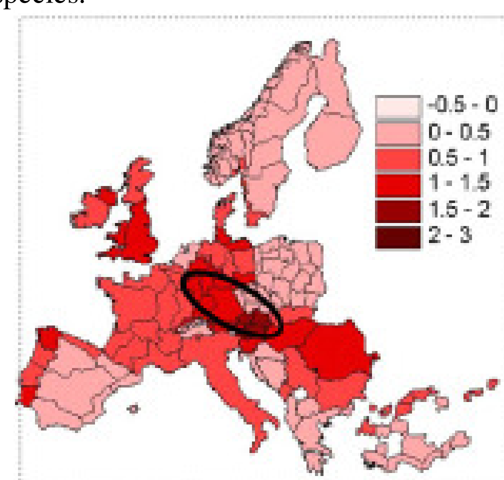


Figure 6: Net biomass production (Mg C/ha/yr).

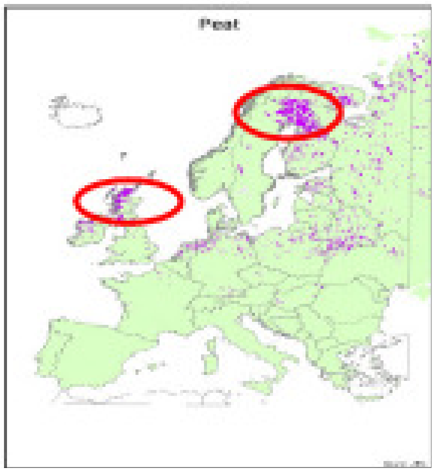


Figure 7: Regions with peat land. Source: (Nabuurs et al., 2008).

The following forest management actions to increase production in boreal and northern temperate forests have been listed (SKA, 2008; for further description see Section 6.4.2):

- Reduced time period between final harvest and planting for regeneration
- Increased fraction of area were planting was used for regeneration
- Increased planting density
- Increased density of trees left for seed production after final harvests
- More use of high quality plant material obtained from breeding activities
- Increased clearing activities
- Increased area fertilized
- 400,000 hectares of former agricultural land converted to forests (compare to current totals forest land in Sweden: 22 million ha)

The actions listed above were predicted to result in a 15% increase in the total forest growth in Sweden after 50 years, as compared to the current forest management applied in Sweden (see Figure 11). It should be remembered the current forest practice in Sweden is already quite intensive. All the actions listed above are quite labour-intensive and hence costly. It was clearly stated in the analysis that if the above actions are to be applied or not clearly depends on the economic return for the forest owner when selling roundwood on the timber market.

Nabuurs et al. (2008) provided a map for peat lands within Europe (Figure 7). This highlights a type of forest operation that is clearly negative for carbon sequestration, namely drainage and planting forests on organic peat land. Humid forest ecosystems on organic soils in northern Europe are clearly net sources for green house gas emissions to the atmosphere (von Arnold et al., 2005) of which emissions of CO_2 are most important. Hence, if an increasing market demand for timber results in forest operations to increase productivity by draining peat lands and planting forests or to clear ditches old drained forests land, then this is negative for the overall forest carbon sequestration. Thus, the origin of timber consumed for carton production need to be clarified from this respect.

The map in the Figure 7 is clearly not including all forest on organic peat soils. The map in Figure 8 shows estimated forest land on peat soils in Sweden (von Arnold et al., 2005) and it represents a much larger area. In fact, forests on peat land are estimated to comprise 5% of the total forest land in Sweden and 15% of the total emissions of greenhouse gases from Swedish forest soils (von Arnold et al., 2005).

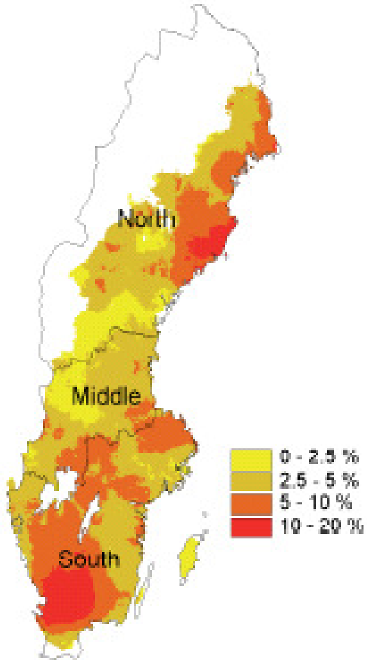


Figure 8: Share of drained forest land on organic peat soils in % of the total forest land in Sweden. Source: von Arnold et al. (2005).

Forest fires represent an important disturbance for forest carbon sequestration in certain regions, such as western Spain, southern France and parts of Italy. It is important that forest operations in response to an increasing timber demand do not result in increasing risk for forest fires. This includes mainly preventing the accumulation of wood debris on the forest floor. Since the predictions of climate change for southern Europe points towards drier conditions, sustainable carbon sequestration in these regions should aim at the choice for more fire resistant species (Nabuurs et al., 2008).

Key conclusions:
Active forest management is needed for obtaining high rates of carbon sequestration to forests. Keeping the forest at a high stock and at the same time carrying out sustainable harvests is very well possible. Some forest management actions, such as too high rates of felling or draining and planting on peat land can be negative for forest carbon sequestration.

6.3 Linking consumer demand, forest management and carbon sequestration

The CEPI Carbon Footprint concept includes as Toe 1 the carbon sequestration in the forest ecosystem. Toe 1 is in the footprint because the activities associated with supplying wood to the industry can sometimes increase or decrease long-term average forest carbon stocks and it is important that the impacts of these activities be recognized. The basic concept is that the purchase of timber by the forest industries, contributes to maintain an efficient forest management in a certain geographical area, involving planting after harvest, thinning, etc. (see previous section). These forest operations maintain a high growth rate and a large and increasing carbon stock providing that the rate of felling is made only as a fraction of the growth.

The main driver for efficient and sustainable forest management is the economic return when selling timber on the timber market (Wibe & Carlén, 2008, Figure 9). Consumer demand is required for the industries to sell their products and hence to maintain production. Buying timber maintains a high price for timber on the timber market and thus gains the economic return of the forest owner. The challenge is to demonstrate that a reduction in timber consumption by the industries will result in a certain decline in forest carbon sequestration. This should however be considered on a long time scale. Also, trying to claim credit for some of the increase in forest carbon stocks currently occurring, the challenge is to demonstrate that the increases occurring now can be attributed to the industry's demand for wood.

A further complication is that the demand for timber should not be too high, so that the rates of felling will exceed forest gross growth. This is in many countries supervised by different governmental institutions. In Sweden, for example, the forest owners are requested to report fellings larger than 0.5 hectare to the Swedish Board of Forestry.

From the discussion above, the CEPI Carbon Footprint deals with the influence of forest management on forest ecosystem carbon sequestration. Thus, these calculations have to be made in relation to a reference scenario, with no forest management applied to the same forest. In the present calculations, the reference scenario is assumed to be old, non-managed forests with a zero carbon sequestration. This assumption might be discussed but it is generally assumed that the relation between net ecosystem productivity (NEP) and tree age follow an optimum curve and that NEP for boreal and temperate forests is close to zero when the tree age is above approximately 70 years (Pregitzer & Euskirchen, 2004, but see also Carey et al., 2001). Others may argue that a reference scenario would be one where the forest is not harvested, but instead allowed to continue to accumulate carbon up to some maximum ”natural” storage level. In that case, the maximum level, where no more carbon is sequestered, would be reached at different points in different forest areas, but in average within a number of decades, why we have not selected this reference scenario.

Key conclusions:
Consumer demand for products that are produced based on forest raw material is a prerequisite for maintaining a sustainable, efficient forest management and hence a high rate of carbon sequestration in forests.

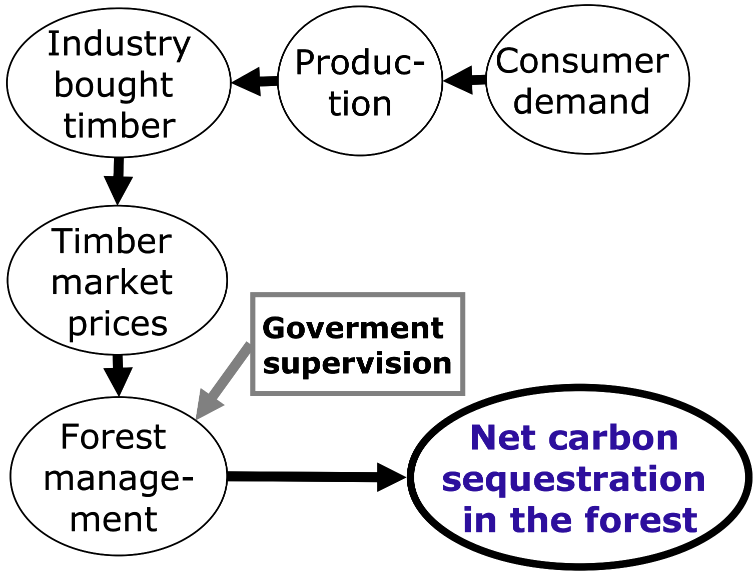


Figure 9: Principles for the CEPI Toe 1, linking consumer demand and net carbon sequestration in the forest.

6.4 Sustainable forest management – Sweden as an example

A sustainable forest management in regard to carbon sequestration is analysed and discussed in detail with an example for Sweden, since Sweden is a main producer of pulp used for carton board production. The forest management in other countries is discussed in Section 6.5.

6.4.1 Historical information

The total gross growth of the Swedish forests (including the growth of trees that are harvested later the same year and including all tree species) has been approximately 20–25% higher than the total rate of fellings, including mortality by other causes, since around 1980 (see Figure 10). That is during the last almost thirty years. As a result, the carbon stock in the living biomass fraction of Swedish forests has been estimated to increase continuously over the same time period (Figure 13).

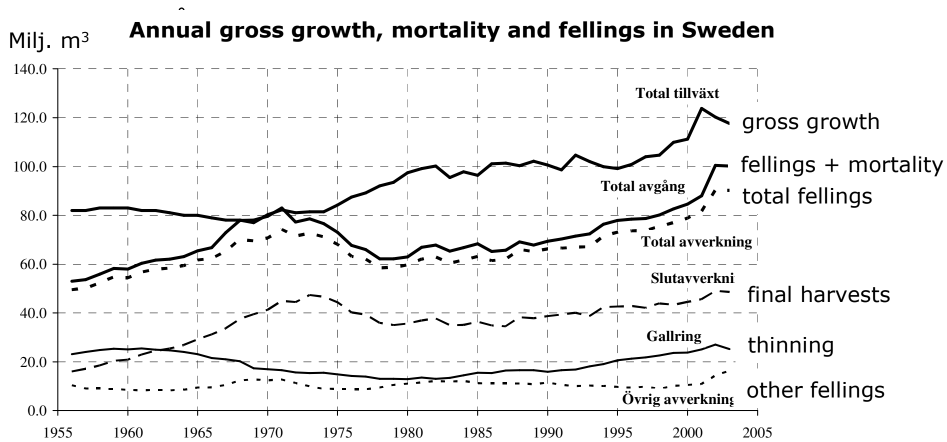


Figure 10: Annual national values for gross growth (including trees that are harvested later the same year) and yearly fellings divided into different categories of fellings for the time period 1956-2003. Values are running five-year means. All tree species. Source: Swedish National Forest Inventory (2008-12-10).

6.4.2 Future predictions

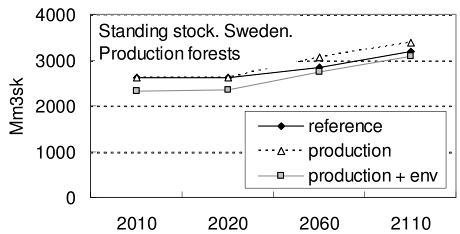
In order to be able to include Toe 1 into the Carbon Footprint calculations, it should be demonstrated that the purchased timber originates from forestry that is sustainable in respect to carbon sequestration into the forests. The time horizon in this respect should preferably be in the order of a hundred years. It is however very difficult to make credible predictions over such long time periods. But reliable, detailed predictions of forestry are possible to make for a time period of the next 20 years (SKA, 2008).

The Swedish Board of Forestry regularly produces long-term scenario analyses (SKA) for the forestry sector in Sweden. The most recent report was published 2008 (SKA, 2008). In this report the impacts different forest management intensities on growth, potential harvest and standing stock were analysed. The analyses had a strict forestry production focus and the rates of harvests were always aiming to be as close as possible to the forest growth. No concern was made to forest carbon sequestration in the construction of scenarios. Aspects of increased forest growth in Sweden due to climate change are included in the analysis.

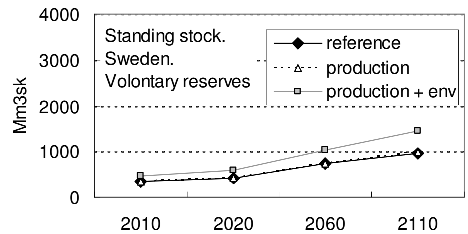
In one production scenario, forest production was increased by introducing increased forest management actions into the model analysis (see Section 6.2). These increased forest management intensities were ambitious, but not unrealistic. This production scenario was compared to normal forest practice in Sweden. There was also one scenario where the production scenario was combined with a scenario where the Swedish Environmental Quality Standards were complied with, including issues such as biodiversity, old forests, nitrogen leaching to surface waters, cultural heritage, social values, etc.

The Swedish forestry is expected to change in the future, in that it will diversify more into production forests, formal reserves and voluntary reserves (Figure 11). Voluntary reserves are set aside by the forest owners in order to preserve especially valuable and vulnerable forests such as forests close to the alpine mountain regions in northern Sweden, forest of special importance for biodiversity, forests with social values, etc. In total, it is expected that the voluntary reservation of productive forest land in Sweden will comprise in the order of 1 million hectares, which after 50 years will comprise a considerable part of the total forest land in Sweden (Figure 11). This is possible in part due to the fact that the Swedish government has large ownerships in one of the larger forest companies in Sweden.

A



B



C

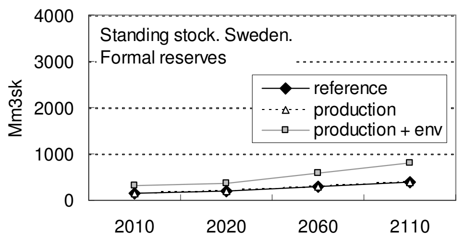


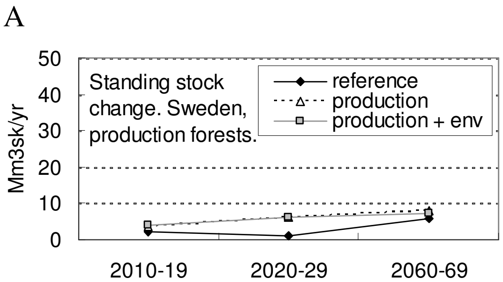
Figure 11: Prediction of standing stock in Swedish forests under three different forest management scenarios; current management (reference), increased production (production) and increased production in combination with ambitious environmental considerations (production + env). All tree species. Standing stock is given for production forests (A), voluntary reserves (B) and formal reserves (C). Source: SKA (2008).

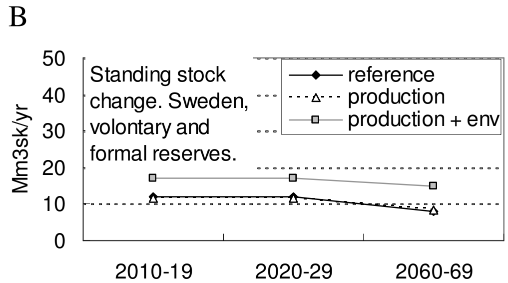
Forest management will be applied also in the voluntary reservations. However, no large clear-cut harvests will be used. The production rates will be lower and the forests will be allowed to reach considerably higher age as compared to production forests. However, due to the transition of production forests into voluntary and formal reserves in the nearest future, there will be a large increase in the total standing stock in this type of forests (Figure 11:B), especially under the scenario with ambitious environmental considerations. Hence, the voluntary and formal reserves will play an important role for forest carbon sequestration in the next 50–100 years, before they reach the age were growth will decline (Figure 12: B).

The analyses in SKA (2008) also calculate forest carbon sequestration. The analysis predicts, despite being focussed on maximum sustainable harvests rates, that the annual carbon sequestration into the Swedish forests in the next 20 years will be in the order of 13–21 million tonnes CO_2e per year, depending on scenario. A major part of this will go into voluntary and formal reserves.

Key conclusions:
There is a difference between gross growth and the rate of fellings in Sweden that has been constant for almost thirty years and that form a strong indication for sustainable carbon sequestration into Swedish forests.

Even with a focus to maximize sustainable harvest rates, it is predicted that the annual carbon sequestration into the Swedish forests in the next 20 years will be in the order of 13–21 million tonnes CO_2e. per year.





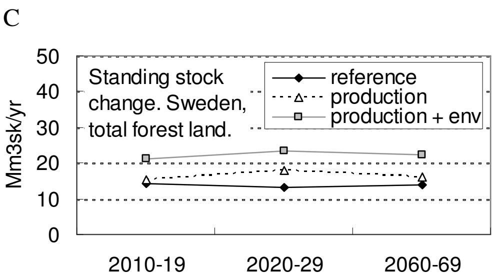


Figure 12: Future scenarios for standing stock change in Swedish forests under three different forest management scenarios; current management (reference), increased production (production) and increased production in combination with ambitious environmental considerations (production + env). All tree species. Standing stock is given for production forests (A), voluntary and formal reserves (B) as well as total forest land (C). Source: SKA (2008).

6.5 Sustainable forest management in other countries

Sustainable forestry, in respect to forest carbon sequestration, in other important European carton-producing countries had to be judged from historical records. Sustainable carbon sequestration can be assessed from data submitted to the Climate Convention by the respective countries (National Inventory Reports, NIR), regarding Land Use, Land Use Change and Forestry (LULUCF). Data are reported in tables as Common Report Formats (CRF). Here we used data from CRF Table 5A, total forest land (Figure 13).

Reporting changes in carbon stock due to forestry to the Climate Convention is voluntary. However, most European carton-producing countries have chosen to do so, with the exception of the United Kingdom. Reporting changes in carbon stocks can be made for different fractions of the forest ecosystem, such as living biomass, dead biomass, mineral soil carbon and organic soil carbon. The different countries have chosen to do so to different extents. Germany, for example, reports only the summarized net carbon stock change for the forest ecosystems. Data has been included for a period going at least 10 years back in time. It can be seen in Figure 13 that all the assessed countries have had a sustainable net carbon sequestration to their forest land for at least a ten year period. Data for Sweden is shown only up to 2003, since data for later years are not yet final, due to the extensive National Forest Inventory method used. The sustainability of carbon sequestration to Swedish forests has been discussed above.

It can be seen from Figure 13 that the highest rates of carbon sequestration is estimated for the fraction living biomass. There is also in most cases a low rate of carbon sequestration estimated for the mineral soil, while organic soils (with forest cover) are regard to release CO_2 to the atmosphere.

Despite the large number of National Forest Inventory observation plots in a country such as Sweden (30,000 plots, revisited every five years), the values for changes in the carbon stocks in Swedish ecosystems have considerable uncertainties. The uncertainty for the net carbon sequestration for e.g. Swedish forest ecosystems is estimated to 36%, divided into 22% for living biomass, 70% for dead biomass and 36% for soil carbon.

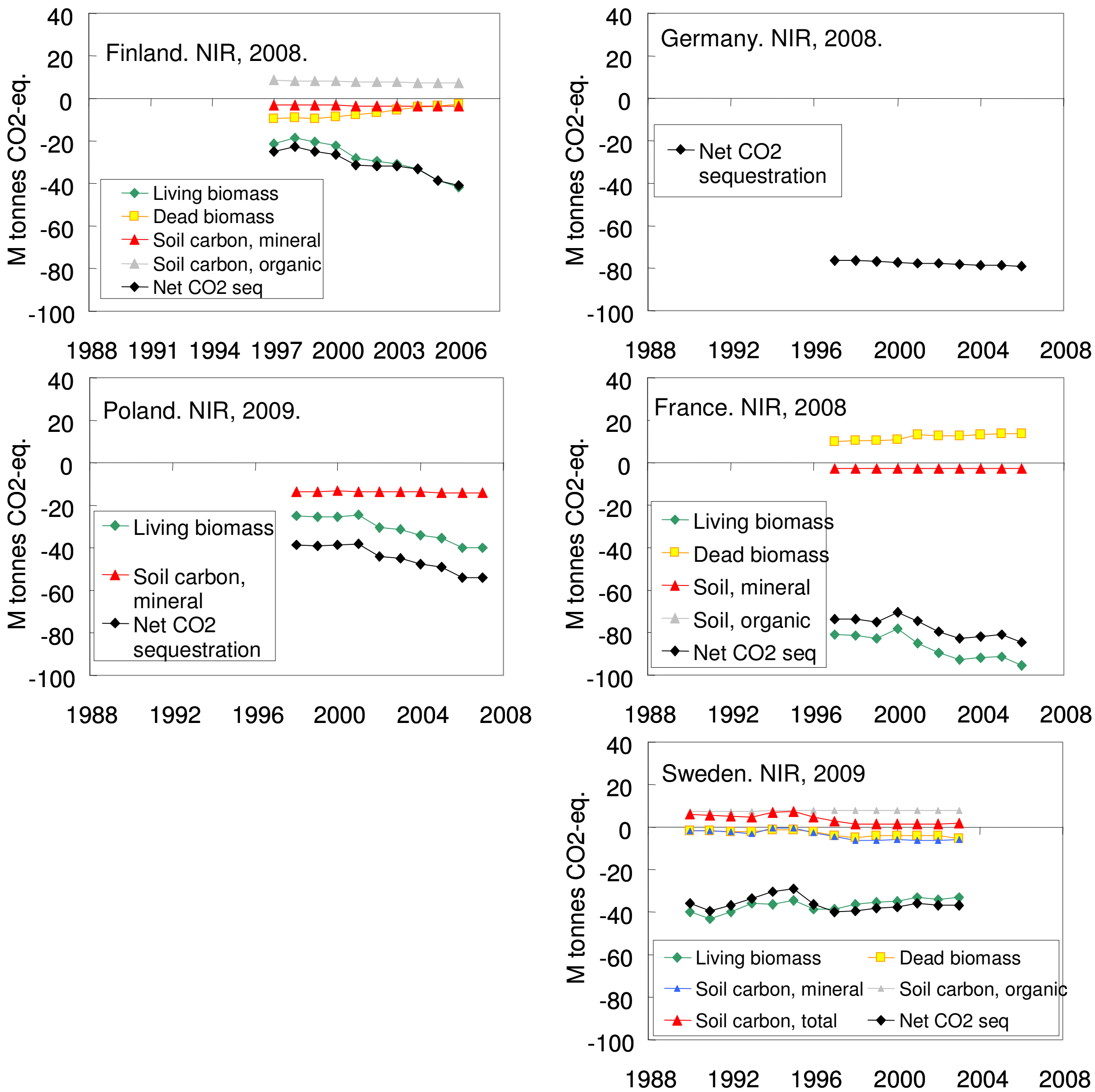


Figure 13: Annual national values for changes in carbon stock in total forest land in Finland, Germany, Poland, France and Sweden. Values are from the National Inventory Reports 2008 or 2009 (Swedish EPA, 2009), and expressed as CO_2-eqvivalents. Positive values indicate emission to, negative values uptake from the atmosphere.

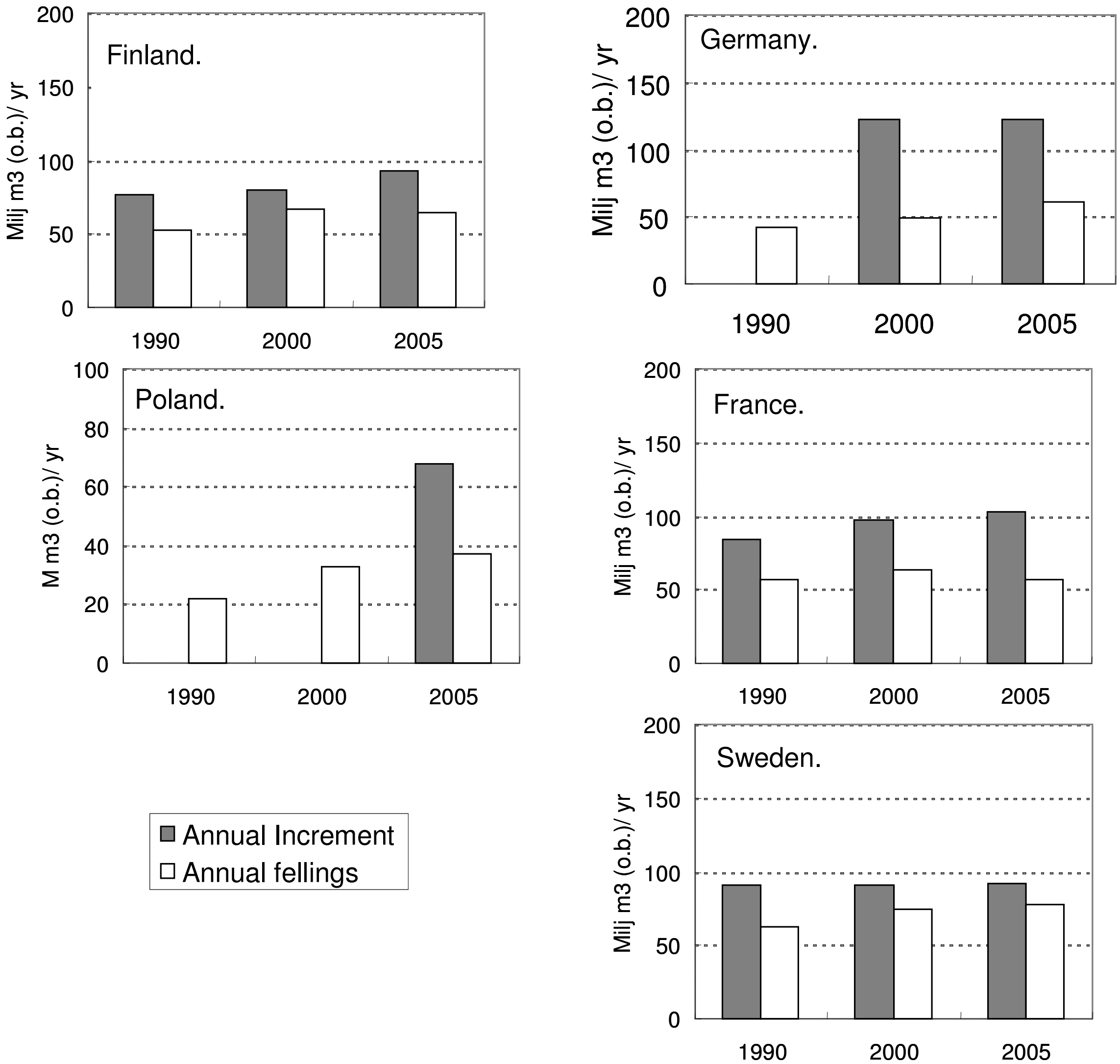


Figure 14: Annual national values for stem volume increment growth and annual fellings in Finland and Germany, Poland, France and Sweden. Values are from United Nations Economic Commission for Europe (UNECE), which in turn is based on FAO statistics.

Another aspect of sustainable carbon sequestration is that the rates of fellings should be kept well below the forest gross growth rates. National data for annual stem volume increment growth and annual rates of fellings have been collected from United Nations Economic Commission for Europe (UNECE), which in turn are based on FAO statistics. UNECE report annual values for the years 1990, 2000 and 2005. It can be seen that the rates of annual felling are well below the annual increment growth for all countries analysed.

Key conclusions:
As judged by the annual carbon sequestration to the forest ecosystems as well as the differences between annual increment growth and annual fellings, carbon sequestration to forest ecosystems can be regarded as sustainable for all important carton-producing countries assessed.

6.6 How to calculate the share of carbon sequestration in the forest that can be connected with purchased timber

The suggested principle to link carbon sequestration in the forest ecosystems to industrial production is that purchased timber can be regarded to support forestry within a certain geographical area. It is important to realize that this principle should be applied on a large geographical scale, i.e. the landscape level. It is also a “virtual” geographical area, which does not necessarily comprise a single unity but can be split in smaller parts across the region. On the other hand, the same sort of forest management and forest growth conditions should apply over the entire virtual area. Within the supported region there are all the time forest stands that are in different stages of growth and some stands that are harvested.

The simplest way to calculate the share of carbon sequestration in the forest that can be connected with purchased timber is to use values for the total amount of annual carbon sequestration in the forest ecosystem within the area and to divide this value with the total fellings in the same area for the same year. The basic assumption here is that the origin of the purchased timber is representative for the forest management and growth conditions of the entire supported region.

The first simple approach is to use nationwide values for wood consumption for carton production, harvest rates as well as for forest carbon sequestration, since the latter are values that are reported by most countries to the Climate Convention and that are in most cases based on the best available knowledge.

Key conclusions:
The general principle to link carbon sequestration in the forest ecosystems to industrial production is that purchased timber can be regarded to support forestry within a certain geographical area. This area does not necessarily comprise a single unity but can be split in smaller parts across the region. The carbon sequestration into the forest ecosystem associated with a volume purchased roundwood could be calculated as the annual total carbon sequestration to the forest in the area divided by the annual rate of fellings for the same year and area (tonnes CO_2 eq./ m^3 (o.b.) roundwood used in production).

6.7 Calculations of the share of carbon sequestration in the forest that can be connected with purchased timber based on national values

In order to reduce uncertainty due to inter-annual variation, we calculated annual values based on the latest five or six year period with reliable data (see Table 3). Data on national, annual total changes in forest carbon stock were collected from the nations’ different National inventory Reports (NIR) for the most recent year available. Uncertainty in the values for total change in forest carbon stocks were taken from the NIR. Based on the uncertainty range, values for the minimum annual total carbon stock change were calculated as a conservative approach. National values for annual rates of fellings were collected from the UNECE statistics or from National Forest Inventories (Figure 14) and values most representative for the selected time periods were used. Roundwood purchased from outside CEPI should be subtracted from the calculations if the origin was not from a sustainable forest management practice. However, for these calculations it was assumed that all roundwood used for production originated from a sustainable forest practise. The company Stora Enso imports some roundwood from Russia, but the company does convincingly show in their environmental statement reports that these forests are managed in a sustainable way. Information on the total forested area in the different countries is shown for information, but not used in the calculations. Finally, the change in forest carbon stocks that can be associated with the roundwood used in production is calculated in the unit tonnes CO_2e / m^3 timber (over bark).

Table 3: Calculations of the change in forest carbon stock that can be associated with roundwood used for production. Calculations from national data.

	Sweden	Finland	Poland	France	Germany
NIR used *	2009	2008	2009	2008	2008
Time period	1999-2003	2002-2006	2000-2005	2000-2005	2000-2005
Annual total change in forest carbon stock, M tonnes CO_2 eq. *	-37	-35	-44	-78	-77
Uncertainty forest carbon stock change, %	36	16	15	25	25
Annual total change in forest carbon stock, lower uncertainty range value, M tonnes CO_2 eq	-24	-30	-37	-59	-58
Annual fellings, total roundwood M m^3 over bark **	63	60	35	23	55
Subtracted fraction of purchased wood imported from outside CEPI, % ***	0	0	0	0	0
Forest area, mill. ha *	28	22	9	16	11
Change in forest carbon stocks connected with purchased timber, tonnes CO_2 eq./ m^3 timber (over bark)	-0.37	-0.50	-1.07	-2.52	-1.06

* Source: National Inventory Reports (NIR) to the climate convention, Table 5A. total forest land.
** Source: National forest Inventories/ UN-ECE.
*** This should be subtracted from purchased timber if the imported roundwood can not be demonstrated to originate from sustainable forestry.

6.8 Sub-national calculations

If the consumed wood is purchased from certain regions within the nations and if the forest management differs considerable between different regions, then it might be necessary to perform calculations of the sub-national level.

6.8.1 An example from Sweden

The main difference in net forest growth between different parts of Sweden is that the gap between gross growth and harvest is relatively large for Svealand (Figure 16). By comparing

Figure 15, Figure 16 and Figure 17 it seems that the cause for the relatively larger values for carbon sequestration into forest in Svealand is due to the lower rates of harvests.

It should be noted that if the demand for timber and thereby the rates of harvest in Svealand would increase, then, at least in the short term, the values that could be credited for in the CEPI Toe 1 methodology would decrease. Values for Toe 1, calculated as carbon sequestration per volume bought roundwood, increase with increasing gap between gross growth and harvests.

Key conclusions: In view of the relatively large uncertainties in the Toe 1 calculations, it is concluded that sub-national variations in forest ecosystem carbon sequestration is of minor importance.

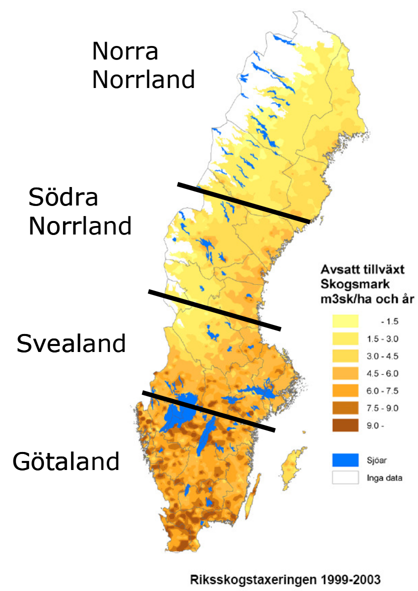


Figure 15: A map showing geographical variations in the estimated, annual gross growth (including growth of harvested trees) in Sweden. Mean values for the period 1999-2003. Source: Swedish National Forest Inventory. Unit: m^3 over bark/ hectare/ yr.

The borders for the different large geographical parts of Sweden are indicated.

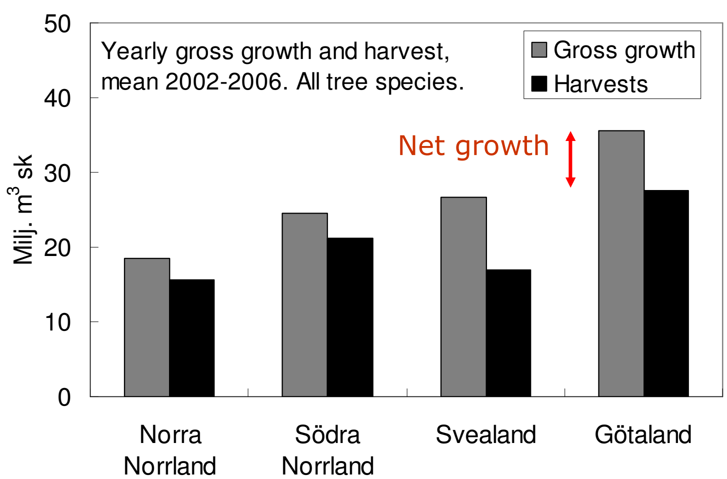
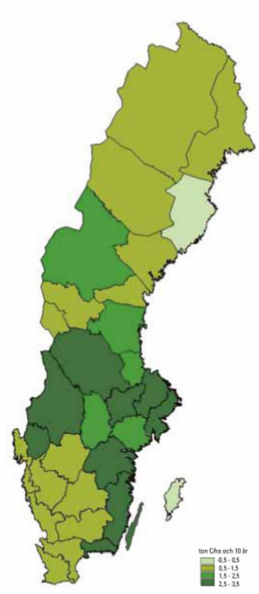


Figure 16: Yearly gross growth and yearly fellings in different geographical areas of Sweden. Unit: million. m^3 over bark/ yr.

Götaland, southern Sweden; Svealand, middle Sweden, Södra Norrland, the southern part of northern Sweden; norra Norrland, the northern part of northern Sweden.



tonnes CO2/ha/10 yr
-0.5 – 0.5
0.5 – 1.5
1.5 – 2.5
2.5 – 3.5

Figure 17: The estimated carbon stock changes in the forest ecosystem in different administrative units in Sweden on an areal basis.

Source: Report from the Swedish LUSTRA research programme (LUSTRA, 2007).

6.9 Key assumptions and uncertainties

The calculations of the CEPI Toe 1 connected with the purchase and consumption of roundwood in industrial production involves a number of important assumptions but also considerable uncertainties. Some of the most important are discussed below.

The basic concept for Toe 1 is that the forest management practice used in the different countries is favourable for forest ecosystem carbon sequestration. The following questions need to be considered:

- Does the roundwood used for production originate from sustainable forestry with rates of fellings kept below growth rates?
- Does the increased demand from consumers result in forest practice operations that are not favourable for forest carbon sequestration, such as forests on drained peat lands?

In the calculations made above, we have used nation-wide data for carbon sequestration reported by the different countries to the Climate Convention. These are official data, based on the most recent scientific methods for forest inventory. All countries report rate of fellings that are considerably below the gross growth rates. We have found no evidence that any of the countries plan to increase forest growth rates by e.g. draining more peat land area. Hence, we conclude that all forest practice in the concerned countries is sustainable.

At present government legislation as well as the forest sector future scenarios are concerned that the rate of harvests should not exceed the rates of forest growth. However, maintaining a significant gap between harvests and fellings (see Figure 14) are not of the same concern. On the contrary, the forest sector aims at keeping harvest rates below, but close to growth rates. This might result in less carbon sequestration to forests in the future. Thus, it is important to strengthen the aspect of forest carbon sequestration on the political agenda.

An important principle in climate research and policy is to avoid double accounting, i.e. that the sequestration of a certain CO_2 molecule into the forest ecosystem is taken credit for more than once. Thus, if the forest industry and the land owner are not identical, it needs to be considered if the forest owner has agreed to transfer the credits for the forest carbon sequestration to the industry. To date, the forest owner organisations have not, as far as we know, claimed credit for forest carbon sequestration. However, if this will be the case in the future, then a solution would be to introduce some sort of licence system, following the roundwood to the market, establishing the right to claim the forest carbon sequestration that can be associated with the purchased roundwood.

By manufacturing products from roundwood harvested from the forest, the industry in general claims to contribute to sustainable forest development. However, the overall key question in this context is: Will a substantial decrease in the demand for carton products result in a significant decrease in the amount of carbon sequestered by the European forests? This issue has, of course, to be regarded over a certain time span, a few years up to tens of years and in conjunction with other forest products. But the links have to be establish in a credible manner (Figure 9): Reduced consumer demand for carton-packed products– (1) reduced production by the carton makers – (2) reduced volumes of roundwood bought for virgin carton production – (3) reduced prices on the roundwood market – (4) postponed forest operations by forest owners, such as harvests, replanting and thinning – (5) reduced forest carbon sequestration. We conclude that we in the text above have established these links in a credible manner.

The calculations of Toe 1 should reflect the current situation. However, due to between-year variation, the last five-year period with reliable data should be used. The calculations should also be accompanies with some predictions about expected forest practice over the next 20 years. However, forest management policy in different countries might change relatively quickly. Hence, Toe 1 calculations need to be revised in relatively short time intervals. We suggest that they should be revised at least every five years.

As seen in Table 3, the relative uncertainties in the estimated national, values of forest ecosystem carbon sequestration can be relatively large, between 15 and 36%, despite large number of observation plots used in the National Forest Inventories. In order to take a conservative approach, we used the values from the lower uncertainty range for our calculation of the Toe 1 values.

6.10 Calculation of biogenic carbon sequestration per ton converted carton on the European market

The European average value for the amount of wood used per ton produced and converted carton is presented in Pro Carton (2009). For wood harvested in UK, no sequestration has been assumed here, since UK has not included sequestration in their National Inventory Reports for GHG emissions. For the wood used from outside Europe, around 20% of the annual amount is produced in other European and non-European countries. This may be an underestimation of the net sequestration per tonne converted cartons sold.

The data on wood used for cartons is taken from Pro Carton (2009): 0.32 ton dry wood per ton carton on the market, 0.11 ton dry chemical pulp per ton carton and 0.05 ton dry mechanical pulp per ton cartons. From these data the total volume of wood consumed per year for cartons are calculated. The calculations take into account the share of softwood and hardwood.

Table 4: The weighted average value for carbon sequestration of the nations where the timber is originating from for carton production.

Country	**Total wood consumed per year for cartons (m^3 sob/ year)**	**Net carbon sequestration per harvested volume (kg CO_2-eq/ m^3 sob)**	**Net carbon sequestration allocated to cartons (kg CO_2-eq/ year)**	**Total amounts of cartons produced (ton/year)**	**Share produced per country of total (weight %)**	**Carbon sequestration in forests (kg CO_2/ ton cartons)**
Sweden	2,878,578	-370	-1,065,073,938	1,953,300	42.97%	**-234.3**
Finland	2,555,576	-500	-1,277,787,966	1,817,725	39.99%	**-281.1**
UK	487,173	0	0	335,750	7.39%	**0.0**
Poland	267,637	-1,070	-286,371,537	184,450	4.06%	**-64.3**
Germany	171,991	-1,060	-182,310,097	136,000	2.99%	**-40.9**
France	197,336	-2,520	-497,286,720	118,533	2.61%	**-111.7**
Total				**4,545,758**	100.00%	**-732.3**

The results show that the net sequestration is 730 kg CO_2 per ton converted cartons put on the market. Again, the UK managed forests are assumed to have no net sequestration since these data have not been reported in the NIR reports, which probably is an underestimate since there should be a net sequestration in UK managed forests. Also, values for the minimum annual total carbon stock change were used in the calculations as a conservative approach

7 Toe 2: Carbon stored in forest products

Toe 2 includes the product carbon stock change in the carton product pool. The carbon content in the product has been calculated based on the carbon content in the fibre assuming a carbon content of 50% in dry fibre. The carbon content in carton products expressed as biogenic CO_2 is 1474 kg per tonne board, taking into account chemicals and non-fibre content. Taking into account that only 44% of the average ton carton is virgin carton per carton put on the market, 649 kg CO_2 is tied into the products per ton converted carton put on the market.

The weighted average life time is assessed to one year in a first approach. In order to calculate the influence of the delay in GHG emissions at use, the impact when assuming as high as two years has been studied.

Based on an average life time, then according to PAS 2050 the following can be applied:

$$\text{Weighting factor} = \frac{100-(0.76*t0)}{100}$$

If the average life time of two years, then the weighting factor is 0.9848**,** explained by a delay of the biogenic CO_2 emission at incineration. This would mean a delay and therefore as PAS 2050 methodology applies it, a reduction by 25 kg CO_2 per ton carton of GHG emissions. If average life time is one year the reduction of GHG emission is 12 kg CO_2.

Below, the influence of the delay of emissions applying the PAS 2050 is put in relation to the end of life emissions.

Incineration

The emission 1650 kg biogenic CO_2 per tonne incinerated board would then be reduced to 1625 kg. This corresponds to a reduction of 4 kg per tonne board on the market; from 263 kg to 259 kg since the share of board to incineration is 16% (see Section 8).

8 GHG emission from production and transport of the converted cartons (Toe 3-7)

Toe 3-7 were not included in the scope of the study (see Section 5). In the final carbon footprint in this study, results from Pro Carton (2009) are used for these toes.

9 Emissions associated with end of life (Toe 9)

9.1 Introduction

The end of life for carton board includes material recycling, landfill and incineration. According to Eurostat (2009), the distribution between these end of life scenarios for paper and board is 75% recycling, 15% landfill and 10% incineration in the EU-27 countries (in 2006). Paper and board however covers a broader segment involving all paper and board, including corrugated board, which has a higher recycling rate than carton board which is the focus in this study.

The material recycling rate for carton board is about 60% according to CEPI (Lombard, 2009) and this rate has been used in this study. Furthermore the same relation between landfill and incineration as for paper and board has been used i.e. landfill = 1.5 times larger than incineration. This means that when the material recycling is 60%, the landfill is 24% and the incineration is 16%.

In order to give as high transparency as possible, the three existing end of life treatment paths (recycling, incineration and landfill) are presented as separate "building blocks" so that the respective treatment mix can be calculated for the relevant market.

9.2 Material recycling

As mentioned above, this study is based on a material recycling rate of 60%. Other rates can however be found:

Based on figures from CEPI, the following average treatment is valid for EU-27: 59% material recycling, 13% incineration and 28% landfill. According to European: Packaging and Packaging Waste statistics 1998-2006, for 2006: 75% (paper and board packaging EU-27). According to Europe CEPI Sustainability Report 2007, 63.6% of paper consumed in. According to Paperrecovery.org: 56.3% was recycled in 2006.

Provided 60% material recycling and assuming that a small amount of virgin fibres are used in recycling processes and some of the fibres are lost in the process, the amount of recovered fibres is about 56% and the requirement of virgin fibres is about 44% (see Figure 18).

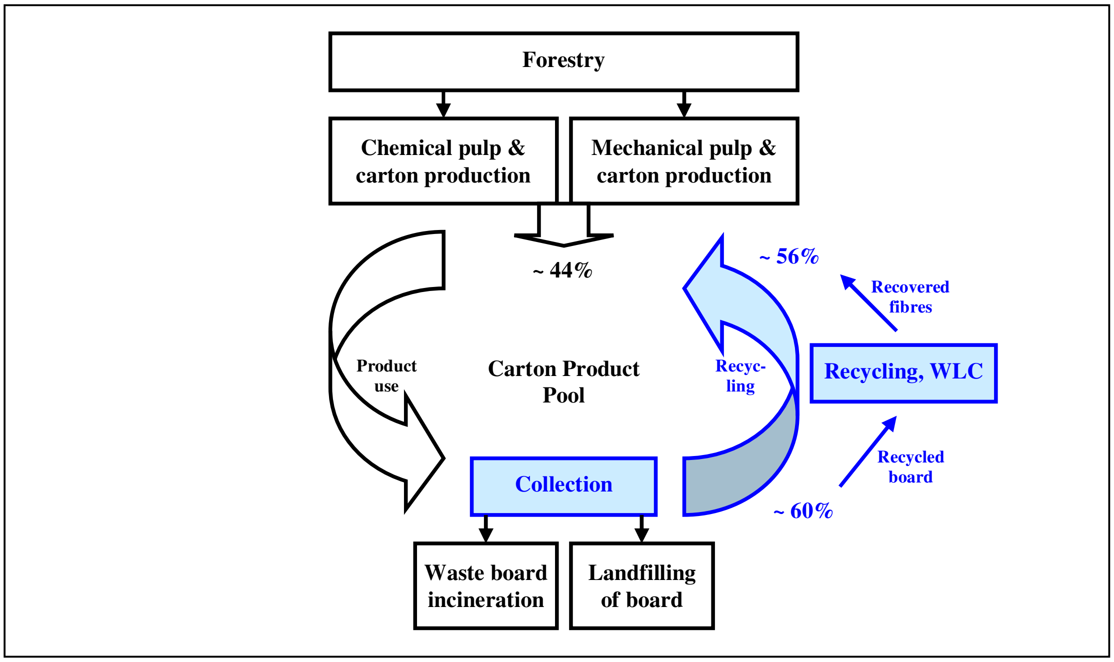


Figure 18: Material recycling of carton board.

The toes 3 to 7 cover the cradle to gate for the carton board (forestry and virgin fibre production) based on data from Pro Carton (2009). These data also cover the recycling process as such, which means that the recycling should not be added here in toe 9.

9.3 Waste incineration of board

The biogenic emission of carbon dioxide from incineration of board is 1074 kg per tonne of incinerated board. This figure was obtained based on the following:

- A dry matter of 93%.
- A cellulose content in the carton board of 63% [(1)].
- An assumed carbon content in dry cellulose fibres of 50%.

This means that the emission of biogenic CO_2 at incineration is:

1000 * 0.93 * 0.63 * 0.5 [kg C per tonne board] * 44 [kg CO_2]/12 [kg C] = 1074 kg per tonne board.

Provided 16% incineration in EU27, 160 kg of board per tonne board on the market is incinerated. This results in a biogenic emission of carbon dioxide of 171 kg per tonne converted cartons.

[(1)] Based on the standard for packaging materials (SFS-EN 13431.Table B1), the composition of cardboard is 66% cellulose, 23% lignin, 11% inert coating based on dry matter and the moisture in the board is 7%.
The project group however decided (at the Stockholm meeting 2009-05-18) that the average coating content to be used in this project is 15%. This means that the content of cellulose is 63% and lignin is 22%.

9.4 Landfill

Provided 24% landfilling in EU27, 240 kg of board per tonne converted cartons put on the market is landfilled.

It has been assumed that 60% of the landfilled material is degraded during the surveyable time period of 100 years resulting in formation of methane and biogenic carbon dioxide. Part of the methane is collected and used as biofuel (see further in Section 10).

When studying the literature, the following information on degradation and biofuel collection is found:

- Total degradation of paper during 100 year: 50-77% (Sundqvist et al: 70%, a study from Netherlands 50-60%, IPCC refers to Tabasran, 1981, 77%, however longer time)
- The methane collection is 50-60%, 50-90%, less than 50%, 60%, 65-70%, according to different articles/reports.
- IPCC global default: 18% (not relevant for Europe with the Waste Directive)
- Assumption methane collection in general 50%
- The methane is assumed to be used for heating purposes or similar (avoided emissions from use for fuel/vehicles/heating)

9.4.1 Formation of methane and carbon dioxide

Provided 93% dry matter, a cellulose content of 63% (2) in dry board and that 60% of the cellulose is degraded at the landfill (Simonson et al, 2000), 84 kg of cellulose is degraded at the landfill per tonne converted cartons put on the market.

Data on formation of methane (CH_4) and carbon dioxide (CO_2) were found in Simonson et al. (2000). According to this report, the amount of methane formed is 0.227 kg per kg of landfilled cellulose and hemicellulose, provided that 70% of the material is degraded. This means that 0.227/0.7 = 0.324 kg of CH_4 is formed per kg of degraded cellulose and hemicellulose.

This corresponds to 27 kg of CH_4 formed per tonne converted cartons. Provided that 1 mol of CO_2 corresponds to 1 mol of CH_4 (Simonson et al, 2000), the amount of CO_2 formed is 75 kg. This means that the amount of landfill gas formed is 103 kg.

Based on several sources, such as Simonson et al. (2000), a collection rate of 50% for the landfill gas is assumed. This means that the amount of biofuel is 51.5 kg, of which the amount of CH_4 is 14 kg.

The remaining landfill gas (51.5 kg) is migrating trough the soil and 10% (3.8 kg) (Simonson et al, 2000) of the CH_4 in the landfill gas is oxidised to CO_2. The total amount of biogenic CO_2 emitted from the remaining landfill gas is therefore 79 kg (about 4 kg from CH_4-oxidising + 38 kg from the landfill gas (50% of the total formation of CO_2) + 38 kg collected as landfill gas and emitted during combustion).

---

(2) Based on the standard for packaging materials (SFS-EN 13431.Table B1), the composition of Cardboard is 66% cellulose, 23% lignin, 11% inert coating based on dry matter and the moisture in the board is 7%.
The project group however decided (at the Stockholm meeting 2009-05-18) that the average coating content to be used in this project is 15%. This means that the content of cellulose is 63% and lignin is 22%.

The amount of CH_4 in the remaining landfill gas is 12 kg (90% (Simonson et al., 2000) of the CH_4 in remaining landfill gas, 0.9 * 14 kg). This CH_4 is emitted to air. This corresponds to 308 kg of CO_2-equivalents per tonne converted cartons on the market.

The calculations above are summarised in Simonson et al. (2000).

Table 5: Summary of the data used for estimating the formation of methane, carbon dioxide and the collection of methane used as biofuel at landfilling of carton board waste.

	Share	**Per tonne of converted cartons**		
Board waste to landfill	24%	240 kg		
Dry board to landfill	93%	224 kg		
Cellulose in board	63%	141 kg		
Cellulose in the board, degraded at landfill	60%	84 kg		
CH_4, total formation	324 kg/tonne degraded cellulose	27 kg		
CO_2, total formation	1 mol CO_2/ mol CH_4	75 kg (1)		
Landfill gas	***$CH_4 + CO_2$***	***103 kg***		
Collected, biofuel as CH_4	***50%***	***14 kg***		
Landfill gas that is migrating trough the soil	50%	51.5 kg		
CO_2, emission formed by CH_4 oxidising	10% of the CH_4 in landfill gas	3.8 kg (2)		
CO_2, emission from the remaining landfill gas	50% of CO_2 in landfill gas	38 kg (3)		
CO_2, collected with landfill gas and emitted at combustion	50% of CO_2 in landfill gas	38 kg (3)		
CO_2 biogenic, emission total	---	***79 kg***	**GWP [kg CO_2-eq/kg emission]**	**GWP [kg CO_2-eq/ tonne of carton]**
CH_4, emission from the remaining landfill gas	***90% of the CH_4 in landfill gas***	***12 kg (4)***	***25 (5)***	***308***

(1) In the landfill gas there is 1 mol of CO_2 per 1 mol of CH_4 $\rightarrow$ 44/16 = 2.75 kg CO_2 per kg CH_4 $\rightarrow$ 2.75 x 27 = 75 kg (Simonson et al., 2000).

(2) The remaining land fill gas is migrating through the soil and 10% of the CH_4 in the landfill gas is oxidised to CO_2 $\rightarrow$ 14 kg x 0.1 = 1.4 kg of CH_4 $\rightarrow$ 2.75 x 1.4 = 3.8 kg of CO_2 (Simonson et al, 2000).

(3) Since 50% of the landfill gas is collected, 50% of the total CO_2 formed is emitted $\rightarrow$ 0.5 x 75 = 38 kg.

(4) 90% of the CH_4 in the remaining landfill gas is emitted $\rightarrow$ 14 kg x 0.9 = 12 kg of CH_4 (Simonson et al., 2000).

(5) Forster et al (2007)

9.4.2 Waste remaining on the landfill

In the PAS 2050 methodology, the delay of emissions due to the non-degraded cellulose in landfill after 100 years may be accounted for. Below, the corresponding calculation is done for illustrative purposes.

Provided that 60% of the cellulose content in the board is degraded (see above), 139 kg of board waste remains on the landfill during the surveyable time period of 100 years. The remaining carton waste consists of cellulose that has not degraded (about 56 kg cellulose) as well as coating and lignin.

Assuming a carbon content of 50%, this would correspond to 103 kg CO_2e in the cellulose in landfill not degraded after 100 years, which could be accounted for as a change of flow/delay of emission in the PAS 2050 methodology.

9.5 Summary - End of life

The emissions associated with end of life treatment of carton board (Toe 9) is summarised in Table 6. The emissions at end of life, including the PAS 2050 methodology of delayed emissions is presented in Table 7.

Table 6: Summary of the emissions associated with end of life (Toe 9) treatment of carton board. The emissions are expressed as global warming potentials [kg CO_2-eq per tonne converted cartons put on the market].

End of life treatment	GWP	CO_2 biogenic
Material recycling	Included in toe 3-7	N.R.
Waste incineration	N.R.	171
Landfilling	308	79
Total	***308***	***250***

Table 7 Summary of the emissions associated with end of life (Toe 9) treatment of carton board if the PAS 2050 methodology of delayed emissions is applied. The emissions are expressed as global warming potentials [kg CO_2-eq per tonne converted cartons put on the market].

Total (from Table 6)	***308***	***250***
Change of flow according to PAS 2050 at landfill	-103	
Total	***205***	***250***

10 Avoided emissions from the production phase and from end of life (Toe 10)

10.1 Production phase

Avoided emissions from the production phase are already included in the toe 3: production of the carton, which is not within the scope of this study.

10.2 Introduction

The distribution between the end-of-life scenarios used in this study is 60% material recycling of, 24% landfill and 16% incineration. For further details, see Section 8.

10.3 Material recycling

The material recycling is already included in the cradle to gate profile of toe 3-7.

10.4 Waste incineration of board

According to Section 8, 160 kg of carton board per tonne board on the market is incinerated. Based on 93% dry matter, this corresponds to about 4 MWh of energy (provided a heat value for carton board of 15.3 MJ/kg [3]).

10.4.1 Amount of electricity and heat

An estimation of the relation between produced electricity and heat as well as the efficiencies for the electricity and heat produced is based on data found in a Swedish report from Avfall Sverige (2008). This report surveys incineration of municipal waste for the 19 largest European countries in year 2005 and also gives prognosis for year 2016.

According to the report about 64% of the energy produced from municipal waste incineration is heat and 36% is electricity. The efficiencies for electricity and heat are 18% and 31% (derived from data on page 48 in the report).

When applying this on carton board, the waste incineration would generate 0.7 MWh of electricity and 1.2 MWh of heat per tonne of incinerated board. This corresponds to 0.11 MWh of electricity and 0.20 MWh of heat per tonne board on the market.

[3] Based on the standard for packaging materials, SFS-EN 13431. Table B1, Cardboard (66% cellulose, 23% lignin, 11% inert coating, dry & 7% moisture), the heat value is 15.3 MJ/kg.

10.4.2 Avoided emissions from replaced electricity

The alternative electricity, which the electricity produced at waste board incineration is replacing has been assumed to be European average for the EU-27 countries.

The data are based on:

- A production mix of energy sources based on IEA (2010). The most recent data are valid for 2005.
- Life cycle inventory data for production of electricity for each energy source are based on the EcoInvent database and the data are valid for 2004.

The resulting global warming potential is 520 kg CO_2-eq per MWh electricity.

This result in avoided green house gas emissions of 58.1 kg CO_2-eq per tonne board put on the market.

10.4.3 Avoided emissions from replaced heat

The alternative production of heat, which the heat produced at waste board incineration is replacing would be an average for district heat production for the EU-27 countries.

Data for this are however not easily compiled. For Swedish district heat IVL has used 119 kg CO_2-eq per MWh and the corresponding figure for Danish district heat is 230 kg CO_2-eq per MWh.

As a rough estimate, data for heat produced from natural gas have been used. The emission of greenhouse gases is 237 kg CO_2-eq per MWh heat. The data for production and combustion of natural gas for producing heat (EU-25) are based on the professional database of the LCA software GaBi (PE International, 2006).

The results in avoided greenhouse gas emissions of 46.7 kg CO_2-eq per tonne converted cartons put on the market.

10.5 Landfill

In Section 9.4.1 , the amount of methane collected for use as biofuel at landfilling of board waste was estimated to be about 14 kg per tonne converted cartons put on the market. This corresponds to 684 MJ of methane (using a heat value of 50 MJ/kg).

The alternative source of energy, which the biofuel is replacing, has been assumed to be natural gas.

The data for production and combustion of natural gas (EU-25) are based on the Gabi LCA software database (PE International, 2006). The emission of greenhouse gases is 0.059 kg CO_2-eq per MJ of natural gas.

Provided that 1 MJ of methane can be replaced by 1 MJ of natural gas, the avoided green house gas emissions is 40.5 kg CO_2-eq per tonne converted cartons put on the market.

10.6 Summary – Avoided end of life emissions

The avoided emissions associated with the end of life treatment of carton board (Toe 10) is summarised in Table 8.

Table 8: Summary of the avoided emissions associated with the end of life (Toe 10). The emissions are expressed as global warming potentials [kg CO_2-eq per tonne converted cartons put on the market].

End of life treatment	**GWP**	**CO_2 biogenic**
Material recycling	N.R.	N.R.
Waste incineration	105	N.R.
Landfilling	40.5	N.R.
Total	***145***	***N.R.***

11 Summary carbon footprint of converted cartons

Below the results of the study are presented, combined with toe 3-7 from Pro Carton (2009). Table 10.1 shows the net flows. In table 10.2 also feedstock carbon is included. Figures should be rounded at external communication.

Table 10.1: The resulting Carbon Footprint presenting the net flows. The delay of emissions according to PAS 2050 at use and in landfills are not included.

Description of the Carbon Footprint ten toes given as GWP100	**GHG emission (kg CO_2/tonne carton)**	**Biogenic CO_2 (kg CO_2/tonne carton)**
Toe 1: Biogenic CO_2 net sequestration in managed forests		-730
Toe 2: Carbon stored in products as biogenic CO_2		
Toe 3-7: GHG emission from production and transport of the converted cartons	964	
Summary Cradle to gate or Cradle to customer gate	***964***	***-730***
Toe 8: Emissions associated with product use		
Toe 9: Emissions associated with end of life	308	
Summary Cradle to grave	***1 272***	
Toe 10: Avoided emissions from the production phase and from end of life	-145	
Summary Cradle to grave including avoided emissions	***1 127***	***-730***

If there would be no landfill in EU27 for paper packaging, the same recycling rate and the rest incineration with energy recovery, the Summary of cradle to grave would be instead 310 kg CO2e/tonne converted carton, and the biogenic net flows the same as in table 10.1.

Table 10.2: The resulting Carbon Footprint presenting the gross flows. The delay of emissions according to PAS 2050 at landfill is included in last two rows.

Description of the Carbon Footprint ten toes given as GWP100	**GHG emission (kg CO_2/tonne carton)**	**Biogenic net CO_2 (kg CO_2/tonne carton)**	**Feedstock biogenic CO2 flow (kg CO2/tonne carton)**
Toe 1: Biogenic CO_2 net sequestration in managed forests		-730	
Toe 2: Carbon tied into products as biogenic CO_2			-649
Toe 3-7: GHG emission from production and transport of the converted cartons	964		
Summary Cradle to gate or Cradle to customer gate	***964***	***-730***	***-649***
Toe 8: Emissions associated with product use			
Toe 9: Emissions associated with end of life	308		250
Summary Cradle to grave	***1 272***	***-730***	*)
Toe 10: Avoided emissions from the production phase and from end of life	-145		
Summary Cradle to grave including avoided emissions	***1 127***	***-730***	*)
Change of flows according to PAS2050 at landfill	-103		
Summary including avoided emissions and landfill delay	***1 024***	***-730***	*)

*) Not relevant to include in a cradle to gate or cradle to grave Carbon Footprint. Feedstock CO2 can however be of interest for customers using carton in other products.

12 Sensitivity check

As checking completeness, the biogenic sequestration may be underestimated since for the wood imported to Europe, no net sequestration has been assumed. Probably, the import has not increased since 2007 why this may be an underestimate of the total net sequestration per tonne converted and printed cartons on the market.

We have tried to use consistent system boundaries and data to the earlier study on toes 3-7: however, since we have not been able to go through the underlying data of the toe 3-7 study, we have not been able to check consistency completely.

The result of the sensitivity check shows that the carbon footprint is very sensitive to whether net biogenic sequestration may be added to the total carbon footprint or not. Also, the results are sensitive to whether PAS 2050 assumptions on reduced emissions because of capturing carbon in the landfilled products can be included or not. Also, the results are sensitive to the share of landfilled cartons, and to the share of degradation in the landfill.

The results are not sensitive to assumptions of retaining the carbon from the atmosphere by the use phase, since the reduction in CO_2 emissions is relative small. Also, such reduction has so far not been accepted in the international community within the working group on ISO 14067 on carbon footprint of products.

13 Conclusions

A methodology for carbon footprint including sequestration of biogenic CO_2 has been developed, showing the link between carton consumption and carbon sequestration in sustainably managed forests. Data from the National Inventory Reports and that of total rate of fellings in the same geographical area have been used to calculate carbon sequestration to the use of products corresponding to toe 1 in the CEPI Carbon Footprint Framework.

A methodology for inclusion of end of life and avoided emissions in the carbon footprint has also been developed. This is based on average statistics for waste treatment and avoided emissions.

The developed methodology is applied to the ECMA carton product pool to calculate the carbon footprint of an average carton board in Europe (see Table 9).

Table 9 The resulting Carbon Footprint presenting the net flows. The delay of emissions according to PAS 2050 at use and in landfills are not included.

Description of the Carbon Footprint ten toes given as GWP100	**GHG emission (kg CO2/tonne carton)**	**Biogenic CO2 (kg CO2/tonne carton)**
Toe 1: Biogenic CO2 net sequestration in managed forests		-730
Toe 2: Carbon stored in products as biogenic CO2		
Toe 3-7: GHG emission from production and transport of the converted cartons	964	
Summary Cradle to gate or Cradle to customer gate	***964***	***-730***
Toe 8: Emissions associated with product use		
Toe 9: Emissions associated with end of life	308	
Summary Cradle to grave	***1 272***	
Toe 10: Avoided emissions from the production phase and from end of life	-145	
Summary Cradle to grave including avoided emissions	***1 127***	***-730***

The Carbon Footprint gives important information to customers, and can serve as a benchmark for individual companies and buyers, and can serve as base for further improvements.

References

Avfall Sverige (2008), *Energi från avfall ur ett internationellt perspektiv* [in Swedish], Rapport 2008:13, ISSN 1103-4092

BSI (2008), *PAS 2050, Publicly Available Specification, Specification for the assessment of the life cycle greenhouse gas emissions of goods and services*, British Standard Institute, October 2008.

Bala, G., Caldeira, K., Mirin, A., Wickett, M., Delire, C. and Philips, T.J. (2006), *Biogeophysical effects of CO_2 fertilization on global climate*. Tellus B, Volume 58, pp. 620–627.

Canadell, J.G., Le Quéré, C., Raupach, M.R., Field, C.B., Buitenhuis, E.T., Ciais, P., Conway, T.J., Gillett, N.P, Houghton, R.A. and Marland, G. (2007), *Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks*. PNAS 104, 18866–18870

Carey, E., Sala, A., Keane, R., Callaway, R.M (2001), *Are old forests underestimated as global carbon sinks?* Global Change Biology 7, pp. 339–344.

CEPI (2007), *Framework for the development of Carbon Footprints for paper and board products* (including separate appendices). Confederation of European Paper Industries, September 2007.

Dalgleish, R. (2009), *Personal communication with Richard Dalgleish, Pro Carton*.

Eurostat (2009), Eurostat web page: ”*Table 1: Quantities of packaging waste generated in the Member States and recovered or incinerated at waste incineration plants with energy recovery within or outside the Member States for the year 2006*”. Available at http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/data/wastestreams/packaging_waste.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland (2007), *Changes in Atmospheric Constituents and in Radiative Forcing*. Available in*: Climate Change 2007:The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Grace, J. (2004), *Understanding and managing the global carbon cycle*. Journal of Ecology 92, pp. 189–202.

Hagberg, L., Karlsson, P. E., Stripple, H., Ek, M., Zetterberg, T. (2008), *Svenska skogsindustrins emissioner och upptag av växthusgaser* [in Swedish]. IVL Report B1774.

Hollinger, D.Y.; Goltz, S.M.; Davidson, E.A.; Lee, J.T.; Tu, K.; Valentine, H.T. (1999), *Seasonal patterns and environmental control of carbon dioxide and water vapour exchange in an ecotonal boreal forest*. Global Change Biol., 5, pp. 891–902.

Hyvönen, R; Ågren, G.I.; Linder, S.; Persson, T.; Cotrufo, F.M.; Ekblad, A.; Freeman, M.; Grelle, A.; Janssens, I.A.; Jarvis, P.G.; Kellomäki, S.; Lindroth, A.; Loustau, D.; Lundmark, T.; Norby, R.J.; Oren, R.; Pilegaard, K.; Ryan, M.G.; Sigurdsson, B.D.; Strömgren, M.; van Oijen, M.; Wallin, G. (2007), *The likely impact of elevated [CO_2], nitrogen deposition, increased temperature and management on carbon sequestration in temperate and boreal forest ecosystems: a literature review*. New Phytologist 173, pp. 463–480.

IEA (2010), International Energy Agency website: *Energy statistics and balances*, Available at www.iea.org/Textbase/stats/index.asp. Last accessed 2010-01-28.

Kaipainen, T., Liski, J., Pussinen, A., Karjalainen, T. (2004). *Managing carbon sinks by changing rotation length in European forests*. Environmental Science and Policy 7, pp. 205–219.

Karltun, E., Lundblad, M. and Peterson, H. (2008), *Osäkerheter och trender i den årliga rapporteringen till EU och Klimatkonventionen av upptag och utsläpp från markanvändnings-sektorn (LULUCF) i Sverige – submission 2009* [in Swedish] Sveriges lantbruksuniversitet Dnr SLU ua XX-0000/08.

Kauppi, P. (2009), *Personal communication with Prof. Pekka Kauppi, University of Helsinki*.

Kowalsky et al., (2004). *Paired comparisons of carbon exchange between undisturbed and regenerating stands in four managed forests in Europe*. Global Change Biology 10, pp. 1707-1723.

Kurz, W.A., Dymond, C.C., Stinson, G., Rampley, G.J., Neilson, E.T., Carroll, A.L., Ebata, T., Safranyik, L. (2008), *Mountain pine beetle and forest carbon feedback to climate change*. NATURE 452, pp. 987-990.

Lombard, B. (2009), *Personal communication with Bernard Lombard, CEPI*.

LUSTRA (2007), *Kolet, klimatet och skogen. Så funkar det*. [in Swedish] ISBN 978-85911-15-8.

Naturvårdsverket (2009), *Sweden's National Inventory Report 2009*. Submitted under the United Nations Framework Convention on Climate Change (UNFCCC).

Nabuurs, G.J., E. Thurig, N. Heidema, K. Armolaitis, P. Biber, E. Cienciala, E. Kaufmann, R. Mäkipää, P. Nilsen, R. Petritsch, T. Pristova, J. Rock, M.J. Schelhaas, R. Sievanen, Z. Somogyi, P. Vallet. *Hotspots of the European forests carbon cycle*. Forest Ecology and Management 256, pp. 194–200.

Pregitzer, K., Euskirchen, E. (2004), *Carbon cycling and storage in world forests: biome patterns related to forest age*. Global Change Biology (2004) 10, pp. 2052–2077.

PE International (2006), *GaBi 4 Professional software and databases*, PE International Leinfelden-Echterdingen, Germany.

Pro Carton (2006), *European Environmental Database for Cartonboard and Carton Production*, Report 2006.

Pro Carton (2009). *European Environmental Database for Cartonboard and Carton Production*, Pro Carton Report 2008.

Royal Society (2001), *The role of land carbon sinks in mitigating global climate change*. Policy document 10/01. ISBN 0 85403 561 3.

Royal Society (2001) *Climate change: what we know and what we need to know*. Policy document 22/02. ISBN 0 85403 581.

Simonson, M., Blomqvist, P., Boldizar, A., Möller, K., Rosell, L. and Tullin, C., Stripple, H. and Sundqvist, J.O. (2000), *Fire LCA-model, TV Case Study*, Swedish National Testing and Research Institute, SP Report 2000:13. Page 109. Table 63: "*Methane formation (during surveyable time period) and concentrations in landfill gas. All figures are related to dry, organic (ash free) substance.*"

SKA (2008), *Skogliga konsekvensanalyser 2008* [in Swedish]. Swedish Board of Forestry. Report 25/2008. ISSN 1100-0295.

von Arnold, K., Hånell, B., Stendahl, J., Klemedtsson, L. (2005), *Greenhouse gas fluxes from drained organic forestland in Sweden*, Scandinavian Journal of Forest Research, 20, pp. 400 – 411.

Wibe, S. Carlén, O. (2008) *Forest Economy – an introduction* [in Swedish]. The Institute of Forest Economy. Swedish University of Agricultural Sciences.