Energy, Carbon and Other Material Flows in the Life Cycle Assessment of Forestry and Forest Products

Achievements of the Working Group 1 of the COST Action E9

Timo Karjalainen, Bernhard Zimmer, Staffan Berg, Johannes Welling, Hannes Schwaiger, Leena Finér and Patricia Cortijo

European Forest Institute
Discussion Paper 10, 2001

EUROPEAN FOREST INSTITUTE

ISBN: 952-9844-92-1
ISSN: 1455-6936

Energy, Carbon and Other Material Flows in the Life Cycle Assessment of Forestry and Forest Products
Achievements of the Working Group 1 of the COST Action E9

Authors: Timo Karjalainen, Bernhard Zimmer, Staffan Berg, Johannes Welling,
Hannes Schwaiger, Leena Finér and Patricia Cortijo

Publisher: European Forest Institute
Torikatu 34
FIN-80100 Joensuu
Finland

Editor-in-Chief: Risto Päivinen

Tel: +358-13-252 020
Fax: +358-13-124 393
Email: publications@efi.fi
WWW: http://www.efi.fi/

The authors would like to thank those who participated in the activities of Working Group 1 in the COST E9 Action, and Tim Green for editing this publication. We are also grateful to COST for the opportunity to collaborate on this matter.

Authors' contact information

Timo Karjalainen
European Forest Institute
34 Torikatu
80100 Joensuu
Finland
Email timo.karjalainen@efi.fi

TABLE OF CONTENTS

1 INTRODUCTION

T. Karjalainen and B. Zimmer

This publication includes results, discussions and conclusions of an activity that has been carried out as part of the COST E9 Action "Life Cycle Assessment of Forestry and Forest Products" in one of its working groups dealing with Production. This working group was concerned in particular with energy, carbon and other material flows. Work has been carried out between the first group meeting in March 1998 (Joensuu, 26-27 March 1998) and September 2001.

COST (European Co-operation in the Field of Scientific Research and Technical Research) is a framework for scientific and technical cooperation, allowing the co-ordination of national research at the European level. COST Actions consist of basic and competitive research as well as activities of public utility. The goal of COST is to ensure that Europe holds a strong position in the field of scientific and technical research for peaceful purposes, by increasing European co-operation and interaction in this field. COST has developed into one of the largest frameworks for research co-operation in Europe and is a valuable mechanism for co-ordinating national research activities at the European level. Today its nearly 200 Actions involve some 40 000 participating scientists from 32 European member countries and from nearly 50 participating institutions from 14 countries. These networks represent a value of more than 2 billion Euros. The official COST web-site is *http://cost.cordis.lu/src/home.cfm* and provides further information about COST.

"Life cycle assessment" (LCA) is a relatively new and developing science, but it has already been seen as an important tool to evaluate the environmental impact of forestry and forest products. The main objective of the COST E9 action is to expand multi-disciplinary life cycle assessments to cover the whole forestry and forest products chain. Background, objectives and scientific programme of the action is described in the Memorandum of Understanding, available at the action web-site at *http://www.rrz.uni-hamburg.de/cost*. This site also includes details of the work carried out in the action, in particular in the working groups.

Regarding the Working Group 1 (WG1) on "Production: energy, carbon and other material cycles", the life cycle of the renewable raw material wood includes a system of short-, medium- and long-term material (carbon and other minerals, water) and energy cycles. The carbon cycle starts with the biosynthesis in the forests. It includes the storage

Energy, Carbon and Other Material Flows in the Life Cycle Assessment of Forestry and Forest Products
Timo Karjalainen, Bernhard Zimmer, Staffan Berg, Johannes Welling, Hannes Schwaiger, Leena Finér and Patricia Cortijo

of carbon in standing trees and processed products and finally completes the cycle by releasing CO_2 into the atmosphere during biodegradation or combustion. Re-use and recycling leads to a prolongation of the life cycle.

The advantages of wood as a renewable raw material for paper and non-paper products as well as for energy generation cannot be fully addressed unless the most important material and energy cycles are considered in LCA.

According to the Memorandum of Understanding of the COST E 9,with some modification by the group, WG1 had the following objectives:

1. To propose methods and guidelines for the integration of energy and material/energy cycles into LCA for forestry and wood products. WG1 had specified that material cycles could include carbon, nitrogen, sulphur, phosphorus, calcium, potassium, magnesium, micronutrients and heavy metals.
2. To propose calculation methods and rules for multi-product systems and for material recycling, energy generation and waste disposal. WG1 had added allocation of flows as an important item for further consideration.

Based on discussions in the group, interpretation of LCA results should be also considered (moreover, minimum requirements for reports and comparison with requirements in the ISO standards) in addition to how to do LCA.

WG1 organized its work as presented in Figure 1. Participants attached themselves to the tasks based on their expertise. Participants agreed to work on these tasks in the meetings and between the meetings in order to be able to provide a report at the end of the action.

Final results of the work on tasks 1, 2, 4 and 5 are provided in the next chapters of this report. Chapter 2 provides results of Task 1 “Identification of problems using case studies”; Chapter 3 provides results of Task 1 “Problems with terms and definitions in inventories for forest sector LCA”; Chapter 4 provides results of Task 2 “Static/dynamic approach, spatio-temporal problems”; Chapter 5 provides results of Task 4 “A comparison of fuel consumption and GHG emissions from forest operations in Europe”; and Chapter 6 provides results of Task 5 “Inclusion of nutrients in LCA of forestry and forest products”.

There is no specific chapter for the results of Task 3, since this task was completed as part of the establishment of the action web-site. Box 1 summarises the work on Task 3.

National representatives in the working group were from 15 countries (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Norway, Slovenia, Sweden, Switzerland and United Kingdom), and mainly from research organizations (Appendix I). The Working Group had seven meetings during the running time of the action. Some of the meetings were joint meetings with other working groups. These joint meetings included parallel working group sessions and joint plenary sessions. In addition, one short-term scientific mission was carried out by Staffan Berg, and results of this mission were presented in the mid-term seminar of the whole action in Espoo, Finland 27–29 March 2000 (see one of the case studies in Chapter 2). The results of Working Group 1 have been presented at the final conference of COST E9, 29 November–1 December 2001, Hamburg, Germany.

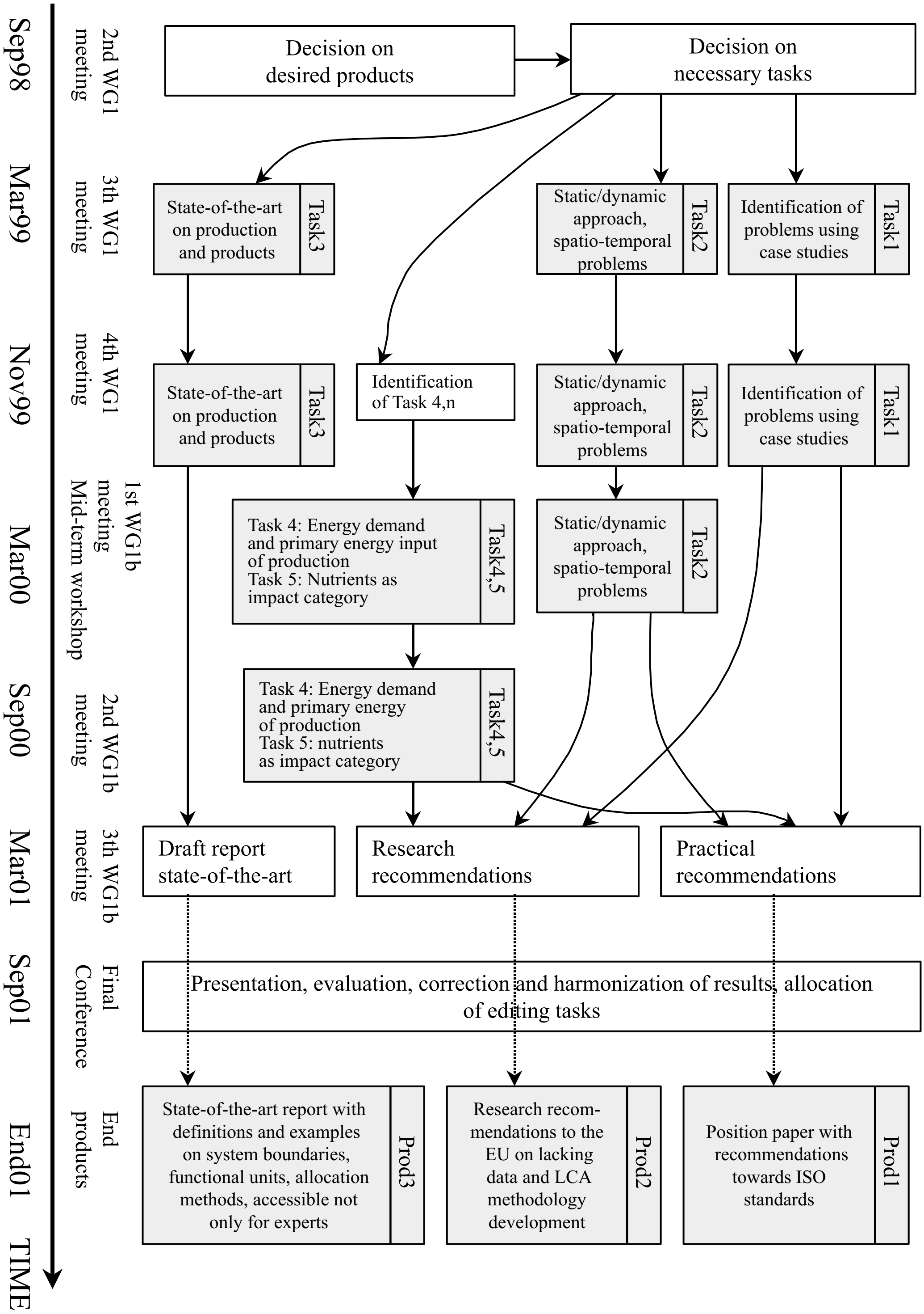

Figure 1. Workplan of the Working Group 1 on “Production: energy, carbon and other material cycles”.

BOX 1. SUMMARY OF THE WORK ON TASK 3 "STATE-OF-THE-ART ON PRODUCTION AND PRODUCTS".

The overall goal seemed to be a web-site with links to other LCA related sites. The practicality of what is achievable by this group was the topic of discussion.

The issue of responsibility for such a project was raised. It was suggested that really it was in the overall control of the management committee of the action and as such anything should be developed in liaison with the management committee. WG3 was also collecting information for an information source. There were also plans to set up some kind of project to get this initiative started.

It was generally accepted that it would not be possible to develop any kind of site that had access to data, as this was not a realistic option. Contents for possible site were also discussed:

- Rules, guidelines and standards for LCA
- Publications – Journal articles, reports etc.
- Web-site links
- People
- Institutions
- Models – for LCA and Forestry

The suggested listing of projects in countries, suggested at the first whole action meeting had only been carried out by some countries. However, it was suggested that this could be a starting point for the information gathering. It was generally acknowledged that there was little point collecting further information until the format had been decided.

The other issue was whether to have a simple or detailed information source. This would really depend who the site was to be used by. Later the management committee of the action decided that the action would have a common web-site. Then working group 1 decided that the collection of national projects the group had collected would be the contribution of the task 3 to the web-site, and this task was then regarded completed. Descriptions of national projects are available at the action web-site.

2 IDENTIFICATION OF PROBLEMS USING CASE STUDIES

Coordinating author: T. Karjalainen

Contributing authors: T. Apneseth, P. Esser, L. Finér, G. Jungmeier, B. Kosir, K.-E. Kvist, J.-M. Roda, H. Schwaiger, S. Berg, B. Zimmer and J. Welling

2.1. INTRODUCTION

The aim was to learn from 'real life' case studies what are the typical problems that are faced in LCA studies. The Working Group decided to have presentations in the meetings on case studies, presenting the study and results, but also spelling out clearly what kind of problems have been faced in different phases of the study. These problems were then discussed and the group tried to find solutions to the identified problems. Altogether 10 case studies are summarized in a standard format.

Case studies have been grouped into the following groups based on the coverage of the study in the forest-wood product chain:

- forestry
- mechanical forest industry
- chemical forest industry (no case studies reported)

Five of the case studies fell under the forestry category and five under the mechanical forest industry category. None of the reported case studies was under the chemical forest industry category.

Since the group felt uncomfortable to provide recommendations and guidelines (group is not able to provide guidelines, since COST E9 Working Group 1 does not have a mandate to this), the group decided instead to provide conclusions to each of the case studies.

It is also worth noting that the system boundary is defined in such a way that production of the raw material, processing and the use of products were considered, but land-use change, biodiversity, and 'infrastructural benefits' such as soil and water protection, protection against avalanches were not considered.

Energy, Carbon and Other Material Flows in the Life Cycle Assessment of Forestry and Forest Products
Timo Karjalainen, Bernhard Zimmer, Staffan Berg, Johannes Welling, Hannes Schwaiger, Leena Finér and Patricia Cortijo

2.2 CASE STUDIES

2.2.1 Forestry, five case studies

Study 1	LCA of poplar plantations in France (Ecobilan du peuplier) (presented in the London workshop, 15th September 1998)
Organization and contact person	Jean Marc Roda (CIRAD. Email roda@cirad.fr) (AFOCEL at that time) for data on energy, Fertilizer and chemical inputs Alain Valadon (CEMAGREF) for data on nutrient cycle Patricia Cortijo (ECOBILAN) for LCA methodology
Short description of the study	Presentation on LCA regarding poplar plantations in France. The research was embedded in a LCA for pallets made from poplar. The LCA data collected should be used to allow a comparison between wooden pallets and plastic pallets. All inputs including breeding of young poplar seedlings, fertilization, maintenance of the plantation and harvesting were quantified.
Main problem(s) encountered	There are good statistics about the consumables, but flows of mineral nutrients could not be determined. They had to be taken from literature references. The available data showed a large variation because of a wide range of boundary conditions. Another problem was caused by the different time scales for: (1) extensive; (2) intensive; and (3) medium intensive cultures. All data were related to a harvest of 300 m^3/ha at the end of rotation. There are few data points, but they do not cover the whole rotation length, or the same kind of production systems. Problems arose from different land demands for producing the functional unit. It was not clear whether nutrition consumption as a function of time should be related to annual increment, m^3 or ha. No eco-indicators were used. Biodiversity was strongly effected by the surrounding land and not so much by the plantation itself. Therefore, site effects are enormous. Plot size is most important. A third difficulty was related to geographical scale: how to extrapolate from a few case studies to national scale?
Conclusions from the working group	Functional unit should be defined better, e.g. m^3, to be able to be related better to the products.
References	–

Study 2	LCA of forestry in Germany (presented in Thessaloniki, 8–9 March 1999)
Organization and contact person	Jörg Schweinle (Bundesforschungsanstalt für Forst- und Holzwirtschaft) Bernhard Zimmer (Holzforschung München, TU München. Email bernhard.zimmer@ht-kuchl.ac.at)

Short description of the study	LCA study was carried out to calculate average life cycle inventory (LCI) data for the forestry of Germany. Data were collected from the German forestry system and assumptions were made using a worst-case scenario. This means, that all the forest operations considered within the study were carried out on the highest possible mechanization level. The investigation was for done the most important tree species in Germany (spruce, pine, oak and beech). Within the system boundaries, the biological system of wood production through photosynthesis was included. The most important forest operations considered were: planting, cleaning, thinning, felling, hauling as well as liming and debarking. The products were stemwood (logs) and industrial wood.
Main problem(s) encountered	Setting the system boundaries because of the long time period; allocation because of the infrastructural functions like water and soil protection which can be seen as a product too.
Conclusions from the working group	To work on definitions and terms. See Chapter 3 of this report, "Problems with terms and definitions".
References	–

Study 3	Some aspects on data-collection and interpreting of results (presented in Thessaloniki, 8–9 March 1999)
Organization and contact person	Staffan Berg (Skogforsk, Sweden. Email staffan.berg@skogforsk.se)
Short description of the study	Presentation demonstrated how different ways of data collection can give considerable differences in results, which may or may not also be dependent on physical factors. Two approaches for data collection in order to compile LCI-data for Swedish forestry were compared. In a 'from above' approach, national data was computed with the aid of gross statistics concerning all Sweden, reflecting the status around 1990. Data were procured from basically two kinds of sources: 1. Statistics regarding actual work volume, ha, cubic metres timber harvested or tonne/km transportation work. 2. Operational data or work study data about production efficiency and fuel consumption per work or time unit. Another approach, 'from below', means that data are collected from a vast forest area during one year of operation. Records were kept of all resources allotted to that area in order to deliver the timber that was transported from the area. During collection data was sorted according to four origins: 1. Measurements, i.e. actual consumption of fossil fuel and actual delivery of timber.

2. Measurements and constants, i.e. for example, actual volume produced, actual machine hours with a measured constant of fuel/ machine hour.
3. Local averages, i.e. data concerning machines or equipment in this specific area.
4. General averages. As a whole in Sweden, for example, some railway data.

Discrepancies between approaches occurred due to several reasons. Gross data did not cover all measures performed. Problems of boundaries between operations, secondary transport, logging and stand treatment. Machine efficiency with regard to production and energy use. Different data quality depending on origin.

Main problem(s) encountered	Data from contractors are seldom available, if these are not certified according to ISO 14000. System boundaries varied and in many cases were not clearly defined for the data. There is a need for a common structure for metadata. Emission factors available in literature were not appropriate with respect to fuels and engines used.
Conclusions from the working group	Better data quality. Check approach ‘from above’ with – data ‘from below’. Investigate emission factors that are representative to the fuel and engines used. Take appropriate emission factors forward.
References	Berg, S. 1998. An inventory of forest operations for LCA of forest products. Paper presented at International Conference on Life Cycle Assessment in Agriculture, Agro-Industry and Forestry, 3–4 December 1998 in Brussels, Belgium. Berg, S. 1995. The Environmental Load of Fossil Fuels in Swedish Forestry – an Inventory for a LCA. Life Cycle Analysis – a Challenge for Forestry and Forest Industry. Frühwald, A. and Solberg, B. (eds.). EFI Proceedings No. 8. Pp 53–61. Berg, S. 1997. Some aspects of LCA in the analysis of forestry operations. Journal of Cleaner Production 5(3).

Study 4	Comparison of emission from forest operations in Sweden and Finland (presented in Espoo, 27–29 March 2000)
Organization and contact person	Staffan Berg (SkogForsk, Sweden. Email staffan.berg@skogforsk.se) Timo Karjalainen (EFI. Email timo.karjalainen@efi.fi)
Short description of the study	The authors of this study have published studies of environmental loads from forest operations in Sweden (Berg, 1995) and Finland (Karjalainen and Asikainen, 1996). These studies are based on data from operations in the late 1980s and early 1990s. The authors have

	compared findings in those reports regarding emission of CO_2 from logging operations, transport of timber to industry, and from some silvicultural activities. The proportion of volumes harvested in thinning and final felling was similar in both countries. Operational conditions in Sweden and Finland were similar concerning the balance between and volumes harvested in thinnings and final fellings. There were also similarities concerning machine types used in logging and also regarding methods used for soil preparation and stand treatment. Differences occurred in terrain difficulty and level of mechanization in thinnings.
Main problem(s) encountered	The study revealed the importance to depend on the origin and quality of data. In forest operations usually two types of data are available, these are either time study data or data from follow-up of routines. Mixed origin of data might cause mistakes in calculating energy consumption.
Conclusions from the working group	Another lesson to be learned from the study is the importance to depend on the origin and quality of data. In forest operations two types of data are usually available. These are either time study data or data from follow-up of routines. Study revealed that the use and origin of data might cause mistakes in calculating energy consumption. Task 4 on Energy demand and primary energy input of roundwood production started.
References	Berg, S. 1995. The Environmental Load of Fossil Fuels in Swedish Forestry – an Inventory for a LCA. Life Cycle Analysis – a Challenge for Forestry and Forest Industry. Frühwald, A. and Solberg, B. (eds.). EFI Proceedings No. 8. Pp 53–61. Karjalainen, T. and Asikainen, A. 1996. Greenhouse gas emissions from the use of primary energy in forest operations and long-distance transportation of timber in Finland. Forestry 69(3):215–228.

Study 5	Resource consumption and emissions induced by logging machinery in a life cycle perspective (presented in Montpellier, 18–19 September 2000)
Organization and contact person	Dimitris Athanassiadis (Swedish University of Agricultural Sciences, Department of Silviculture. Email: Dimitris.Athanassiadis@ssko.slu.se).
Short description of the study	The study summarizes and discusses results from four separate studies on energy and resource consumption and emissions during the life cycle phases of harvesters and forwarders i.e. logging machinery in the cut-to-length harvesting system. Energy input during operation was 82 MJ/m^3u.b., 11% was due to energy consumption during the production phase of the fuel. Exhaust emissions varied considerably depending on the kind of fuel that was examined (rapeseed methyl ester, environmental class 1 and environmental class 3 diesel fuels)

	and on whether emissions produced during the production phase of the fuels were taken into consideration. It was also estimated that 35 liters/1000 m^3u.b. of chainsaw oil was used for felling and crosscutting while hydraulic oil spillage from both harvesters and forwarders was 20 liters/1000 m^3u.b. On the subject of spare part replacement, it was estimated that 52% of the mass of a forwarder would be replaced during its operational lifetime while the corresponding figures for the single- and two-grip harvesters are 56% and 50%, respectively. The manufacturing phase of the forest machinery was found to contribute only modestly to the total environmental impact of timber harvesting and terrain transportation (measured per unit of timber production). Some 6%of the machinery's life cycle energy consumption was due to activities connected with the production of the vehicles; raw material acquisition and intermediate processing, fabrication of individual components, assembly of the vehicles, and associated transports.
Main problem(s) encountered	It was difficult to get specific data from the industry (confidentiality problems) so aggregated data had to be used. On the other hand it was judged that aggregated data from many different manufacturers was the only way to satisfy the aim of the study. The system was very large, and therefore, not all of the requirements of ISO 14040, 14041, 14042 could be satisfied. No free LCA databases were available when the study was performed (1996–1999).
Conclusions from the working group	In the working group, discussion concentrated on study specific matters such as system boundaries and allocation procedures. It was mentioned that it is possible that the values on energy consumption and emissions for machine manufacturing stated in the study could be used for other kind of work machinery in other LCA studies. Some more specific comments were made: in the study, CO_2 emissions during combustion of rape methyl ester (RME) are reported. The working group had the opinion that it should made clearer that CO_2 emissions during combustion of RME are balanced with the CO_2 fixed by photosynthesis.
References	Athanassiadis, D. 2000. Resource consumption and emissions induced by logging emissions induced by logging machinery in a life cycle perspective. Acta Universitatis Agriculturae Sueciae, Silvestria 143, Swedish University of Agricultural Sciences, Doctoral Thesis.

2.2.2 Mechanical forest industry, five case studies

Study 6	LCA of a Dutch window frame (presented in Thessaloniki, 8–9 March 1999)

Organization and contact person	Petra Esser (Part of the Life-Sys-Wood project – Co-ordinator TNO, Netherlands)
Short description of the study	• Comparison of window frames manufactured from spruce and tropical dark red Meranti wood • Meranti from Malaysia and Indonesia • All burdens allocated to timber
Main problem(s) encountered	Collection of data from Malaysia and Indonesia was very difficult and gave room for error European data were used to describe tropical operations (Swiss EMPA data were used for the calculation of energy use of dark red meranti; European average bark content was used for bark of dark red meranti) Discrepancies in terminology (e.g. wood waste was used for energy production)
Conclusion from the working group	• More field visits to obtain reliable local information • Environmental effects of selective logging in Malaysia and Indonesia to be considered, felling of many other tree species may in turn have implications for allocation if used in some way • Consideration of wood waste needs further clarification
References	–

Study 7	Environmental Analysis of the Danish Wood and Furniture Industry (presented in Montpellier, 18–19 September 2000)
Organization and contact person	Knud Erik Kvist, Christian Kofod, Marianne Fox (Danish Technology Institute, Wood Technology. Email knud.erik.kvist@dti.dk)
Short description of the study	Objectives of study: • To analyse the size and composition of the entire industry • To identify and assess the environmental impact of the sector – from cradle to grave. • To recommend actions that will improve the environmental efforts through development of more environmentally friendly industrial products, thus strengthening the competitiveness on the domestic end export markets. • To illustrate the possibilities of integrating environmental considerations into the product development process by using computer-based tools for environmental assessment. The Danish wood and furniture industry has a tradition for importing low cost goods and processing them into high value goods. This study has supported this theory by performing an in-depth study of both the material and financial and energy flows within the sector. Based on this statistical information three products, typical of the sector have been selected for further investigation as to their

environmental performance using the Danish Life Cycle Assessment method, the EDIP-method.
The chosen products are an office chair, a solid wood table and a window. Based on the LCAs approximately 80 new sets of data containing information regarding energy consumption, processes, emissions etc. have been aggregated. These data will consequently be added to the Danish LCA database.
During the compilation of the LCAs, several focus points have been emphasised. Some of these included: consumption of steel; processing of wood (especially exhaustion of wood particles, shavings and chips); emission of solvents from lacquers; and energy loss through windows during the use stage. As shown in other assessments, this study also emphasises the significance of optimal disposal of both production waste and during disposal of the used product.

To illustrate how to integrate environmental considerations into the product development for small- and medium-sized enterprises (SMEs) in a simple way a 6xR Philosophy was developed:

- Re-place: Replace problematic material with better alternatives.
- Re-duce: Reduce the number and the amount of materials.
- Re-cycle: Design so that the product can be separated in fractions.
- Re-use: Use second hand components in new products.
- Re-pair: Make sure that the product can be repaired.
- Re-think: Set up environmental objectives for products, raw materials and production. Think at environment as part of quality and marketing.

Main problem(s) encountered

- System boundaries vary
- Difficult to collect qualified data in SMEs (internal registration systems in SMEs gives only ‘rough’ data)
- Interpretations problems (LCA-terminology demands a new vocabulary for people within SMEs)
- Allocation of data
- The EDIP-method had limited possibilities in calculation of how the working environment and the indoor-air quality influence the LCA-study
- Recommendations in ISO 14025 are not very clear

Conclusions from the working group

- Training of staff in SMEs in LCA- aspects, thinking and ‘Low-cost-LCA-studies’.
- Development of a more SME-user-friendly LCA/PC-calculation system.
- More efforts on collecting qualified data on European scale (Internal market). From nurseries to disposal of industrial products.
- Clearer definitions of allocations methods
- Clearer links between LCA-methods and product labeling systems/ requirement of documentation.

	• Mutual EU-agreement of a standard for an environmental product declaration
References	Miljørapport no. 556. ISBN 87-7944-252-8, ISSN 0105-3094 *http://www.mst.dk*

Study 8	Environmental declaration of a window-system (presented in Montpellier, 18–19 September 2000)
Organization and contact person	Knud Erik Kvist (Danish Technology Institute, Wood Technology.), Christian Kofod for a Danish window company
Short description of the study	Environmental declaration of a window-system based on a LCA-study (Danish EDIP-method). Presentation of the company and the product should use the form/structure from a Nordic Wood project 'Environmental declarations' The declaration should be a part of the company's marketing activities and further product development.
Main problem(s) encountered	• System boundaries. Data from sub-suppliers were difficult to obtain. • Some communication problems. The terminology by the LCA-staff in the company did not comply with that used by the marketing staff.
Conclusions from the working group	Same as the above Environmental analysis. A solution could be if 'The European Flower' also included a form to present industrial products in an LCA-perspective.
References	Confidential report owned by the client *http://www.dti.dk* (Wood Technology)

Study 9	LCA of laminated veneer lumber – Finnforest study (presented in Espoo 27–29 March 2000)
Organization and contact person	Bernhard Zimmer (Institute for Wood Research, Life Science Center Weihenstephan of the Technical University of Munich. Email bernhard.zimmer@ht-kuchl.ac.at)
Short description of the study	This LCA was carried out for KERTO®-Laminated Veneer Lumber (LVL), manufactured by Finnforest Oy. The study was a Cooperation project involving the Institute for Wood Research of the Technical University of Munich, Finnforest Oy and Otawood. The objective of the product-related LCA was to systematically assess and evaluate the environmental effects related to the manufacture and use of KERTO®-LVL. The aim also was to show which environmental effects occurred during which phase of the KERTO®-LVL life-cycle and what potential remedies exist. In this context a critical look was also taken at those life-cycle phases that are beyond Finnforest's direct sphere of

	influence, such as raw material supply, transport and production of processing materials. No comparison with other structural materials was attempted as no data of comparable accuracy were available. The methodological principles for the compilation of this study are based on the standards for product-related Life-Cycle-Assessment, issued or about to be agreed by the International Standards Organization.
Main problem(s) encountered	Collection of LCI data for the glue production and the data quality of the data for the Finnish forestry. The study is an example of how to include the absorption of CO_2 through photosynthesis into methodology of LCA.
Conclusions from the working group	–
References	–

Study 10	Wood versus concrete buildings in a life cycle perspective
Organization and contact person	Leif Gustavsson (Department of Environmental and Energy Systems Studies, Lund University, Sweden. Email leif.gustavsson@miljo.lth.se)
Short description of the study	Primary energy use, CO_2 and methane (CH_4) emissions from the construction of a multi-storey building, with either a wood or a concrete frame, are calculated in a life cycle perspective. The primary energy use, based mainly on fossil fuels, in the production of building materials is about 60–80% greater if concrete frames are used instead of wood frames. The GHG balance of wood materials will strongly depend on how the wood is treated after its utilization. The GHG balance will be slightly positive if all demolition wood is used to replace fossil fuels, slightly negative if part of the demolition wood is re-used, and clearly positive if all wood is deposited in landfills with the production of CH_4 as a result. However, if the biogas produced is collected and used to replace fossil fuels, the net GHG emissions will be insignificant. If concrete frames are used, the net GHG emissions will be up to twice as high as when demolition wood from the wood framed building is deposited in landfills and no biogas is collected. However, the net GHG emissions from the concrete framed building are reduced by more than 50% if the re-bound of CO_2 to the concrete by the carbonization process is considered. All primary energy used to produce building materials can be based on bioenergy from forest. The net amount of forest land needed to supply both raw material and energy for the production of building materials will be about twice as high when wood frames are used instead of concrete frames. However, the wood frame alternative results in an excess of wood waste and logging residues. The GHG mitigation efficiency, expressed as CO_2 equivalents per unit of forest land, will be higher when wood

	frames are used if the excess wood waste and logging residues are used to replace fossil fuels. The excess forest in the concrete frame alternative is used to replace fossil fuels, but if the forest is used for carbon storage, the mitigation efficiency will be higher for the first forest rotation period, but lower for the following rotation periods.
Main problem(s) encountered	Several data used in the analyses are uncertain, but an understanding of the complexity involved in a comparison of different alternatives of using forest for GHG mitigation, and of the fact that the time perspective greatly affects the results, is more important for the results than the precise figures used in the calculations.
Conclusions from the working group	–
References building	Börjesson, P. and Gustavsson, L. 2000. Greenhouse gas balances in construction: wood versus concrete from life-cycle and forest land-use perspectives (*Energy Policy* 28: 575–588).

2.3 DISCUSSION

Availability of inventory data from forestry is dependent on management and landowner structure. In Europe forests are distributed between large companies and owners of small woodlots. In some cases the operations are performed by the owners themselves, or by contractors. Their choice of technology fits into the local market and might depend on the kind of owner. The inventory data therefore reflects the quality of forest operations, and also the ability of contractors and landowners to provide data. This can be considered when LCA practitioner is using inventory data for comparing raw material acquisition.

An estimate of data quality for some combinations of contractor-landowner is demonstrated in Figure 2.

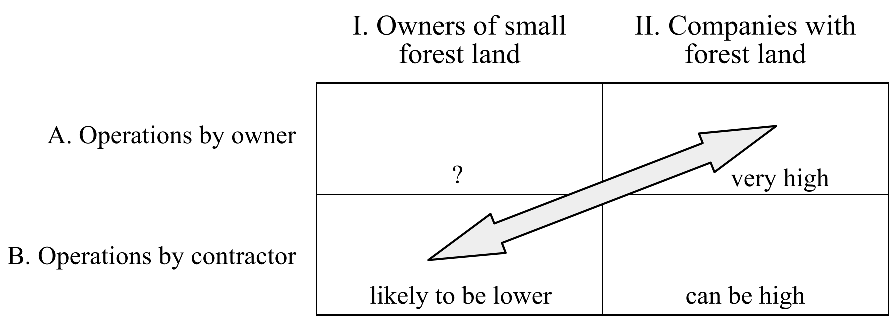

Figure 2. Estimate of data quality for combinations of contractor-landowner.

Self interest and presence of strong partners is likely to produce operations statistics of good quality in box AII-BII. The presence of environmental certification encourages companies and contractors to keep track of operations data for benchmarking of operations or impact on environment. The block arrow expresses an anticipated gradient in data quality between AII-BI. Combinations involving small forest holdings (AI-BI) might lead to lower data quality since the pressure from environmental management systems can be less strong or administrative skill of landowners might be less. The findings of Berg and Karjalainen (2001) also indicate that interpretation of data may also depend on whether it originated from follow-up routines or work study data. The latter can be expected be less comprehensive as they are referring to an artificial study situation. The authors also stress that clear and transparent definition of boundaries of study regarding the technological level and extension of the forest technology system is necessary for possible comparison between different systems (Figure 3). This is also clearly demonstrated in the experiences from case studies.

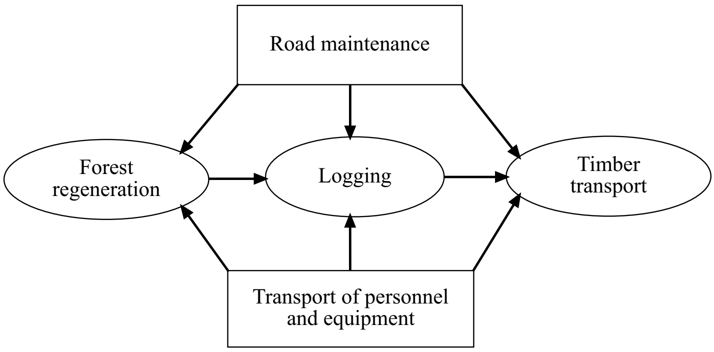

Figure 3. Some components in the forest technology system.

Too strong interpretation of data variation with disregard to market structure, level of mechanisation and data origin might lead to misleading conclusions.

2.4 CONCLUSIONS

From the case studies presented, the following problem types were the most common:

1. Definition of problems;
2. Large variability of production systems in forestry and forestry products; and
3. Interpretation of the quality of inventory data for LCA.

2.4.1 Definition of problems

In forestry and forest production, it is not always easy to identify what are products and what is waste. Interpretation of the ISO definition of waste (“any output of the product system that is disposed of") might cause problems when combined with unclear definitions for products. Co-products and by-products (such as wood chips, shavings, bark, etc.) are intended or not intended outputs. The distinction between by-products/co-products and waste is not always clear, since both by-product/co-product and waste may have an economic value. In wood processing, many 'waste streams' are used for internal heat and/or energy generation. This may cause problems in the allocation procedure and definition of system boundaries. Another obstacle is the definition of wood itself as output. It can be refered to as 'kg absolute dry' or in 'kg with X% moisture content dry base'. The use of 'kg absolute dry', especially, causes many calculation problems.

In forestry the major product is most often wood in the rough. There are other products/services as well, but they may be difficult to classify ('recreation value', game, nuts, etc.). It is not always clear what types of forests need to be identified within LCA and what the definition is of the 'forestry process' in this context.

The Group decided to form a specific task for definition issues, and a report has been prepared and is included in Chapter 3. It should be noted that Working Group 3 is also dealing with 'end of life' and 'waste' issues, which are also discussed in their reports (Jungmeier et al. 2001).

2.4.2 Large variability of production systems

In general there is a large variability of forestry systems and forestry production systems across Europe and beyond. Is there a need for LCA technique when relating imported wood products from tropical forests with home-grown wood products based on inventory data from forest management systems?

Sawmills in Europe and across the world may vary enormously in size and organization. Data collection of energy use, etc. for different sawmill products are not always possible on a detailed level when aggregated data is at hand. In manufacturing plants, the output of products is mostly measured in terms of economic output and not in volumes of timber products. The net output can be calculated using the input data of raw material used.

2.4.3 Data quality

Comparison of results from different LCA studies is often difficult. Information regarding data on data 'metadata' can be conveyed with the aid of a data format, e.g. SPOLD or SPINE. The development of ISO 14048 document on metadata may improve user's access to data with defined quality.

2.4.4 Final remarks

For data quality interpretation, benchmarking of data from different countries with similar processes (e.g. sawmilling) can be performed. Furthermore, a sensitivity analysis can be used to study the influence of a particular figure/measure that is of doubtful quality. It may also be useful to try and define more precisely how the data should be collected, and how much data should be collected.

Finally, the problems that arise should always be solved in relation to the identified Goal and Scope of the specific LCA studies.

References

Athanassiadis, D. 2000. Resource consumption and emissions induced by logging emissions induced by logging machinery in a life cycle perspective. Acta Universitatis Agriculturae Sueciae, Silvestria 143, Swedish University of Agricultural Sciences, Doctoral Thesis.

Berg, S. 1998. An inventory of forest operations for LCA of forest products. Paper presented at International Conference on Life Cycle Assessment in Agriculture, Agro-Industry and Forestry, 3–4 December 1998 in Brussels, Belgium

Berg, S. 1995. The Environmental Load of Fossil Fuels in Swedish Forestry – an Inventory for a LCA. Life Cycle Analysis – a Challenge for Forestry and Forest Industry. Frühwald, A. and Solberg, B. (eds.). EFI Proceedings No. 8. Pp. 53–61.

Berg, S. 1997. Some aspects of LCA in the analysis of forestry operations. Journal of Cleaner Production 5(3).

Berg, S. and Karjalainen, T. 2000. Comparison of Emissions from Forest Operations in Finland and Sweden. Presentation at COST Action E9 Mid-term Seminar in Espoo/Finland, Dipoli, 27–29. March 2000 and poster presented at the International Science Conference "The Role of Boreal Forests and Forestry in the Global Carbon Budget" May 8–12th, 2000 Edmonton, Alberta, Canada. (Paper in preparation).

Börjesson, P. and Gustavsson, L. 2000. Greenhouse gas balances in building construction: Wood versus concrete from life-cycle and forest land-use perspectives. Energy Policy 28: 575–588.

Jungmeier, G., Werner, F., Jarnehammar, A., Hohenthal, K. and Richter, K. 2001. Allocation in Multi Product Systems -Recommendations for LCA of Forest Products. Proceedings of the Final conference of COST Action E9, Hamburg 29.11. – 1.12. 2001 (in press)

Karjalainen, T. and Asikainen, A. 1996. Greenhouse gas emissions from the use of primary energy in forest operations and long-distance transportation of timber in Finland. Forestry 69(3):215–228.

Miljørapport no. 556. ISBN 87-7944-252-8, ISSN 0105-3094.

3 PROBLEMS WITH TERMS AND DEFINITIONS IN INVENTORIES FOR FOREST SECTOR LCA

S. Berg

3.1 INTRODUCTION

The Task1 within Cost E9 "Identification of problems arising from case studies" has demonstrated that different interpretation of terms related to production can cause severe problems when drawing conclusions about the impact on environment within the forest industries sector. Firstly, there seems to be shifting understanding of the meaning of the terms product or service; and secondly, the definition of the output of the system that is disposed of, usually defined as waste.

The impact of these problems with definition, is that conclusions made from studies of this kind will vary considerably depending on the terms and definitions used. Allocation of flows and emissions to appropriate units will vary with definitions.

Therefore, the aim of this chapter is to focus on the meaning of the term product and also on the allocation of flows to them, in order to disclose some differences in interpretations and uses. This is meant as a contribution to increased transparency and thus improved prospects for comparing study results.

3.2 TERMS

A questionnaire (see Appendix II) was sent out to members of WG1 as a result of a decision made at the Cost Action E9 mid-term seminar 27–29 March 2000. Ten members, representing their research bodies answered. The answers indicated that almost everyone had undertaken some LCA-related studies of the forestry system. Many were satisfied with the definitions in general provided within the ISO 14000 family of standards. Respondents also recognized that definitions in these standards must be very general because they apply to all the different sectors, not only to forestry and the wood industry. In these specific sectors, a more detailed definition of certain terms may be necessary and useful. One respondent expressed that:

Energy, Carbon and Other Material Flows in the Life Cycle Assessment of Forestry and Forest Products
Timo Karjalainen, Bernhard Zimmer, Staffan Berg, Johannes Welling, Hannes Schwaiger, Leena Finér and Patricia Cortijo

… within our LCA studies in the field of biomass and energy, the definitions of the ISO 14041 were appropriate enough. We see these definitions as a basis in LCA and defined the terms of 'products' 'co-products' and 'by-products' study specific.

Some respondents regard a directive for the use of terms as a helpful tool to make the results of LCA comparable to a certain extent. It is not necessary that this will be integrated in the reviewed ISO14041. In fact this could be complicated, as then all the other sectors would have to do the same.

3.2.1 Product

The ISO 14000-family of standards does not offer a definition of product itself, however product system in ISO 14040 (3.15), (Swedish Standards Institution 1998a) is defined as;

a collection of materially and energetically connected unit processes which performs one or more defined functions.

In this international standard the term 'product' used alone includes not only product systems, but also 'service systems' (further details in ISO 14041 (4.2), (Swedish Standards Institution 1998b):

Product system is a collection of unit processes connected by flows of intermediate products which perform one or more defined functions. A product system description includes unit processes elementary flows and product flows across the system boundaries; and intermediate product flows within the system.

Among the respondents, it is clear that the concept of 'product' (Appendix III) is either a physical product and/or service. Other traits are it is a part of an economic production process and is offered to a market.

The term product is broken down to many 'sub-terms' (Appendix III) such as 'main product', 'final product', 'by-product' and 'co-product'. There seems to be no general understanding of the terms. The definitions are dependent on the actual market conditions.

3.2.2 Waste

It is also recognised among respondents that the crucial definition is the one concerning waste. Waste is defined in national legislation as a means to control the process of disposal of unwanted or dangerous output from industrial processes or goods in general. In the LCA context, waste is defined as ISO 14040 (3.20), (Swedish Standards Institution 1998a):

Any output from the product system, which is disposed of.

The working group agrees with this definition. The disposal of the waste is usually connected with a cost, but it does not have a market value. For example, if a retailer specialises in buying waste (that is output from a process) for a certain price in order to add value by transforming the output to materials of construction or energy, then the output is a product. If the primary process disposed the very same output as a mass in a landfill, to a cost, then the output would be waste (Figure 4).

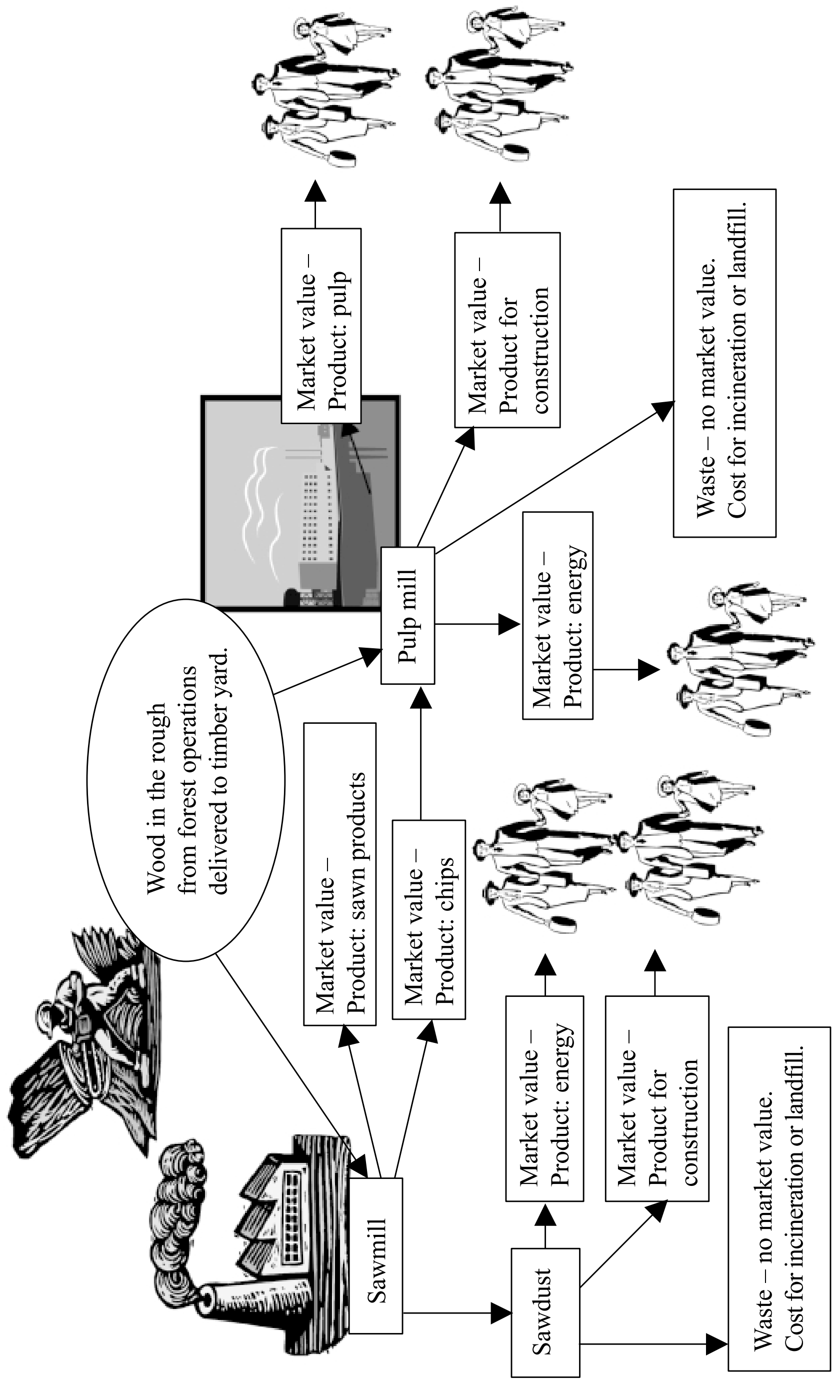

Figure 4. Relation between products and waste.

3.3 ALLOCATION

Allocation is the apportioning of the input or output flows of a unit process to the product system under study ISO 14040 (Swedish Standards Institution 1998a). This can be understood in different ways. *WG1 suggests that flows are allocated to all products and services that have a market value.* The way an allocation is done will affect the result of an assessment.

ISO 14041 (Swedish Standards Institution 1998b) has some recommendations. The main rule is to avoid allocation by system expansion or by dividing a process into subprocesses. If allocation cannot be avoided, then the inputs and outputs should be apportioned according to a pattern that reflects the underlying physical relationship. For example, mass, volume, some other measure of importance, as monetary value. For forestry, allocation to mass or economic value are possibilities. Allocation to value has a fundamental disadvantage as market price for forest products have a very volatile variation over time and between different markets depending on local economy, society and infrastructure. The result would then rather reflect the society by which the product was produced and used than the product itself. *For forestry, WG1 considers the allocation to roundwood produced as fair, and allocation products according to mass as reasonable.*

WGIII puts perspectives and point of views on allocation (Jungmeier et al. 2001).

3.4 CONCLUDING REMARKS

The exercise dealing with problems of terms and definitions basically touched three areas:

1. What is agreed upon in international fora?
2. What do the terms means in their technical and social context in national languages according to a widely accepted use of the term, sometimes codified in national legislation?
3. What do the terms mean when they are translated from another European language to English?

A striking example is the meaning of the terms (in various languages) that are translated into English as ‘products’ and ‘waste’. The allocation of flow is dependent on these definitions. *The recommendation of WG1 is that the user carefully considers conflicts between recent standards and traditional use of particular terms.*

References

Swedish Standards Institution. 1998a. Environmental management – Life cycle assessment – Principles and framework (SS-EN ISO 14040:1997)

Swedish Standards Institution. 1998b. Environmental management – Goal and Scope definition and inventory analysis (SS-EN ISO 14041:1998)

Jungmeier, G., Werner, F., Jarnehammar, A., Hohenthal, C. and Richter, K. 2001. Allocation in Multi Product Systems – Recommendations for LCA of Forest Products, Proceedings of the Final conference of COST Action E9, Hamburg 29.11. – 1.12. 2001 (in press).

4 STATIC/DYNAMIC APPROACH – SPATIO-TEMPORAL PROBLEMS

Coordinating authors: T. Karjalainen and J. Welling

Contributing authors: S. Berg, L. Finér, B. Kosir, N. Knechtle, K.-E. Kvist, B. Muys, D. Perruchoud, K. Radoglou, M. Salisbury, H. Schwaiger and B. Zimmer

4.1 BACKGROUND

Task Group 2 on "Static/dynamic approach, spatio-temporal problems" agreed that at present LCA is a static tool (ISO prescriptions). This can cause difficulties when attempting to include dynamic processes in an LCA study. For example, how to cope with long-term emissions of creosote from treated railway sleepers or wooden garden fences? In particular, biological production systems, such as forestry, have an important spatial and temporal impact: they use large areas of land for their production processes that may take decades or even centuries. A well-developed methodology with some clear rules and conventions is necessary to transform data from space and time consuming processes into the static LCA framework. Questions related to the temporal scale include: How can we handle the long-term production systems in forestry? What kind of models shall we use? How can we convert results of dynamic modelling into aggregated results (e.g. into 'one figure')? What time span should we look at in order to be as accurate as necessary? How can you allocate change of land use to products? Questions related to the spatial scale include: How should we deal with spatial impacts within LCA?

Because biological production systems as forestry do have an important spatial and temporal impact, a link between static approach and a dynamic approach referring to the spatial and temporal character of forestry is needed. The group found this task a difficult one, but was able to tackle main underlying questions and draw conclusions.

4.2 UNDERLYING QUESTIONS

The following two tables (Tables 1 and 2) present questions on temporal and spatial problems that have been raised and conclusions from the working group.

Table 1. Analysis of temporal problems in LCA.

Question 1	***How can we handle the long-term production systems in forestry?***
Why is this question important?	Industry normally does not know long-lasting product chains or processes. There is a remarkable difference in time span and spatial relation between industrial product chains and primary production chains in forestry and agriculture. If the static approach in LCA is suitable for industrial processes, it is problematic for forestry processes.
Conclusions	1. Use a modeling approach to feed the Life Cycle Inventory Database with representative data.
Question 2	***What kind of models shall we use?***
Why is this question important?	–
Conclusions	Two basic types of modeling approach were found: 1. *empirical models:* inventory-based modeling is based on knowledge of the past and present situation. *2. process-based models: p*rocess-built modeling allows you to predict developments in the future taking into account changes in the production factors. Non-linear effects can be taken into consideration by using corresponding productivity models or other process models. 3. Hybrid models are also possible. Cost-effective choices with the appropriate level of detail are to be made.
Question 3	***How can we convert results of dynamic modeling into aggregated results (e.g. into 'one figure')?***
Why is this question important?	Although dynamic modeling reflects the 'truth' more accurate, there are simplifications (on the one hand because of uncertainties and estimations, on the other hand because of allocations' rules, conventions, etc.) necessary to transform the complex modeling result into a single outcome useful in LCA.
Conclusions	*1. Documentation:* Declare simplifications, estimations and other inputs which influence the result as clearly as possible.
Question 4	***What time span should we look at in order to be as accurate as necessary?***
Why is this question important?	According to the modeled time span, results of Life Cycle Assessment are expected to be different.
Conclusions	1. Modeled time span = 1 rotation: We suggest to model at least one rotation. 2. If looking at non-rotation type forests, we suggest to model over a time span of 120 years. 120 years is a common rotation length for several important tree species in Europe.
Question 5	***How can you allocate change of land use to products?***
Why is this question important?	Land use can change over time. The change of land use can implement non-recurring environmental impacts. This problem cannot be solved objectively. A convention is needed.
Conclusions	*1. Allocation to the first product:* all environmental impacts caused by land use change are allocated to the first product of the new land use. *2. Equilibrium:* starting at the moment of land use change, modeling could be done until the site is again in equilibrated situation. The environmental impacts caused by land use will be allocated to all products within the time span 'land use change–equilibrium'.

Table 2. Spatial problems of LCA.

Question	***How should we deal with spatial impacts within LCA?***
Why is this question important?	Until now LCA has not usually included the spatial differentiation of the environmentally assessed topic. Normally the spatial differentiation is taken into consideration by classification (e.g. LCA of different forest types, different sites). In the forestry sector – as the production-chain is very much related to space – the question should be answered.
Conclusions	1. Generate database related to pixels. 2. Use geographical information systems (GIS) to scale up life cycle impacts from pixel to landscape level. 3. vary the area of the pixels according to the problem. 4. vary the area of the pixels according to the geographical reference (e.g. there is another resolution needed when looking to one country compared with the whole Europe.

The handling of spatial problems is also relevant for Working Group 2 dealing with land use issues.

Within the timber production system there is the biological system (where the timber is grown) and the technical system (where the timber is processed), as Perruchoud and Knechtle suggested in Thessaloniki, 8–9 March 1999 (Figure 5). Both these systems are within the remit of WG1 to study and identify LCA problems and make recommendations for solutions.

The ISO terminology for LCA is that it is an assessment of human activities related to products.

Biological Production System: these require dynamic modelling related to site parameters and management parameters in order to assess the substance fluxes per year.

Technical production system: this can be split into five main areas:

1. Raw timber supply;
2. Raw timber manufacturing;
3. Transportation;
4. Use (including maintenance); and
5. Waste (end of use).

The issue is how to link the biological and technical chains. Therefore, the group should look at how the biological production system feeds into the technical production system, i.e. the management differences. Also the impact on allocation rules should be considered.

4.3 CONCLUSIONS

The group discussed in Montpellier (18–19 September 2000) the two main differences identified between LCA models and Dynamic models (Tables 3).

Table 3. The main differences between LCA and dynamic models.

	Classical LCA model	Classical 'forestry' model
Temporal dimension	LCA corresponds to a static approach where the temporal dimension can not be taken into account. Flows, which are quantified, correspond to emissions taking place during a certain period but this duration is not memorised or used.	Dynamic models are used to predict for instance the amount of nutrients, which will be used by the trees during 10, 20 or 50 years. Hence, the temporal dimension if a fundamental dimension.
Stocks	Only flows between the system and the environment are taken into account.	Stocks are a key information in these models as they enable to know, for instance, if the harvesting leads to a depletion of nutrients in the soil.

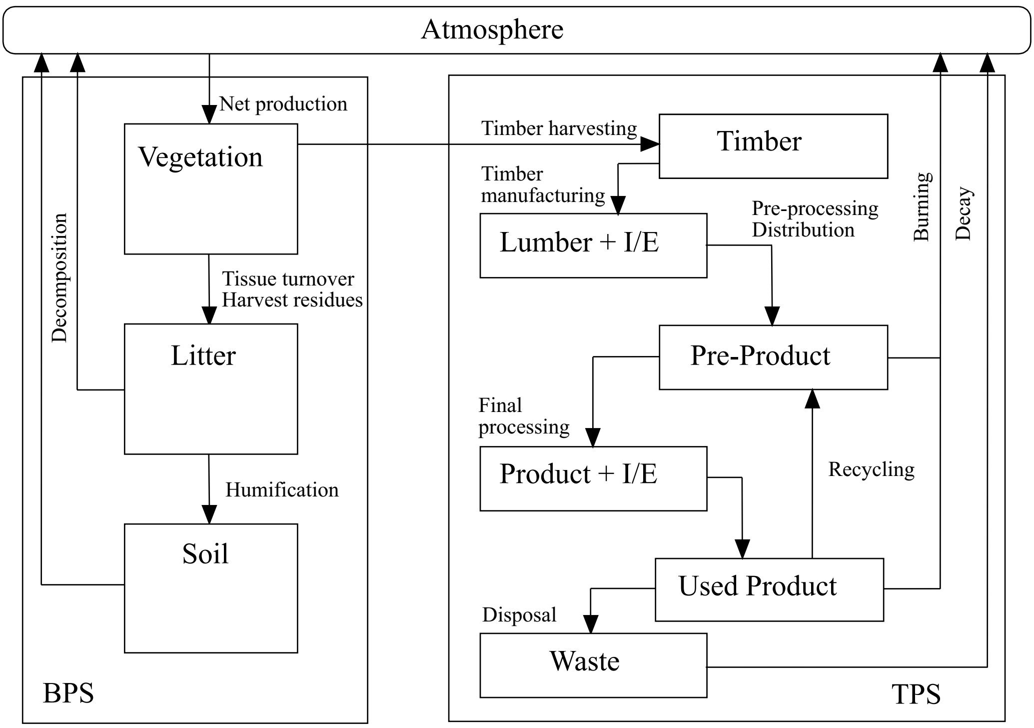

Figure 5. Components and processes of the wood production chain in the biological (BPS) and technical production system (TPS) modified after Karjalainen (1996). Arrows describe mass fluxes between compartments (boxes) (Perruchoud and Knechtle, presentation to the COST E9 meeting in Thessaloniki, 8–9 March 1999).

For considering temporal and spatial changes of stocks in LCA studies – which would be highly desirable – some system and methodology related axioms have to be considered:

- LCA is always based on a life cycle inventory which comprises of a list of physically measurable inputs and outputs related to a functional unit;
- during impact assessment only the information contained in the inventory can be related to impact categories;
- data in the life cycle inventory which can not be related to impact categories are lost in view of the interpretation of LCA;
- rating and valuation of impact categories is only partly objective, it highly depends on the goal and scope definition and on political perspectives.

An integration concerning the possibility for LCA to integrate temporal and stock dimensions. The integration of the temporal dimension in LCA would enable, for instance, to translate flows into actual pollutant concentrations in the environment. However, it should be underlined that: (1) a complete static forestry LCA is not yet achievable; and (2) this temporal integration would have to be done for all the wooden product life cycle stages.

What seems more feasible in a short-term perspective is to use dynamic models to deal with new issues in LCA of forestry and wood products, such as nutrients related flows (CO_2, NH_3, NO_3^-, etc.). Even for CO_2, it does not seem as easy as one has to take into account carbon storage in soil and product lifetime. It seems all the more difficult for other nutrients related flows (for example nitrates). These flows are important and should be accounted for when comparing, for instance, different forestry practices as they may vary considerably from one to another.

This showed that the group was finally getting closer to an agreement on how dynamic processes in forests might be taken into account in LCA. In the meeting in Slovenia (June 2001) one presentation (Karjalainen) was given on how outputs from dynamic modelling may be helpful for LCA purposes. Conclusions were drawn based on the discussion then and are detailed below.

This question, however, leads to another issue, which is the use of LCA to compare different forestry systems. So far, such analysis would be limited as widely recognised data and methods are lacking for biodiversity, soil occupation and nutrients related flows. Only 'classical' LCA flows, such as CO_2 emissions due to diesel consumption, can be taken into account.

In Slovenia (June 2001), Karjalainen presented a study "Carbon Balance Implications of Wood Production Chain, Manufacturing and Use of Wood Products" (for further details see *http:www.efi.fi/projects/carbon_balance/*). This provided a view of how outputs from dynamic modelling may be helpful for LCA purposes. The aim of this study was to assess carbon (C) balance implications of typical wood production chain (including both production and procurement), manufacturing and use of wood products by examining the C fluxes and stocks in a typical Finnish forestry system. The whole forest sector was included, because partial examination could easily lead to inaccurate conclusions. Four models were combined to calculate the pools and fluxes of carbon and the use of primary energy in the chain of growing timber, harvesting roundwood, producing wood products, and disposing the products after use: (i) a forest model; (ii) a wood product model; (iii) a model for fossil carbon emissions from harvesting; and (iv) a model for energy use in processing. Results were presented as average C stocks (tons/hectare) and average C fluxes (tons/hectare/year). The developed approach is also applicable to other forestry systems. One paper dealing with impact of varying rotation length on forestry carbon balance has been accepted for publication (Liski et al. 2001).

This presentation showed that temporal and spatial problems might be solved by including representative data based on, for example, dynamic modelling, or forest inventory (average data on regional or national level). This data should be representative in terms of time and space, and should present typical production, manufacturing and use.

The group concluded that:

- dynamic modeling could provide data for checking static LCA data (is it relevant)
- could help solving problems regarding space and time
- importance of calculating over time (can cover then the whole life span of the product). Relationship to relevant international product standard can be helpful for definition of the life span of and industrial product according to when a ‘forest product’ is a part of this product e.g. MDF, particle board – in furniture or in a construction element
- LCA should take into account that there are dynamic models (forest, products, energy)

References

Karjalainen, T. 1996. Dynamics of the carbon flow through forest ecosystem and the potential of carbon sequestration in forets and wood products in Finland. Research Notes, Faculty of Forestry, University of Joensuu. 31 p.

Liski, J., Pussinen, A., Pingoud, K., Mäkipää, R., Karjalainen, T. 2001. Which rotation length is favourable to mitigation of climate change? (Accepted for publication in Canadian Journal of Forest Research).

5 A COMPARISON OF FUEL CONSUMPTION AND GREENHOUSE GAS EMISSIONS FROM FOREST OPERATIONS IN EUROPE

H. Schwaiger and B. Zimmer

5.1 INTRODUCTION

Since the Rio de Janeiro Conference on the Environment in 1992, all countries are committed to the principles of sustainable development. Forests, forestry and wood are dealt with in various chapters of Agenda 21. Furthermore, effective measures for the protection of the earth's climate were discussed in subsequent conferences and defined objectives for reducing the emission of greenhouse gases (GHG) were laid down in the Kyoto Protocol (1997). To be more specific, the countries of the European Community have committed themselves to reduce the emission of GHG by 8% in the period 2008 to 2012 compared to 1990 levels.

Combustion of fossil fuels is the main reason for the build-up of GHG CO_2 in the earth's atmosphere, with emissions currently at about 6 GtC (Gigatons carbon) yr^{-1}. Additional CO_2 emissions, estimated at about 1.6 GtC yr^{-1}, come from changes in land use in the tropics, mainly deforestation. The increasing concentration of GHG in the atmosphere is believed to influence the earth's climate (IPCC 1995). In this context, specific reference was made to the forests' potential as both carbon source and carbon sink as well as that of corresponding silvicultural measures. Forests fulfil multifarious ecological functions; they are the habitat for plants, animals and people, and they produce wood and non-woody products of all kinds. Moreover, forests store approximately 80% (1648 Gt) of the total amount of carbon stored by plants on land (2060 Gt) (Burschel 1990; Perruchoud and Fischlin 1995; Watson et al. 2000). Compared with the oceans' carbon reservoir (38 000 Gt), the size of the forest carbon reservoir appears relatively small; however, in contrast to the carbon reservoir in oceans, the forest carbon reservoir can be easily influenced by effective land use and management methods. Mankind and society are thus capable of controlling the size of this biomass store or carbon sink more or less effectively – in a positive as well as in a negative sense. From climate protection points of view, the objective must be to relieve the carbon reservoir in the atmosphere of about 750 Gt and to add no further inordinate amounts of fossil GHG (mainly CO_2). The proportions of the three most important carbon reservoirs show that forests have the same sink potential as the oceans (+2 Gt/a), with an annual carbon addition to the atmosphere of 3 Gt (Houghton 1997; Schulze 2000).

Forest vegetation extracts CO_2 from the atmosphere through the process of photosynthesis. Forest growth combined with the production of biomass accumulate

Energy, Carbon and Other Material Flows in the Life Cycle Assessment of Forestry and Forest Products
Timo Karjalainen, Bernhard Zimmer, Staffan Berg, Johannes Welling, Hannes Schwaiger, Leena Finér and Patricia Cortijo

carbon over a certain period of time, when carbon is stored in compartments of living vegetation, dead organic matter and the forest soil. In unmanaged forests, in the long term, the same amount of CO_2 is returned by the respiration of the forest system (steady state of the ecosystem) and the decay of organic matter in soil and litter compartments. Forests in many European countries are not in a steady state, they are net sinks for carbon, because growth exceeds carbon losses due to harvesting and disturbances. Carbon is also accumulating in wood products (Wegener and Zimmer 2000). On the other hand, GHG emissions caused by, for example, forest operations and transport processes are released into the atmosphere.

5.2 AIMS AND SCOPE

This study aims, based on a study presented by Berg and Karjalainen (COST E9 workshop LCA of Forestry and Forest Products, 27–29 March 2000, Espoo, Finland), at collecting LCA-related forest and forestry data from various European countries participating in the COST Action E9 “Life Cycle Assessment of Forestry and Forest Products”. The fuel consumption and the related GHG emissions for the main forest operation processes (harvesting, hauling and transport) in the different countries are compared to show the benchmarks for existing forest operation processes in the European forest management systems. The results should clarify the mean variation of fuel consumption and the impacts of GHG emissions within the European forest systems to form assumptions and to simplify later studies on life cycles of wood-based materials and wooden products. In addition to the forest operations mentioned, the roundwood transport systems were also taken into consideration.

The study is restricted to the forest operations ‘harvesting’ and ‘hauling’ due to lack of available data for all the other forest processes such as ‘scarification’, ‘stand establishment’, ‘tending of seedlings’, ‘clearing’ or ‘use of pesticides’, ‘forest road construction and maintenance’, ‘limbing’, ‘debarking’ etc.

Twelve countries (Austria, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Norway, Slovenia, Sweden and Switzerland) provided general data on national forests, forest operation systems and roundwood transport systems.

5.3 METHODOLOGY

A questionnaire was drawn up to collect national data, in order to evaluate the fuel consumption and the proportion of forest operations to GHG emissions. The questionnaire was sent out to the delegates of the COST Action E9, mainly to the members of WG1 to collect LCA-related, national data for forest operations. Apart from basic forest data, e.g. the area of exploitable forest land, growing stock, annual increment and the proportion of tree species (with reference to the volume), specific data related to the forest operation systems applied in the countries was requested. The aim was to determine each applied forest operation (e.g. motor-manual or mechanized cutting) for each country and the amount of wood, separated into wood from thinning and final cuttings. Based on these data a kind of 'national forest operation process mix' was created.

In a second step the LCA-related process data already published was analysed. There are only a few studies in this field made in Austria (Pröll, personal communication, 2001; FPP 1990, 1991), Finland (Karjalainen and Asikainen 1996), Germany (Schweinle 1996; Fedrau 2000), Sweden (Berg 1995, 1997; Athanassiadis 2000), Switzerland (Winkler 1997; Knechtle 1997) referring to national data on harvesting, hauling and transport operations. Berg and Karjalainen (2000) compared the Finnish and Swedish data. The most important studies were taken into consideration to create 'typical, representative processes' for the forest operations applied in the European countries. The aim was to develop standardized processes.

In the study "Materialprofile von Holzerntesystemen" (Material Profiles of Forest Operation Systems; Knechtle 1997), Knechtle came to the conclusion that the primary energy demand of the different harvesting and hauling systems is closely related to the fuel consumption of the machines applied and to the productivity of each system. The other input factors like the energy demand for machinery production or for repair work during the life span had only little influence on the primary energy demand of the whole system. The influence of life span of the machinery equipment was also not significant.

The conclusion for the present study is, that it is mainly the productivity of the harvesting and hauling systems, which influences the ecological burden, and also the economics of the forest operation systems. The productivity itself mainly depends on the diameter of trees targeted for thinning and final felling operations. Against this background the national 'forest operation process mix' shows not only the optimised technological and economical situation of the national forest management system, but also reflects the environmental impacts.

5.4 Results

The following sections contain an analysis of the questionnaires returned. The degree of data availability and quality varies significantly. In some countries, such as Austria, Finland, Sweden and Switzerland, useful data of good quality as regards the proportion of the different forest operations on a national scale are available. It should be noted that neither the amounts of non-wood products nor the differentiation between wood from thinning and final cuttings were generally available, as shown in the tables below. Table 4 depicts the data sources and references required for the questionnaires for each country involved.

5.4.1 Basic forest data

The total area of forest land of the 12 European countries is 110.5 million ha of which 90.55 million ha are exploitable forest land. Some 57% of the forests represented in this study are located in Northern Europe, 15% in Central Europe, 16% in Western Europe and 12% in Southern Europe.

Table 4. List of all data sources and references considered.

	Data provided by	References
Austria	Schwaiger Hannes	BMLF (1996), BMLFUW (1999), FBVA (1997);
Denmark	Kvist Knut-Erik, Niels Heding	
Finland	Karjalainen Timo	Karjalainen and Asikainen (1996), Finnish Statistical Yearbook of Forestry (1999)
France	Roda Jean-Marc	
Germany	Zimmer Bernhard	AID (2001), BML (1993, 1994), KWF (2001), ZMP (2000);
Greece	Radoglou Calliope, Galis Christos	
Ireland	O'Carroll Joe	
Italy	Pollini Claudio	ISTAT (1996)
Norway	Svanaes Jarle	NIJOS (2000), SSB (1999), TF (2001)
Slovenia	Kosir Bostjan	Slovenia (1998, 1999, 2000)
Sweden	Berg Staffan	Berg (1995, 1997); Berg and Karjalainen (2000), Statistical Yearbook of Forestry (2000)
Switzerland	Brandenberger Regina	BUWAL (1996), LFI (2001), Schweiz (1991, 1993)

Figure 6 depicts the national forest area data for European countries. In general, the share of exploitable forests in the total forest area is higher in Northern than in Central and Southern European countries. The highest percentage of national forest land cover was reported from Finland, Sweden, Slovenia and Greece. Comparing the exploitable areas with total forest areas, the highest amounts of exploitable forests are found in Germany (97%), Italy (96%) and Switzerland (93%), and the lowest in Norway (62%) and Greece (52%).

Figure 7 shows the growing stock in national exploitable European forests, where the highest levels of growing stock volume are reported for Switzerland (354 m^3/ha), Austria (295m^3/ha) and Germany (271m^3/ha). In general, the highest growing stock rates per hectare are reported for Central European countries, and the lowest for Southern and Northern European countries (e.g. Greece with 42m^3/ha).

Table 5 gives an overview of the forest ownership in the countries involved. The fact that forests are mainly in private property is one of the reasons for the missing data for forest operation processes. The available data are often based on those of the state and federal forests and in Sweden for example on the company forests.

Figure 8 shows the share of coniferous and deciduous tree species with reference to the volume over bark. There is a clear dominance of the coniferous species in Northern and Central Europe (except Slovenia), while the share of hardwood (deciduous) species is more important in the South and the Western countries, except Ireland with 100% coniferous species, mainly spruce and pine (Table 6). Significant amounts of oak are reported for Italy and France, fir for Greece, beech for Denmark and Slovenia, poplar for Italy, and birch for Finland and Sweden.

Table 6 provides a more detailed overview of the reported volume-related tree species distribution per country. As regards the fuel consumption per cubic meter of wood for the forest operations harvesting and hauling, it may be necessary to distinguish not only between coniferous and non-coniferous, but also between tree species. The primary energy demand for harvesting spruce (stem wood from final cuttings) is, for example, double that

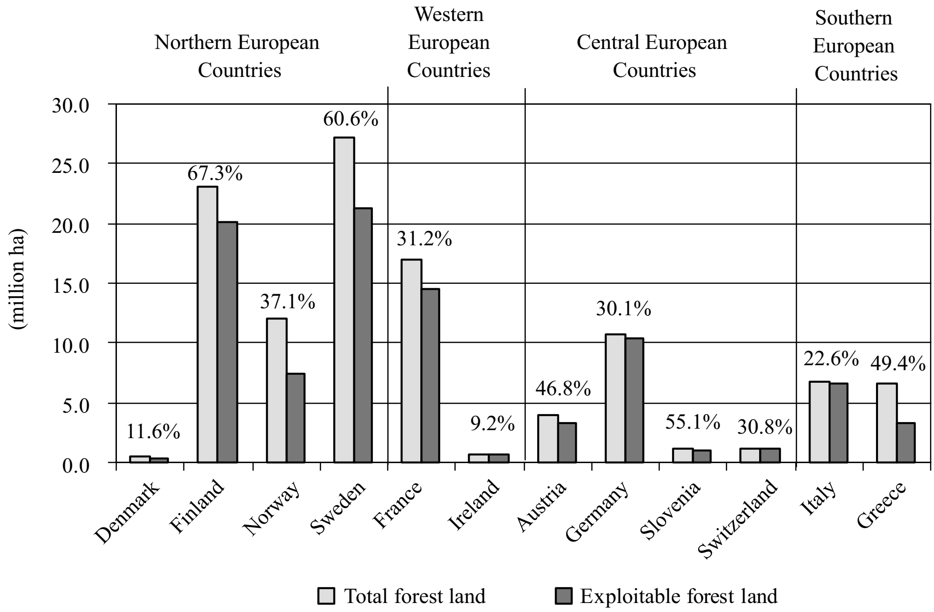

Figure 6. General data on national total forest and exploitable forest areas in Europe, numbers (in percent) represent the ratio between total forest area and total national area per country.

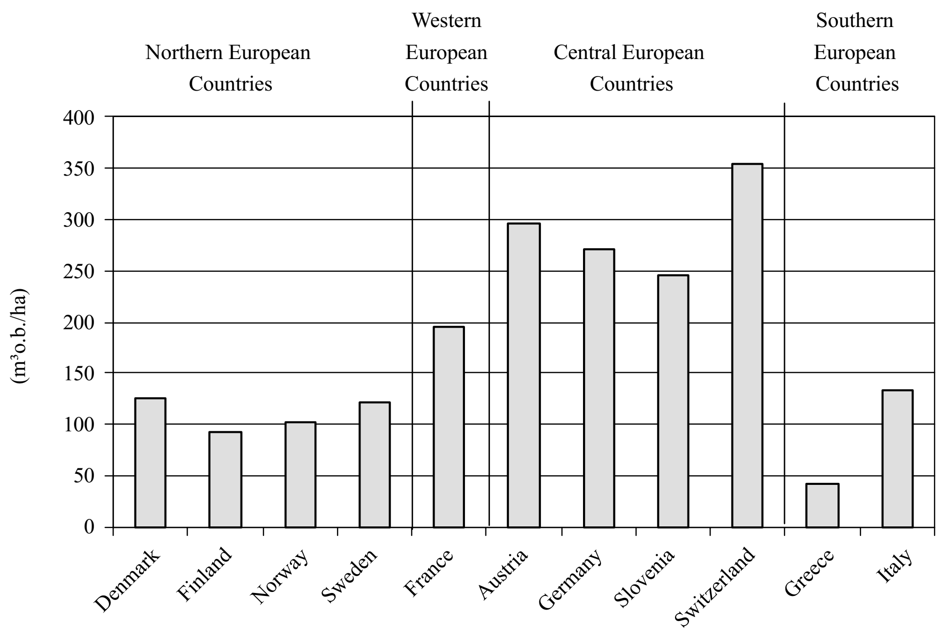

Figure 7. Growing stock per hectare in the exploitable forests in Europe (data for Ireland are not reported).

Table 5. Distribution of the forest ownership in the different countries.

	State forest	Federal forest	Corporation forest	Private forest	Company forest
Austria	17.0	3.5	9.8	69.7	-
Denmark	40.0	-	-	-	60.0
Finland	33.2	-	4.7*)	54.3	7.8
France	10.2	-	16.2	73.6	-
Germany	4.3	29.6	26.1	40.0	-
Greece	-	-	-	-	-
Ireland	-	-	-	35.0	65.0
Italy	7.6	-	27.4	59.9	5.1
Norway	7.0	2.0	-	91.0	-
Slovenia	32.6	-	-	64.9	2.4
Sweden	3.4	-	8.0	49.2	39.4
Switzerland	5.0	1.0	62.0	29.0	3.0

*) refers to non industrial private ownership

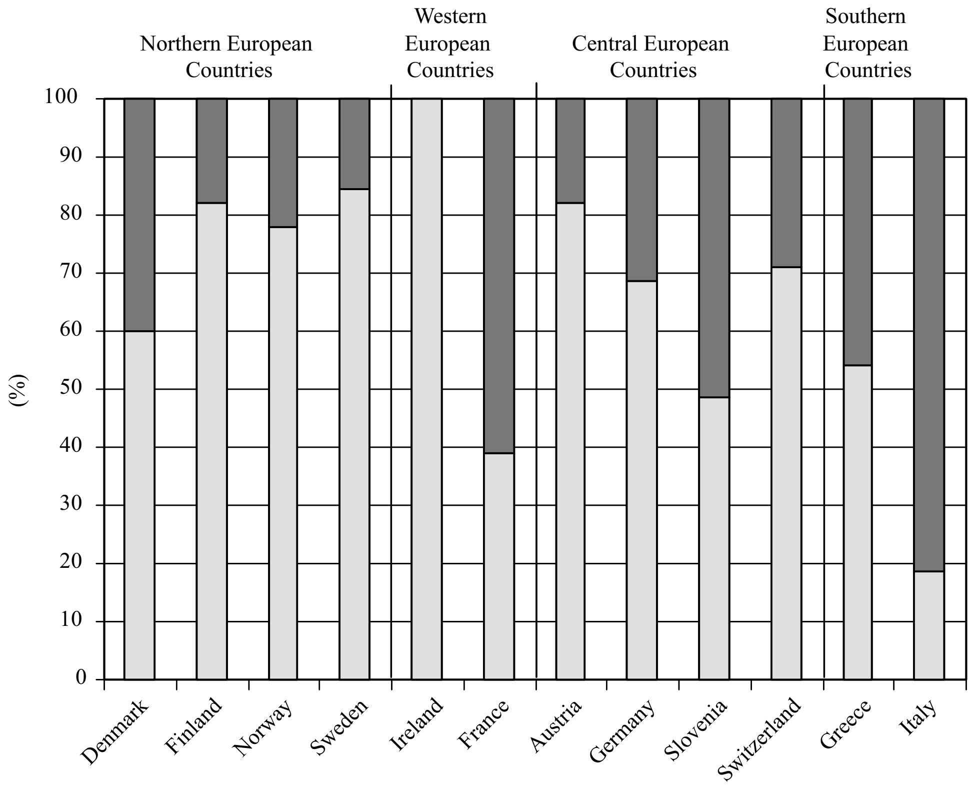

Figure 8. Overview of the proportion of softwoods and hardwoods in the different countries.

Table 6. Distribution of the main tree species in the European countries (volume-related).

	spruce	pine	fir	douglas fir	larch	other coniferous	oak	beech	others	poplar	birch	other deciduous
Austria	61.4	9.1	4.6	-	6.8	-	2.4	9.2	2.6	-	-	3.9
Denmark	50.0	1.0	2.0	1.0	6.0	-	4.0	30.0	6.0	-	-	-
Finland	35.7	46.4	-	-	-	-	-	-	-	-	14.7	3.2
France	15.6	16.4	-	2.0	-	5.1	28.7	11.6	9.2	-	-	11.6
Germany	40.6	22.5	2.5	0.8	2.3	-	7.7	16.9	3.0	-	-	3.6
Greece	0.1	24.4	29.4	-	-	-	19.9	20.1	-	-	0.1	6.0
Ireland	70.0	25.0	-	-	-	5.0	-	-	-	-	-	-
Italy	12.4	4.3	-	-	1.6	0.3	26.8	6.8	9.9	15.7	-	22.2
Norway	45.0	33.0	-	-	-	-	1.0	15.0	-	-	-	6.0
Slovenia	32.0	7.5	9.2	-	-	-	8.9	31.9	3.5	-	-	7.0
Sweden	44.4	38.4	-	-	-	1.7	0.9	0.5	0.3	1.4	10.2	2.2
Switzerland	47.0	4.0	14.5	-	5.0	0.5	2.0	17.5	5.5	-	-	4.0

for harvesting oak, beech or pine because of the higher effort required to debranch the stems (Schweinle 1996). The effect of the individual species on the fuel consumption is only one aspect. Another more important aspect is the influence of the unit volume of the trees harvested on the productivity of the process and, as a result, on the fuel consumption.

5.4.2 Forest products

Forestry is typically a linked production that means that apart from a main product several by-products are produced, which cannot be avoided. While managing forests, not only stem wood of a good quality can be produced, but also wood with small dimensions, wood with low quality, branches and bark. Besides these wooden products and by-products, the forests provide us with non-wood products and benefits. One example are the environmental benefits and functions the forests fulfil, such as soil and water protection, protection against avalanches, benefits for recreation or percolation of emissions. All these functions are not strictly dependent on the kind or the intensity of the forest management, and they are not bound up with mass or energy flows going into or coming out of the forest system. Other examples of non-wood products are resin, mushrooms, game and berries. They are bound up with mass flows.

In LCA, inputs and outputs can be allocated to the main product and to the by-product, for example, by mass or volume. When considering the environmental benefits as a by-product of the forest system, which are not connected to physical flows, it is not recommended to allocate inputs and outputs (or impacts) on wood because the mass and energy balances are not balanced.

A second point is the question concerning the market value of these by-products. There is no doubt that they have a value, but often they have no market. Therefore WG1 of the COST Action E9 decided that a by-product in the sense of LCA should have a market value and there should be a market. That means that the environmental benefits in this study are not mentioned as a product or by-product, but they should be mentioned in the impact category ‘land use’ (see WG2 ‘land use’ of the COST Action E9).

Wood Products

Figure 9 shows the current increment and harvest regimes in European countries with high increments per hectare in Western and Central European countries. Within all countries, amounts of harvested volume are lower than forest increments. Therefore, forests are currently net carbon sinks regarding carbon stock changes in forest vegetation. The highest carbon stock changes of vegetation per hectare are calculated for Germany (4.93 m^3/ha, Slovenia (3.88 m^3/ha), and France (3.80 m^3/ha), and the lowest for Greece (0.62 m^3/ha), Sweden (0.92 m^3/ha) and Finland/Italy (1.58m^3/ha). The ratio between harvested volume and increment is lowest in Norway (38%) and highest in Sweden (77%).

In Figure 10 the amount of annual harvested volume of wood from exploitable European forests is depicted. With the exception of Slovenia (only thinning operations are reported for 1998), fellings from final cuttings exceed those of thinning operations in all countries. The highest cutting rates per hectare are achieved in Denmark, Austria and Switzerland, and the lowest in Southern European countries and Norway.

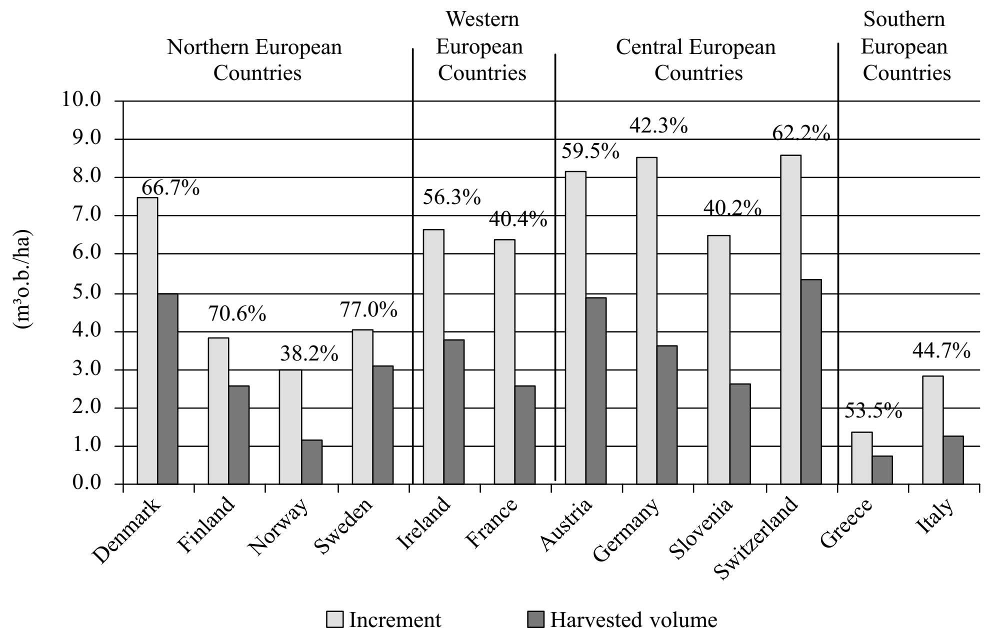

Figure 9. Data of increment and harvested volume (calculated from the industry-paid volume up to m³ over bark) per hectare reported by country. Numbers (in percent) represent the ratio of increment and harvest volume.

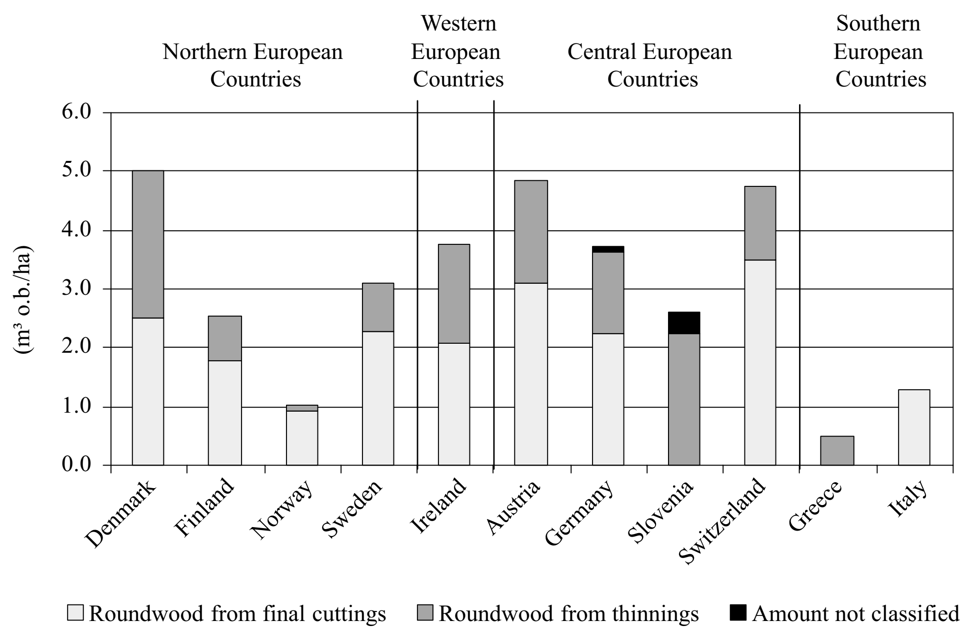

Figure 10. Harvest volume per country distributed to final cuttings, thinnings and amounts not classified.

Non-Wood Products

Apart from the wood products described above, forests also supply non-wood products shown in Table 7. These products have a market value, so they can be also defined as forestry by- or co-products. Up to now the non-wood products have not been mentioned in LCAs on wood products, and no environmental impacts have as yet been allocated. Compared to the mass of wood produced and harvested in the forests, the amount of non-wood products is rather small (generally below 1%).

Table 7. Survey of reported non-wood products in tons per year.

	resin	mushrooms	game and other hunted animals	berries	reindeer	cork	chestnuts	others
Austria	-	-	-	-	-	-	-	-
Denmark	-	-	-	-	-	-	-	-
Finland	-	1408	5857	8441	2200	-	-	311 *)
France	-	8200	-	1000	-	4000	-	600
Germany	-	-	-	-	-	-	-	-
Greece	6140	-	-	-	-	-	-	-
Ireland	-	-	-	-	-	-	-	-
Italy	-	2614	-	496	-	9204	69852	22658
Norway	-	1200	7787	25000	-	-	-	1500
Slovenia	-	800	840	600	-	-	-	3000
Sweden	-	8500	17000	20700	-	-	-	26163
Switzerland	-	735	1597	-	-	-	-	525

*) in addition, Finland uses 30.1 million m^3 of peat for energy and 1.6 million m^3 for horticultural and bedding peat out of forests

However, for some European countries data about non-wood products from forests are not available. The data shown in Table 7 were derived from specific national databases (references Table 4) and additionally from a UN-ECE/FAO study (Forest resources of Europe, CIS, North America, Australia, Japan and New Zealand (industrialized temperate/ boreal countries) UN-ECE/FAO contribution to the Global Forests Resources Assessment 2000. Main report. 445 p.). Most non-wood forest products related to weight (t/year) are mushrooms, game, berries and chestnuts. Berries are picked in Northern European countries, whereas the production of cork (Italy and France), chestnuts (Italy) and resin (Greece) are more common in Western and Southern European countries.

5.4.3 Forest operations

The most important LCA and LCA-related studies in forestry were taken into consideration to create ‘typical, representative processes’ for the forest operations applied. The aim was to develop standardized processes, which are necessary to compare the different European ‘operation mixes’.

Harvesting

There are generally two different processes to describe harvesting in forest management. Firstly, the widespread motor-manual cutting with chain saws and secondly the more mechanized one with harvesters. The harvester is very common in the countries in the north of Europe (Figure 11) and is becoming more and more important in Central European countries like Germany and Austria. The highest level of productivity for mechanized harvesting can be reached if the stands are as even as possible, with regard to the tree species as well as the diameters of the stems harvested.

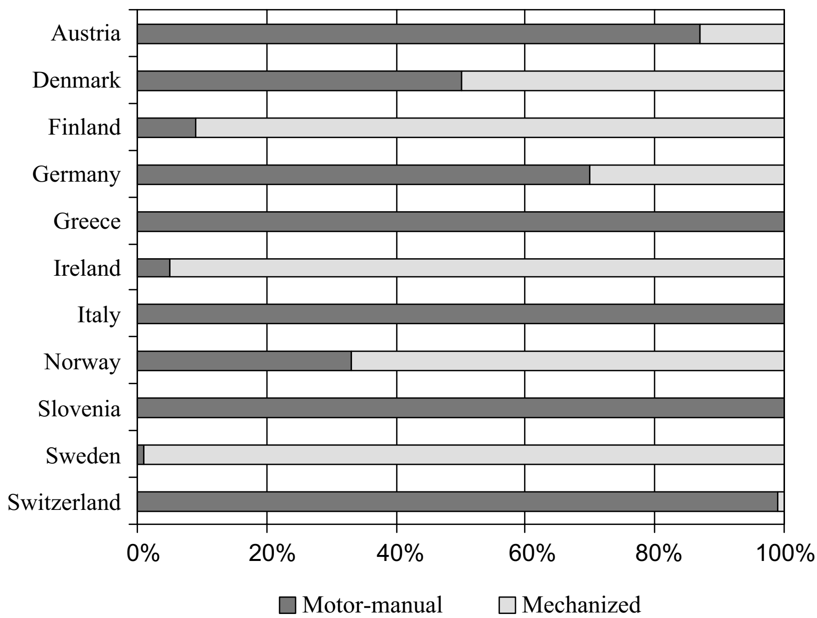

Figure 11. Share of different harvesting processes in European countries.

Compared with the motor-manual harvesting process, productivity is usually higher in thinnings. The following studies were analysed for the two harvesting processes: ‘motor-manual’ and ‘mechanized’. The main publications considered are Schweinle (1996), Winkler (1997), Knechtle (1997), Berg (1995) and (1997), Athanassiadis (2000), Fedrau (2000) and also Pröll W. (personal communication, 2001), FPP (1990) and (1991), Karjalainen and Asikainen (1996), and Berg and Karjalainen (2000).

The ‘mechanized’ process is based on the data published for the Timberjack 1270 harvester. The productivity for this process depends very strictly on the mean tree diameter of the stands; in other words, on the unit volume of the harvested stems. The mean productivity supposed in the present study is 13 m^3/hr. The other basic data for the process are shown in Table 8.

Table 8. Basic process data for the forest operation considered. Data mainly based on Trzesniowski (1989), Frischknecht (1995), Schweinle (1996), Winkler (1997), Knechtle (1997), Berg (1995) and (1997), Athanassiadis (2000) and Fedrau (2000).

	Type of Machinery	Reference	Consumption	Productivity	Fuel consumption	Emission factors, g/kg fuel*)		
Forest Harvesting			l/h	m^3/h	kg/m^3	CO_2	N_2O	CH_4
motor manual	Chainsaw (Stihl 026)	Fedrau (2000)	1.5	4.0	0.28	3150	0.02	6.91
	Chainsaw (Stihl 036)	Fedrau (2000)	2.4	8.0	0.23	3150	0.02	6.91
	Chainsaw (Stihl 026/036)	Fedrau (2000)	2.0	6.0	0.24	3150	0.02	6.91
mechanized cutting (harvester)	Timberjack 1270	Knechtle (1997)	11.3	13.0	0.77	3455	2.2	5.23
Hauling, Logging								
manual and animals	Man, Horse	FPP (1991)	-	1.5	-	-	-	-
tractor (agriculture), specific tractor (forestry), skidder	Mahler Unifant	FVA BAWÜ in Fedrau (2000)	6.0	7.0	0.64	3455	2.2	5.23
forwarder	Timberjack 810B	Knechtle (1997)	9.8	17.0	0.43	3455	2.2	5.23
cableway	Turmfalke	Winkler (1997)	7.2	6.0	0.90	3455	2.2	5.23
log line	Leykam	Trzesniowski (1989)	-	1.5	-	-	-	-
Transportation								
truck	MAN	Frischknecht (1995)	4.0			3180	0.1	0.2

The 'motor-manual' process is more complicated because the variation of the unit volumes is much higher. If countries like Greece, Italy, Slovenia, Switzerland, Austria, and Germany are considered, the motor-manual process is used in thinnings as well as in final fellings, as shown in Figure 11. In the countries in the north of Europe the use of the motor-manual process is decreasing. In his comparison of the two harvesting processes, Knechtle (1997) supposed the same unit volume of the harvested stems of 0.2 m^3, which is typical for thinnings. The unit volumes of stems from final fellings are mainly between 0.3 and 0.9 $m^{3,}$ and range up to 1.7 m^3. The Stihl 026 chain saw (Knechtle 1997) is not suitable for the description of the motor-manual process in final fellings. In order to take the variation of the unit volume into account in the present study, data about two different chain saws were used and additionally an 'average' chain saw was set up. The basic data for the chain saws are given in Table 8. The chain saws were taken into consideration depending on the expected diameters of the stands and the unit volumes.

Hauling

Various existing processes are applied in the European countries for hauling and logging the harvested stems. There are five different processes to take into account to describe hauling in forest management. Figure 12 shows the percentage of the different hauling processes in the countries.

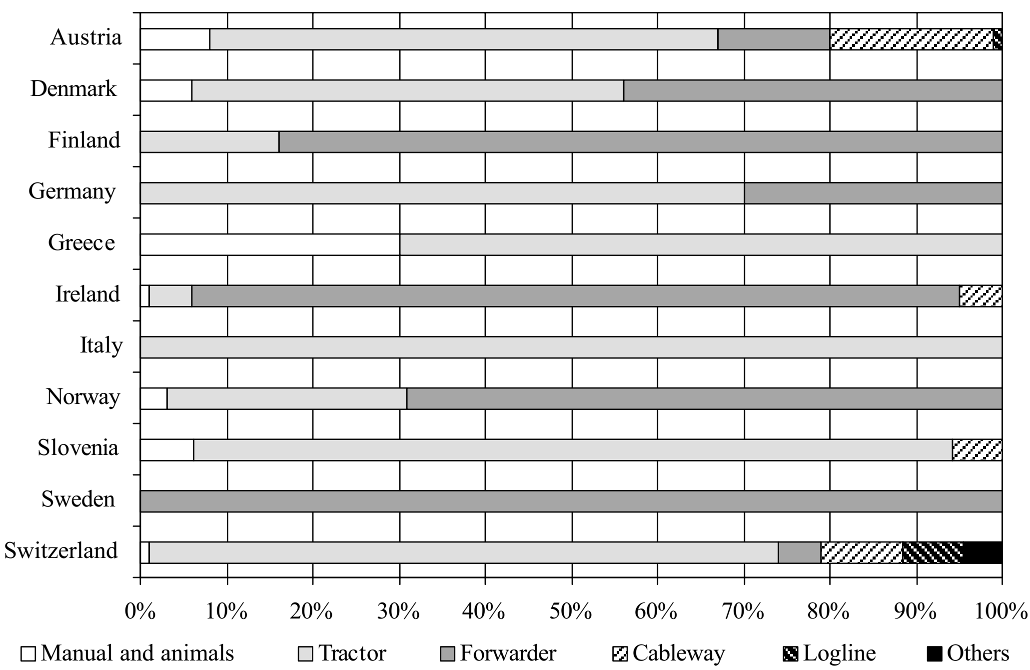

Figure 12. Percentages of different hauling processes in European countries.

Firstly hauling by man and animals, mainly horses, is termed ‘manual and animal’. This process is quantitatively important in Greece (30%), Ireland (10%), Austria (8%) and Slovenia (6%). No LCA-related data are available for this process. In the present study, the fuel consumption was set to zero for the amounts hauled by man and horses. Of course, horses also need energy (biomass) to work in the forest and there are GHG emissions, such as CO_2 and CH_4 that are taken into consideration by handling the process as described above.

Hauling by agricultural tractors, specific forest tractors or skidders is very widespread in all European countries. This process besides logging by forwarder is the most important process. Data for the ‘Mahler Unifant’ tractor (Table 8) were used (Knechtle 1997; Fedrau 2000) to calculate the fuel consumption and the GHG emissions.

The ‘forwarder’ process is mostly combined with the mechanized harvesting process. Data for the ‘Timberjack 810B’ forwarder (Table 8) were used (Schweinle 1996; Winkler 1997; Knechtle 1997; Athanassiadis 2000; Fedrau 2000) to calculate the fuel consumption and the GHG emissions.

The hauling process ‘Cableway’ is quantitatively important in the hilly countries like Austria (17%), Switzerland (9.5%) and Slovenia (6%). In some countries (e.g. Southern Germany) this process is applied, but no data for the amount of wood logged are available.

Another very special hauling process is the ‘Log line’ which is a kind of slide for stems. This process requires slopes and is, therefore, restricted to mountainous regions. It is quantitatively important only in Switzerland (7%) and Austria (1%). Fuel consumption and GHG emissions were not calculated in a similar way to the ‘manual and animals’ method. The wood moves mainly by gravity, which causes no emissions but the process is often combined with a tractor or skidder.

5.4.4 Roundwood transport

The roundwood transport is, apart from the forest operations, the next most important module. The fuel consumption and the corresponding emissions of GHGs depend on the transport distances as well as on the transport system. The percentage of the main transportation systems used in roundwood transport is shown in Figure 13. Roundwood transport by ships is only used in the Northern countries like Finland (5–6%) and Norway (4%). Roundwood is mainly transported by truck. The total weight permitted by law for the trucks varies very widely. From about 24 tons in Greece, 38 tons in Austria and 40 tons in Ireland, Germany, Slovenia and Switzerland, up to 44 tons in Italy, 48 tons in Denmark and France, 50 tons in Norway, 56 tons in Finland and 60 tons in Sweden. In addition the weight permitted by law differs, depending on the number of axles. For example, in Finland a 5-axle truck can have a weight of 44 tons, a 6-axle track 48 tons, and the weight permitted for a 7-axle truck is about 56 tons (Huttner 2001).

The present study is focused on roundwood transport by truck. Specific fuel consumption per kilometer for a truck is influenced by the type and age of the engine of the truck, the total weight and the route. With regard to the route, the percentage of highways, country roads and forest roads will have a great influence on fuel consumption. Because of lack of data concerning different routes, the focus was set on the differences caused by the different total weights. The greater the total weight, the higher the fuel

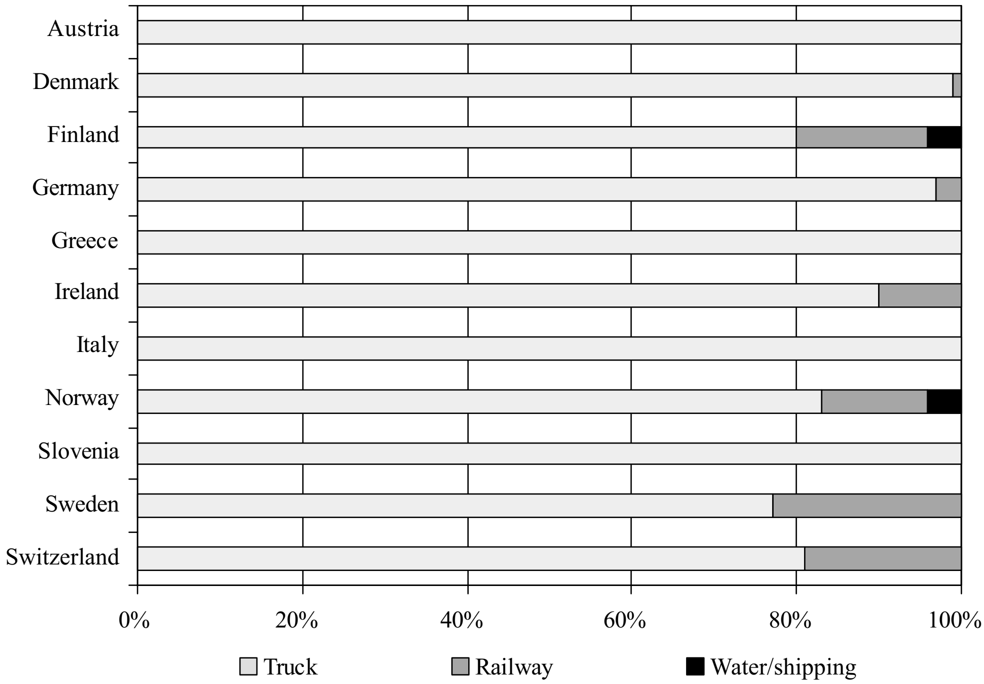

Figure 13. Percentage of different transportation systems with reference to the volume of wood in European countries.

consumption. In contrast to this, the fuel consumption per ton loaded decreases, the greater the total weight becomes, because the empty weights of the trucks increase slightly. For example, in Sweden a truck of 60 tons total weight can load approximately 39 tons of roundwood, while in Germany the 40 ton trucks can load only 27 tons.

The specific fuel consumption of the roundwood transport in kilograms per cubic meter roundwood and 100 kilometers is calculated and shown in Table 9 (Anon. 1984). The calculation is based on a mass of 1 m^3 roundwood of 900 kg (Kollmann 1951) as an average over all tree species. The weight of roundwood depends on the tree species, the diameter of the log, the share of heartwood and sapwood and the moisture.

The lowest specific fuel consumption is reported from Sweden and Finland, and the highest from Austria and Greece.

5.4.5 Comparison of fuel consumption and GHG emissions

In this section, the fuel consumption and related GHG emissions due to fossil fuel use are compared for different forest operations and countries. In Table 10, fossil fuel inputs for different forest operation processes per country are listed. Numbers are calculated on the basis of the above defined national harvest process chains and related to annual harvested volume.

Table 9. Fuel consumption for roundwood transportation expressed in kilograms fuel per cubic meter and kilometer (Anon. 1984).

Fuel consumption and total weight of truckspermitted by law		
	[kg/m³*100km]	total weight [t]
Austria	1.47	38
Denmark	1.28	48
Finland	1.16	56
France	-	48
Germany	1.42	40
Greece	1.47	24
Ireland	1.43	40
Italy	1.42	44
Norway	1.28	50
Slovenia	1.42	40
Sweden	1.14	60
Switzerland	1.42	40

Table 10. Fossil fuel input for different forest operation processes in Europe (no data for France have been reported).

	Harvesting	Hauling [kg fuel/m³]	Transport	Total
Austria	0.31	0.59	3.68	4.6
Denmark	0.51	0.46	1.28	2.3
Finland	0.73	0.36	2.08	3.2
France	-	-	-	-
Germany	0.40	0.58	1.42	2.4
Greece	0.28	0.45	5.89	6.6
Ireland	0.75	0.48	1.98	3.2
Italy	0.24	0.64	0.86	1.7
Norway	0.60	0.47	1.41	2.5
Slovenia	0.24	0.62	0.99	1.9
Sweden	0.77	0.43	2.08	3.3
Switzerland	0.25	0.58	1.22	2.0

Fuel inputs for harvesting operations are higher for Northern European countries, where the rate of mechanized cuttings of thinnings and final fellings is much higher than in other European countries. The highest mechanization rates combined with higher energy efforts per cubic meter timber are calculated for Sweden, Finland and Ireland, and the lowest for Slovenia, Italy and Switzerland. The latter reported higher rates of motor manual harvest operations. Currently, for alpine countries, like Switzerland and Austria, steep slopes of forest sites mainly cause lower mechanization rates. The differences between countries are rather small (between 0.36 and 0.64 kg fuel/m^3) for hauling processes, because similar hauling processes are used in all countries. Due to the essential use of agricultural tractors etc. in hauling operations with lower productivity, the energy input in Austria (0.59 kg/m^3), Slovenia (0.62 kg/m^3) and Italy (0.64 kg/m^3) exceed those of other countries with forwarder use.

Energy efforts of hauling processes exceed those of harvesting operations except in countries of highly mechanized forest harvesting. Energy inputs for transportation operations per cubic meter of timber are generally higher in all countries. Fuel demands per cubic meter of timber were assessed with higher results for Sweden and Austria on the basis of reported average distances to national wood-processing industries and total weight of transports on trucks permitted by law. Lower total weights permitted by law influenced these numbers significantly.

The total amounts of CO_2 emissions per kilogram fossil fuel are multiplied with the appropriate fuel consumption per cubic meter of timber to calculate the results for Table 11. Total emissions of CH_4 and N_2O are calculated in the same way as described for CO_2. The latter are then multiplied with the factors 21 and 310 to account for their radiative forcing compared with CO_2; time period assumed: 100 years; (IPCC 1995) and added to the total CO_2 emissions, resulting in total GHG emissions (CO_2 equivalents). The highest emission rates for harvest operations are assessed for Sweden (2.54 kg CO_2 equiv./m^3), the lowest for Italy and Slovenia (0.8 kg CO_2 equiv./m^3).

Table 11. GHG emissions for different forest operation processes in Europe (no data for France have been reported).

	Harvesting	Hauling	Transport	Total
		[kg CO equiv./m^3]		
Austria	1.04	2.50	11.81	15.3
Denmark	1.70	1.96	4.12	7.8
Finland	2.40	1.53	6.68	10.6
France	-	-	-	-
Germany	1.33	2.46	4.55	8.3
Greece	0.93	1.91	18.90	21.7
Ireland	2.47	2.04	6.37	10.9
Italy	0.80	2.73	2.74	6.3
Norway	1.98	2.01	4.54	8.5
Slovenia	0.80	2.62	3.18	6.6
Sweden	2.54	1.84	6.67	11.0
Switzerland	0.82	2.45	3.91	7.2

Also, transport processes for timber to the national forest industries cause emissions released to the atmosphere with the highest emission rates per cubic meter harvested timber – compare with Table 10 – in Greece (18.9 kg CO_2 equiv./m^3) and Austria (11.8 kg CO_2 equiv./m^3).

5.4.6 Sensitivity analysis

Tables 12 and 13 show the results of the sensitivity analysis carried out to demonstrate the influence of productivity on fuel consumption in forest operations. In the left row a lower productivity is assumed, and in the right row a higher productivity is assumed.

Table 12. Fuel consumption for *harvesting* calculated for different levels of productivity in the processes.

	Fuel Consumption (kg/m³)		
Productivity:	low	average	high
Austria	0.47	0.31	0.24
Denmark	0.72	0.51	0.41
Finland	0.95	0.73	0.59
France	-	-	-
Germany	0.56	0.40	0.32
Greece	0.30	0.28	0.18
Ireland	0.97	0.75	0.61
Italy	0.37	0.24	0.18
Norway	0.79	0.60	0.48
Slovenia	0.37	0.24	0.18
Sweden	1.00	0.77	0.63
Switzerland	0.40	0.25	0.19

Table 13. Fuel consumption for *hauling* calculated for different levels of productivity in the processes.

	Fuel Consumption (kg/m³)		
Productivity:	low	average	high
Austria	0.92	0.59	0.47
Denmark	0.72	0.46	0.37
Finland	0.48	0.36	0.30
France	-	-	-
Germany	0.95	0.58	0.46
Greece	0.79	0.45	0.35
Ireland	0.61	0.48	0.41
Italy	1.13	0.64	0.50
Norway	0.67	0.47	0.39
Slovenia	1.05	0.62	0.48
Sweden	0.53	0.43	0.37
Switzerland	0.95	0.58	0.46

5.5 CONCLUSIONS

The availability of forest data in European countries differs significantly. Where data on forest land use (ha), distribution of tree species (%), growing stock, increment and harvest (m^3 o.b.) are available in all countries, specific data and information on different forest operations are rather small. Distributions of motor manual and mechanized harvest operation on thinning and final felling roundwood are not common in all countries. The same conclusion can be drawn for different hauling systems. Distances and data on the transportation of forest wood products are assumed in all countries. Data on non-wood forest products are also not available in most countries.

In all countries the fuel consumption for transport processes of forest products to the forest industry exceeds the consumption of harvesting and hauling operations, where the differences in the country-specific amounts are highly dependent on the total weight of trucks permitted by national laws. Between 0.5% and 3.2% of the energy stored in the wood is needed to transport roundwood to industry in Europe.

A greater degree of mechanization in Northern and Western European countries causes greater fuel inputs per cubic meter of roundwood in harvesting than in hauling processes. Hauling operations release greater GHG emissions due to greater fuel consumptions for the other European countries. The mean demand for fuel for the forest operations harvesting and hauling in Europe is about 0.83 kg fuel per cubic meter roundwood, and varies from 0.53 to 1.58 kg fuel per cubic meter roundwood. The lowest energy demand was found in the countries with less mechanized forest management and a high share of final cuttings. As a result, the more highly mechanized the forest operations are, the greater the fuel consumption.

Compared with the solar energy stored in the wood itself, forest operations (only harvesting and hauling) consume from 0.25% to 0.75%. This seems to be a very low amount compared with other industrial processes.

Similar to the fuel consumption, the GHG emissions from forest operations are very low (from 0.3% to 0.5%) compared with the carbon stored in the wood through forest growth.

References

AID. 2001. Auswertungs- und Informationsdienst für Ernährung, Landwirtschaft und Forsten (Hrsg.) Forst und Holz, Bonn. 20 pages. http://*www.aid.de/landwirtschaft/produkte/forstholz2001/ftp/forstholz2001.pdf*

Anon. 1984. Vorbild Schweden. Verkehrsrundschau 33(08):11.

Athanassiadis, D. 2000. Resource Consumption and Emissions Induced by Logging Machinery in a Life Cycle Perspective. Doctoral thesis of the Swedish University of Agricultural Sciences in Umea. Silvestria No. 143.

Berg, S and Karjalainen, T. 2000. Comparison of Emissions from Forest Operations in Finland and Sweden. (Presentation at COST Action E9 Mid-term Seminar in Espoo/Finland, Dipoli, 27–29 March 2000 and poster presented at International Science Conference "The Role of Boreal Forests and Forestry in the Global Carbon Budget" May 8–12th, 2000 Edmonton, Alberta, Canada. (Paper in preparation).

Berg, S. 1995. The Environmental Load of Fossil Fuels in Swedish Forestry – an Inventory for a LCA. Life Cycle Analysis – a Challenge for Forestry and Forest Industry. Frühwald, A. and Solberg, B. (eds.). EFI Proceedings No. 8.

Berg, S. 1997. Some aspects of LCA in the analysis of forestry operations. Journal of Cleaner Production 5(3).

BML. 1993. Die Bundeswaldinventur 1986–1990. Bonn: Bundesministerium für Ernährung, Landwirtschaft und Forsten (Hrsg.) Band I; 118 Seiten.

BML. 1994. Der Wald in den neuen Bundesländern – Eine Auswertung vorhandener Daten nach dem Muster der Bundeswaldinventur. Eberswalde: Bundesforschungsanstalt für Forst- und Holzwirtschaft; 20 Seiten.

BMLF. 1996. Österreichischer Waldbericht 1995, Jahresbericht über die Forstwirtschaft und Bericht des Bundesministers für Land- und Forstwirtschaft, Wien 1996.

BMLFUW. 1999. Holzeinschlagsmeldung des Bundesministeriums für Landwirtschaft, Forstwirtschaft, Umwelt und Wasserwirtschaft 1999.

BUWAL. 1996. Holztransporte 1993 in der Schweiz. Bern (Switzerland): BUWAL Umweltmaterialien Heft Nr. 61.

Burschel, P. 1990. Das Menetekel – Klimaänderung. Konsequenzen für die Forstwirtschaft weltweit. Allg. Forst Zeitschr. 45(11):255–257.

DNS. 2001. Skogen I tall – The Forest in Numbers. Skogselskapet 2001.

FBVA. 1997. Österreichische Waldinventur 1992/96, CD-Rom, Federal Research Centre, Vienna.

Fedrau, S. 2000. Erstellung einer Sachbilanz für das Forstamt Kempten. München: Diplomarbeit, Holzforschung München der Technischen Universität München.

Finnish Statistical Yearbook of Forestry. 1999. Finnish Forest Research Institute. Gummerus Kirjapaino Oy, Jyväskylä, 352 p.

FPP. 1991. Kooperationsabkommen Forst-Platte-Papier, Maschinen in der Durchforstung, Harvester/ Prozessoren, Wien Oktober 1991.

FPP. 1990. Kooperationsabkommen Forst-Platte-Papier, Holzernte in der Durchforstung, Verfahren Methodische Arbeit; Schleppergelände, Wien April 1990.

Houghton, J. 1997. Globale Erwärmung – Fakten, Gefahren und Lösungswege. Berlin, Heidelberg: Springer Vlg.; 230 S.

Huttner Fahrzeugbau GmbH. 2001. Weight permitted by law. Extract of EU Guideline 96/53/EG.

IPCC. 1995. Climate Change 1995 – The Science of Climate Change, Contribution of Working Group 1 to The Second Assessment Report of The Intergovernmental Panel on Climate Change, Cambridge University Press.

ISTAT. 1996. Statistiche forestali (Forestry statistics). Istituto Nazionale di Statistica Statistic National Institute, Ed. Abete industria poligrafica s.p.a., Roma, 91 pp.

Karjalainen, T. and Asikainen, A. 1996. Greenhouse gas emissions from the use of primary energy in forest operations and long-distance transportation of timber in Finland. Forestry 69(3):215–228.

Knechtle, N. 1997. Materialprofile von Holzerntesystemen – Analyse ausgewähler Beispiele als Grundlage für ein forsttechnisches Ökoinventar. Diplomarbeit ETH-Zürich, Department für Wald und Holzforschung; 66 Seiten.

Kollmann, F. 1951. Technologie des Holzes und der Holzwerkstoffe. Berlin, Heidelberg, New York: Springer Vlg; 2. Auflage 1982, 1050 S.

KWF. 2001. Kuratorium für Waldarbeit und Forsttechnik. Personal communication.

LFI. 2001. Swiss National Forest Inventory 1993–1995. *http://www.wsl.ch/land/products/lfi/*

NIJOS. 2000. Skog 2000 – Statistics of forest conditions and resources in Norway. Norsk institutt for jord- og skogkartlegging.

Perruchoud, D.O. and Fischlin, A. 1995. The response of the carbon cycle in undisturbed forest ecosystems to climate change: a review of plant-soil models. Journal of Biogeography 22:759–774.

Pröll W. 2001. personal communication.

Schulze, E.-D. 2000. Der Einfluss des Menschen auf die biogeochemischen Kreisläufe der Erde. JV 2000.76–90.

National Board of Forestry, Sweden. 2000. Statistical Yearbook of Forestry 2000. Official Statistics of Sweden. National Board of Forestry. Jönköping.

Schweinle. 1996. Analyse und Bewertung der forstlichen Produktion als Grundlage für weiterführende forst- und holzwirtschaftliche Produktlinien-Analysen. Mitteilungen der Bundesforschungsanstalt für Forst- und Holzwirtschaft Hamburg; ISSN 0368-8798, Heft Nr. 184, 123 S.

Schweiz. 1991. Vollerhebung zu Holzverbrauch und Produktion aller Stammholz verarbeitenden Betriebe der Schweiz 1991.

Schweiz. 1993. Schweizerische Jahresstatistik – Aussenhandelsstatistik. Bern (Switzerland): Eidgenössische Oberzolldirektion.

Slovenia. 1998. Public Forest Service Report 1998. Ljubljana.

Slovenia. 1999. State Office for Statistical Studies. Ljubljana.

Slovenia. 2000. Forest Inventory Database 2000. Public Forest Service (Ed.); Ljubljana.

SSB. 1999. Forestry Statistics 1999 and supported web-pages. Statistics Norway 1999.

TF. 2001. Personal contact with Transportbrukernes Fellesorganisasjon (Norway).

UN-ECE/FAO. 2000. Socio economic functions of forest and other wooded land. Chapter VI of "Forest Resources of Europe, CIS, North America, Australia, Japan and New Zealand (industrialized temperate/boreal countries). UN-ECE /FAO Contribution to the Global Forest Resources Assessment 2000". Main report, United Nations Publication, Sales No.99-II-E-36; ISBN 92-1-116735-3; ISSN 1020-2269. Pp. 355–357. http://www.unece.org/trade/timber/fra/screen/chp6_tot.pdf

Watson R.T., Noble I.R., Bolin B., Ravindranath N.H., Verardo D.J. and Dokken D.J. (eds.). 2000. Land Use, Land-Use Change and Forestry. A Special Report of the IPCC. Cambridge University Press. 377 s.

Wegener, G. and Zimmer, B. 2000. Wald und Holz als Kohlenstoffspeicher und Energieträger: Chancen und Wege für die Forst- und Holzwirtschaft. In: Schulte, A. et al. (Hrsg.): Weltforstwirtschaft nach Kyoto: Wald und Holz als Kohlenstoffspeicher und regenerativer Energieträger. Aachen: Shaker Vlg. ISBN 3-8265-8641-7; S.: 113-122.

Winkler, C. 1997. Ökoinventare von Holzerntesystemen (Vorstudie). Zürich: Eidgenössische Technische Hochschule; Forstliches Ingenieurwesen; Interne Berichte Nr. 7; 51 Seiten.

ZMP. 2000. Forst und Holz – Marktbilanz 2000. Bonn: ZMP, Zentrale Markt- und Preisberichtstelle (Hrsg.); CD-Rom. ISBN: 3-933721-73-3.

6 INCLUSION OF NUTRIENTS IN LCA OF FORESTRY AND FOREST PRODUCTS

Coordinating authors: L. Finér and P. Cortijo

Contributing authors: S. Berg, T. Karjalainen, B. Kosir, J.-M. Roda, H. Schwaiger and B. Zimmer

6.1 INTRODUCTION

LCA is defined as compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 1997). LCAs have not only been carried out to compare different products, but also to get information about material and energy flows connected with products and systems. The main products considered in LCAs are wood, pulp, paper and board and the common functional units are either cubic meters (in the case of wood) or metric tons. The other resources or materials often considered are the consumption of energy, water and chemicals (see Figure 14). Also the transportation distances of products and emissions are included and sometimes even the land use.

Nutrient flows are not often studied directly and detailed in LCAs, and thus some ideas will be discussed here. The main objectives of this paper are to identify the nutrient flows that have an impact on the environment and present the main current limitations in the evaluation of these flows.

6.2 CONTRIBUTIONS OF NUTRIENT FLUXES TO ENVIRONMENTAL IMPACTS

6.2.1 Nutrients in discussion

The nutrients of interest from the environmental point of view are the macronutrients (N, P, K, Ca, Mg, S) and the micronutrients (Fe, Mn, Zn, Cu, B…). The nutrients are both stored and cycled in the forest-wood product system. The nutrients flows that may contribute to the impacts of forest on the environment are those that are between the forest and the environment. The nutrient flows within trees have no impact.

Energy, Carbon and Other Material Flows in the Life Cycle Assessment of Forestry and Forest Products
Timo Karjalainen, Bernhard Zimmer, Staffan Berg, Johannes Welling, Hannes Schwaiger, Leena Finér and Patricia Cortijo

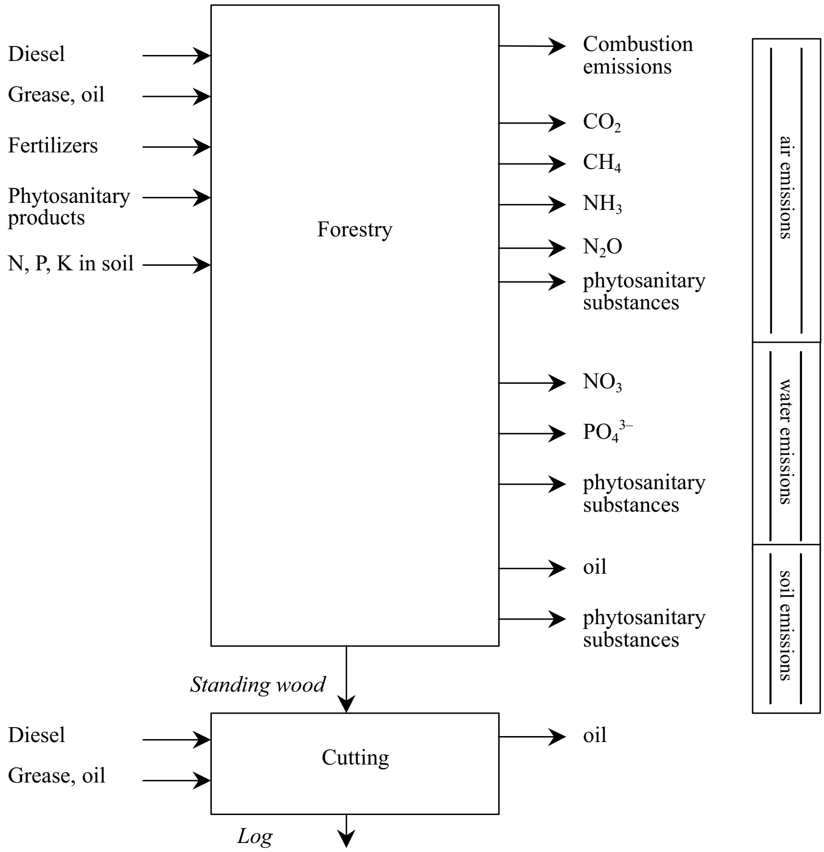

Figure 14. Forestry LCA flows.

6.2.2 Nitrogen flows

The forest-wood product system nutrient pools and fluxes can be defined for N as in Figure 15. The main pools of N in the forest are in trees and soil. The N input comes from the atmosphere by N fixation and by the atmospheric deposition. Nitrogen leaching and timber harvesting cause outputs from the forest system. Harvesting can also increase leaching losses and decrease atmospheric inputs by removing the intercepting tree canopy. The harvested timber is used to make products that can be recycled or sent to landfills or are burnt to generate energy. The burning process releases N immediately into the atmosphere, but N is released very slowly from landfills. The system description does not include the transportation of timber, wood products and waste. The system has many components similar to those described for carbon by Karjalainen (1996).

From this cycle, the flows that may have environmental impacts are presented in (Table 14). The exchange with the environment may correspond to releases (NH_3, NO_2 and N_2O to the atmosphere) or to both releases and uptakes (NO_3 to water and to soil).

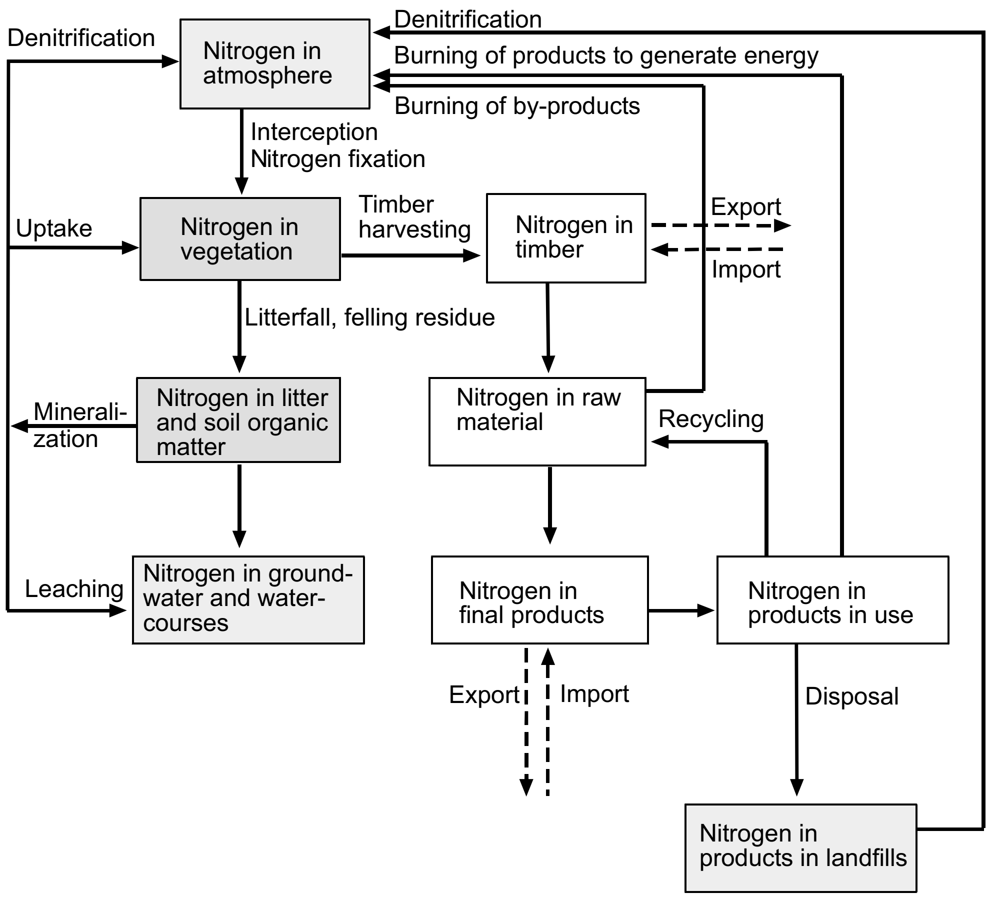

Figure 15. Example of defining the nitrogen pools and fluxes related to forest-wood product chain. Boxes are pools and arrows are fluxes. The process causing the flux is indicated above the arrow.

Table 14. Nitrogen flows potentially contributing to environmental impacts.

Chemical form of N	Compartment	Origin	Impact
Nitrate (NO_3)	soil	mineralization/uptake	soil depletion
Nitrate (NO_3)	water	mineralization/uptake	eutrophication
Ammonia (NH_3)	air	fertilization	acidification
Nitrous oxide (N_2O) emission in atmosphere	air	denitrification	greenhouse effect
Nitrogen oxides (NO_x)	air	combustion	acidification

6.2.3 Phosphorus and base cations (Ca, Mg, K) flows

Very similar system description as for N can be presented for P and the base cations (Figure 16). The main difference is that there is no output from the forest wood product system to the atmosphere and back to the cycle, but there is a possibility to return the wood ash from burning process back to forest. However, this is not a very significant flow at the moment. In the production of paper, chemicals are used that contain Ca and this flow should also be included in LCA for Ca. The main environmental impact associated with base cations is soil depletion whereas phosphorus release into the watercourses may cause eutrophication.

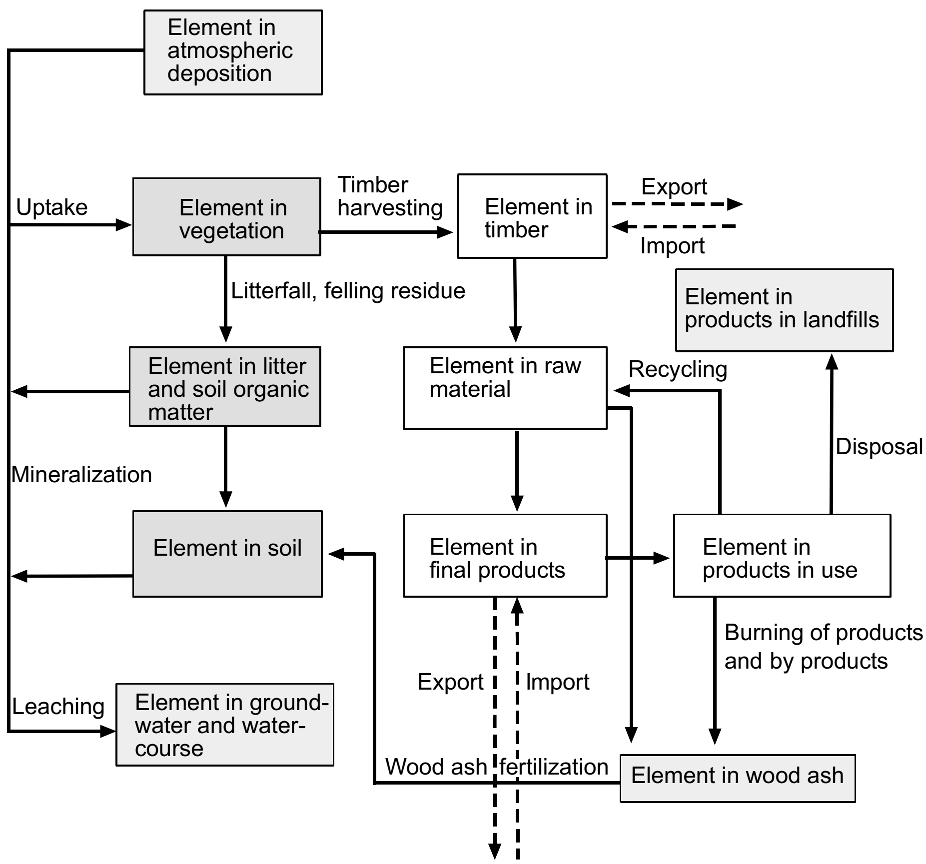

Figure 16. Example of defining the P and base cations (Ca, Mg, K) pools and fluxes related to forest-wood product chain. Boxes are pools and arrows are fluxes. The process causing the flux is indicated above the arrow.

6.3 MAIN LIMITATIONS IN ASSESSING THESE FLOWS

There are limitations in evaluating nutrient flows. Contrary to pollutant flows from industrial plants, it is far more laborious to measure directly the nutrient fluxes from forest.

Nutrient pools and fluxes have been studied in some forest ecosystems (e.g. Mälkönen 1974; Finér 1989, 1991; Helmisaari 2000). In these studies soil and vegetation nutrient contents have been determined as well as the nutrient fluxes by vegetation uptake and litter fall, and by inputs and outputs into and out of the ecosystem. Nutrient pool and flux studies are time and cost-intensive since the biomass and nutrient concentrations of different ecosystem components have to be determined and the fluxes have to be monitored for several years to get accurate estimates. These studies cannot be done on a regular basis and consequently, these pools and fluxes should be estimated using models. Such models are still in development. Until now, modelling research has mainly focussed on assessing the harvesting effects on soil depletion. For instance a simulation study has been carried out where the effects of varying rotation, thinning, fertilization and harvest intensity on the nitrogen cycle of Scots pine stands were studied (Kellomäki and Seppälä 1987). As the environmental problems are far more critical, work is much more advanced for agriculture. Models have already been tested with field measurements and most of the parameters playing a role in flow values are identified. Table 15 provides examples of such parameters for phosphorus.

Table 15. Key factors characterising magnitude of major flows of phosphorus through agricultural systems (Weidema et al. 2000).

Farm typology	Geographical factors	Management factors
- Crop or livestock type - Stocking density for livestock	- Soil type (including typography) - P status (Total P, % saturation or P sorption capacity) - Hydrologically effective rainfall (excess rain) quantity, intensity and duration	- Quantity of concentrates, fertilisers, and/or organic waste(s) - Tillage (timing, type) - Drainage

Once the models are available and the needed parameters are identified, the next stage is to get the parameter values at the adequate geographical, site type, tree species and soil type level. For agricultural systems, the Farm Accountancy Data Network, which is a European instrument for evaluating the income of agricultural holdings and the impacts of the Common Agricultural Policy, is already measuring some of the parameters, which are useful for flow evaluation. Moreover, this network could integrate the monitoring of new parameters.

6.4 CONCLUSIONS

Nutrients are the raw material needed for production of timber and they are involved in many of the potential environmental impacts of the forestry and forest industry. Acidification of ecosystems can result from emissions of gaseous forms of N and S into the atmosphere. Outputs of heavy metals (e.g. Cu, Zn, Fe, Cd, Cr) can be toxic to living organisms. Outputs of N and P into watercourses causes eutrophication. Wood contains nutrients and its retrieval from forest gradually depletes the soil fertility. Seldom are the nutrients returned back to the forest where they were harvested.

It has been proposed that the system investigated should include all environmentally important processes (Ekvall et al. 1977). The first stage would be to identify which are the relevant flows for wood products: is it worthwhile to take into account all the nutrient related flows or should we focus on the more important ones?

Once the inclusion of nutrients in LCAs is fully justified, consistent methods and data to evaluate the flows still need to be found. Methods for assessing the different environmental impacts related to nutrient outputs from the forest- forest product system have already been presented e.g. by Seppälä (1997). It should also be clarified if the required parameters can be monitored using existing forest networks such as the European Forestry Information and Data Analysis System (EFIDAS) or the European Forest Resource Database (EEFR) or International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems (UN ECE ICP) or if a new specific database dedicated to the environmental impacts of European forests should be developed.

References

Ekvall, T., Rydberg, T., Hedenberg, Ö., Backlund Jacobson, B., Pajula, T. and Wessman, H. 1997. Guidelines of life cycle impact assessment of pulp and paper. Nordpap DP2/55. Scan Forskrapport 688. 30 p.

Finér, L. 1989. Biomass and nutrient cycle in fertilized and unfertilized pine, mixed birch and pine and spruce stands on a drained mire. Acta Forestalia Fennica 208. 63 p.

Finér, L. 1991. Effect of fertilization on dry mass accumulation and nutrient cycling in Scots pine on an ombrotrophic bog. Acta Forestalia Fennica 223. 42 p.

ISO. 1997. Environmental Management – Life cycle assessment – Principles and framework. (ISO 14040:1977).

Karjalainen, T. 1996. Dynamics of the carbon flow through forest ecosystem and the potential of carbon sequestration in forests and wood products in Finland. Research Notes, Faculty of Forestry, University of Joensuu. 31 p.

Kellomäki, S. and Seppälä, M. 1987. Simulations on the effects of timber harvesting and forest management on the nutrient cycle and productivity of Scots pine stands. Silva Fennica 21(2):203-236.

Mälkönen, E. 1974. Annual primary production and nutrient cycle in some Scots pine stands. Communicationes Instituti Forestalis Fenniae 84(5):1–87.

Seppälä, J. 1997. Decision analysis as a tool for life cycle impact assessment. The Finnish Environment 123. 137 p.

Weidema, B.P. and Meeusen, M.J.G. 2000, Agricultural data for Life Cycle Assessment, Agricultural Economics Research Institute (LEI), The Hague.

APPENDIX I: NAMES, ORGANIZATIONS, AND CONTACT INFORMATION OF THE PARTICIPANTS IN WORKING GROUP 1.

Hannes Schwaiger
Joanneum Research Institute of Energy Research
Elisabethstr. 5
A-8010 GRAZ
AUSTRIA
Tel: +43 316 876 1316
Fax: +43 316 876 9 1316
Email: hannes.schwaiger@joanneum.at

Reinhart Ceulemans
Department of Biology
University of Antwerpen (UIA)
Universiteitsplein 1
B-2610 Wilrijk
BELGIUM

Bart Muys
Laboratory of Forest, Nature and Landscape Research
KULeuven
Vital Decosterstraat 102
B-3000 Leuven
BELGIUM
Tel: +32 16 329 726
Fax: +32 16 329 760
Email: bart.muys@agr.kuleuven.ac.be

Knud Erik Kvist
Danish Technological Institute,
Gregersensvej
P.B. 141
DK-2630 Taastrup
DENMARK
Email: knud.erik.kvist@teknologisk.dk

Leena Finér
Finnish Forest Research Institute
Joensuu Research Station
Box 68
FIN-80101 Joensuu
FINLAND
Tel: +358 13 251 4040
Fax: + 358 13 251 4567
Email: leena.finer@metla.fi

Timo Karjalainen
European Forest Institute
Torikatu 34
FIN-80100 Joensuu
FINLAND
Tel: +358-13-252 0240
Fax: +358-13-124 393
Email: timo.karjalainen@efi.fi

Patricia Cortijo
Ecobilan-PriceWaterhouseCoopers
Tour AIG – 34
place des Corolles 92908
Paris la Défense Cedex
FRANCE
Tel (standard): +33 (0)1 56 57 58 59
Tel (direct): +33 (0)1 56 57 80 95
Fax: +33 (0)1 56 57 16 36
Email: patricia.cortijo@fr.pwcglobal.com

Jean-Marc Roda
CIRAD-FORÊT/CIRAD's Forestry Department
Programme Bois / Forest Products Programme
Maison de la Technologie
73 rue J-F Breton
BP 5035
34032 Montpellier Cedex 01
FRANCE
Tel: +33 (0)4 67 61 44 99
Fax: + 33 (0)4 67 61 57 25
Email: jean-marc.roda@cirad.fr

Johannes Welling
Bundesforschungsanstalt für Forst- und Holzwirtschaft
Institut für Holzphysik
Leuschnerstrasse 91
D-21031 Hamburg
GERMANY
Tel: +49 (0)40 73962 619
Fax: +49 (0)40 42891 2925 or +49 (0)40 73962 480
Email: welling@holz.uni-hamburg.de

Bernhard Zimmer
Institut für Holzforschung
Technische Universität München
Winzererstrasse 45
D-80797 München
GERMANY

Current address:
Holztechnikum Kuchl
FH Studiengang Holztechnik und Holzwirtschaft
Markt 136
A-5431 Kuchl
AUSTRIA
Tel: +43 – 6244 – 5372 152
Fax: +43 – 6244 – 53722
Email: bernhard.zimmer@ht-kuchl.ac.at

Kalliopi Radoglou
Forest Research Institute
57006 Vassilika, Thessaloniki
GREECE
Tel: +30-31 461 171
Fax: +30-31 929 806
Email: radoglou@spark.net.gr

Maarten A. Nieuwenhuis
Univ. College Dublin
Department of Forestry
Belfield
Dublin 4
IRELAND

Alistair Pfeifer
Coillte Teoranta
Research and Development
Newtownmountkennedy
Co. Wicklow
IRELAND

Riccardo Scarpa
Disafri-Università della Tuscia
Via De Lellis
I-01100-Viterbo
ITALY

Petra Esser
Centre for Timber Research
TNO Building and Construction Research
PO Box 49
2600 AA Delft
NETHERLANDS

Patrick Jansen
Institute for Forest and Forest Products (SBH)
Bosrandweg 5
P.O. Box 253
NL-6700 AG
NETHERLANDS

Tor Kristensen
Norsk Treteknisk Institutt
Postboks 113 Blindern
N-0314 Oslo
NORWAY

Bostjan Kosir
University of Ljubljana
Department of forestry
Vecna pot 2
1000 Ljubljana
SLOVENIA
Email: bostjan.kosir@Uni-Lj.si

Dimitris Athanassiadis
Swedish University of Agricultural Sciences, Faculty of Forestry, Department of Silviculture, Division of Forest Technology
S-90183 Umeå
SWEDEN
Tel: +46 90 7866287
Fax: +46 90 7866278
Email: dimitris.athanassiadis@ssko.slu.se

Staffan Berg
Skogfors
Uppsala Science Park
S-75183 Uppsala
SWEDEN
Tel: +46 18 188500
Fax: +46 18 188600
Email: staffan.berg@skogforsk.se

Norbert Knechtle
Dep. of Forest and Wood Sciences
Section of Forest Engineering
ETH Zentrum HG G 22.4
CH-8092 Zürich
SWITZERLAND

Daniel Perruchoud
Swiss Fed. Institute for Forest, Snow and
Landscape Research
National Forest Inventory
Zuercherstr. 111, HV F04
CH-8903 Birmensdorf
SWITZERLAND

Peter Bonfield
Centre for Timber Technology & Construction,
Building Research
Establishment
Garston, Watford
Herts WD2 7JR
UNITED KINGDOM
Tel: 01923 664815
Fax: 01923 664785
Email: bonfieldp@bre.co.uk

APPENDIX II: QUESTIONNAIRE LCA TERMS USED IN FOREST RELATED STUDIES

Scope

List of terms in definitions used in studies related to task 1 “Identification of problems using case studies.”

Rationale

Due to decision at Cost Action E9 Midterm seminar 27–29 March 2000

Questions

1. Has your institute undertaken any LCA related studies of forestry or forest products?
   Yes □ No □

2. Does your institute find terms and definitions given in ISO 14041 satisfactory?
   Yes □ No □

3. List, where appropriate, definitions and references to publications.

Suggested terms	Definition	Reference
Product		
Main product		
Final product		
By-product		
Co-product		
Waste		
Other		

APPENDIX III: RESPONSES TO THE QUESTIONNAIRE

Ten scientists from eight institutes have responded to the questions. Joanneum, Austria; University of Ljubljana, Slovenia; Price Waterhouse Coopers Ecobilan, France ; Bundesforschungsanstalt für Forst- und Holzwirtschaft (BFH), Germany; Dansk Teknologisk Institut (DTI), Denmark; Eidgenössische Materialprüfungs- und Forschungsanstalt (EMPA), Switzerland; Metsäteho, Finland; SkogForsk, Sweden; Imperial College of Science, Technology and Medicine, UK.

1. Has your institute undertaken any LCA related studies of forestry or forest products?
   Yes 7
   No 1

2. Does your institute find terms and definitions given in ISO 14041 satisfactory?
   Yes 6
   No 3

3. Terms and definitions

Comment: There are a wide range of opinions of terms and definitions. Two representative general remarks are copied below. These are followed by a table that demonstrates the variety of concepts in the replies (Table 16). If the terms are based on a reference, then the reference is mentioned; otherwise they should be regarded as the scientist's interpretation of the term in colloquial language.

We need to use different terms to designate flows if we apply different methodology rules to these flows. In practice, we almost never use the ISO definitions as we try to identify the specific methodology rules, which fit best with each by- or co-product we have to deal with.

Within our LCA studies in the field of biomass and energy, the definitions of the ISO 14041 where appropriate enough. We see these definitions as a basis in LCA and defined the terms of 'products' 'co-products' and 'by-products' study specific. Especially when we allocate emissions, environmental effects, etc. on the products, we didn´t need other definitions than those of the ISO 14041.

Table 16. List of terms and definitions.

Terms	Definition
Product	• Physical things with measurable characteristics as dimensions, colour, taste, etc., or services that are offered to the market and demanded by the consumers, as in a process of manufacture. • See product system in ISO 14040 (Swedish Standards Institution 1998a) "collection of materially and energetically connected unit processes which performs one or more defined functions". Note in this international standard the term 'product' used alone includes, not only product systems, but also 'service systems'. *ISO 14040* (further details in *ISO 14041* – Swedish Standards Institution 1998b). • A tradeable good or service produced by an economic process, which is or may be used in a different economic process (Heijungs et al. 1992). • General term. Type of output of a LCI module. Product is an output from a production step, process or service that can be used for a certain purpose. • Any material or energetic output that can be used for something. • Main products + by-products. • Same as final product. *ISO 14041*. • Collection of materially and energetically connected unit processes which performs one or more defined functions.
Main product	• Is product or co-product • Type of product. The question, whether a product is a main product, a final product or a by- or co-product depends strongly on economics and on the conversion or production process itself. • A main product is defined by the purpose of the process. It must contribute considerably to the economics regardless of its fraction of the total output. • The product of certain organisation that represents majority of its resources and market share. • The main product of a unit process is the product justifying the existence of the process. There may be several main products for a unit process (refinery, for instance): in this case, they are co-products. The main product for a given unit process may change; for instance, if the price of a former by-product becomes higher than the price of the main product. • This definition is important, as a methodological rule may be to allocate all the environmental burdens to the main products. • As final product. *ISO 14041*.
Final product	• Product which requires no additional transformation prior to its use. *ISO 14041*. • The term final product relates more to the user requirements than to the pre-defined system boundary. A final product can be used or marketed without further processing. • E.g. sawn timber can be the final product of a sawmill. This sawn timber can be dried, in which case a new final product is created. Dried sawn timber can be an input for a furniture production. Here the sawn timber is processed and converted, by adding other 'final products' (from other modules) to result in a piece of furniture, which is the new final product of the furniture production. The piece of furniture is used by an end consumer. • Product at the end of technological process. • We almost never use this ISO 14041 definition, which may appear as confusing. Are the products used by industry considered as final products?
By-product	• The product is not the intended output of the process, but it is a necessary output of the process and there is a market for the product. Economic value is

	relatively low. An example of a by-product could be bark produced in a sawmill and used for energy production. *Life-Sys Wood Decision List.* • Both terms relate to co-production (Kuppelproduktion). In German, there is no clear differentiation between Kuppelprodukt (co-product) and Nebenprodukt (by-product). I personally do not see any difference. Both terms describe the same. • A co- or by-product is a type of output in a LCI module, which is strongly linked to the generation of the main product(s). Its generation cannot be avoided (but its fraction eventually can be altered). A co- or by-product must have a value and it must be useful for other purposes. • Secondary or incidental product of the technological process • If a difference should be done between By-product and Co-product, I would say that the 'by-products' are flows called waste according to regulation that are recovered while term 'co-products' is used when there are several main products. From *ISO 14041* definition for co-product. • The prefix 'by' indicates that this product is incidental to the process. By this definition the process will continue whether there is a market for the by-product or no. The economics of the process, and thereby the rate and extent of the process, are little affected by the value of by-products (c.f. co-product). Only a very limited portion of the environmental impacts of the producing process (and its antecedents) can realistically be apportioned to by-products if the real world causal chain is to be accurately represented.
Co-product (see By-product)	• Any of two or more products from the same unit process. *ISO 14041.* • Production of this product is the intended output of the (multi product) process with a defined market (= no process without this product). Economic value is (relatively) high. An example of two co-products could be the co-production of pulp chips and sawn timber using a chipper head rig. *Life-Sys Wood.* • The prefix 'co' indicates equality of importance to the process. This is taken here to imply that the process will not take place in the absence of a market for the co-product, or take place only to a very limited extent. Co-products should share an allocation of environmental impacts, which reflects their importance (c.f. 'causal force') to the producing process (and its antecedents). Where physical characteristics, such as mass or volume, are greatly at odds with the status and importance of the co-products, allocation of impacts on such physical bases will be inappropriate and misleading. • Product that are produced jointly with another product.
Waste	• Any output from the product system, which is disposed of. *ISO14040.* • Solid waste which will not undergo further processing. • An output stream in solid form, which is accumulated onsite or offsite a system unit, and with potential impact on health, environment or resource impacts through discharges to air, water or soil. *ISO/SETAC.* • Waste which is emitted to the environment (in landfill for example) and not further processed within the economic system. • The product is not the anticipated output of the process, and there is no market for this product. Economical value is negative (e.g. wood waste for landfill/incineration). An example of waste could be sludge from a CCA impregnation plant. *Life-Sys Wood Decision List.* • Removable entities which are disposed of by the owner or whose disposal is in the public interest. *BUWAL SRU 300* 1998 • Type of output, but not necessarily a product. Waste, in my definition, is an output which one must get rid of. This normally can only be achieved with additional costs (negative price). Waste can be an input for other modules. Waste can even be processed into products. • Waste, which is emitted to the environment (in landfill for example) and not

	further processed within the economic system. • Unused or not properly used material, rejected as useless or worthless, not of any use for the working process. • There is the official definition and the LCA one. As it is more operational for LCA practices, I would prefer the *ISO 14041* definition. • All kinds of waste (landfill, reuse to energy 3.5 'feedstock energy'. *ISO 14041)*. • An output stream in solid form, which is accumulated onsite or offsite a system unit, and with potential impact on health, environment or resource impacts through discharges to air, water or soil. • Waste processing is any material produced by a process in the life cycle, and which is not consumed as a product with a positive value. If this material passes through processing stages to render it useable, either within this life cycle (closed-loop recycling) or without the life cycle (open-loop recycling), then those processing stages must be accounted within this life cycle. For example, any cleaning, sorting, crushing and transportation required to transform waste glass into cullet (broken or refuse glass) at a glassworks. • Any output from the product system which is disposed of.
Flow	• Exchange of materials between LCI modules related to the functional unit. • Within a module there cannot be a flow, even though some people think this is possible! This creates problems when dynamic systems (e.g. wood production in short rotation plantations) shall be modelled.
Points of view regarding system boundaries	• Are silvicultural systems included in the product system? (compilers interpretation: yes). • The boundary between those elements which are defined as a part of a given product system for a life cycle assessment, and other elements and the environment. • Interface between a product system and the environment or other product systems. *ISO/SETAC*. • In selecting which processes are to be included in the analysis, and which are to be excluded, we effectively draw an artificial boundary around an individual life-cycle. Where that boundary is set can significantly affect the conclusions of the analysis, so that the boundary itself and the assumptions made in setting the boundary must be presented and discussed. The environmental system is considered to lie outside that boundary, although it may be possible to include parts of the environmental system in site-specific fate models.
Other terms from ISO14041, checked and discussed in WG1	• Energy flow 3.4. • Fugitive emission 3.7. • Intermediate product (component) 3.8. • Process energy 3.9. • Reference flow 3.10. • Sensitivity and uncertainty analysis in sense of input/output mass flow balance 3.11 and 3.12.