The Finnish Environment 752

ENVIRONMENTAL PROTECTION

Helena Dahlbo, Jari Laukka, Tuuli Myllymaa, Sirkka Koskela, Jyrki Tenhunen, Jyri Seppälä, Timo Jouttijärvi and Matti Melanen

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Life cycle assessment report

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HELSINKI 2005

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This publication is also available in the Internet
www.environment.fi/publications

ISBN 952-11-1956-X
ISBN 952-11-1957-8 (PDF)
ISSN 1238-7312

Cover photo: Erika Várkonyi
Page layout: Ritva Koskinen

Printing: Edita Prima Ltd, Helsinki 2005

Preface

The Finnish Environment Institute (SYKE) and the University of Helsinki carried out in 2002 – 2004 a joint project called "Life cycle approach to sustainability of waste management – a case study on newspaper (LCA-WASTE)". The project was financed by Tekes, the National Technology Agency of Finland. It belonged to two national research programmes: 1) The technology programme "Streams - Recycling technologies and waste management" of Tekes, and 2) the research programme "Sunare – Sustainable use of natural resources" of the Academy of Finland.

The project group of the LCA-WASTE study consisted of researchers from

- SYKE, Research Programme for Environmental Technology: Matti Melanen (person in charge of the project), Helena Dahlbo, Timo Jouttijärvi, Sirkka Koskela, Jari Laukka (involved in the project in 2002-2003), Tuuli Myllymaa, Jyri Seppälä and Jyrki Tenhunen, and
- University of Helsinki, Department of Economics and Management, Environmental and Resource Economics: Markku Ollikainen and Sanna Peltola.

The LCA-WASTE project was guided by a steering group. The members of the steering group were: Jarkko Hukkanen (UPM-Kymmene Group), Kyösti Pöyry (Paperinkeräys Oy), Juha Kaila (YTV Waste Management, from January 2004 Kasui Oy), Helena Manninen (National Technology Agency, Tekes), Gabriel Sundman (Stora-Enso Oyj), Juha-Heikki Tanskanen (Itä-Uudenmaan Jätehuolto Oy), Hannu Laaksonen (Ministry of the Environment) and Alec Estlander (SYKE).

In the LCA-WASTE project an LCA was performed on newspaper with particular attention to waste management practices in the Helsinki Metropolitan Area (HMA) and aiming at generating information on the impacts of different waste management strategies needed in waste policy concerning newspaper. In addition to ecological impacts, also economic impacts of different newspaper waste recovery and treatment practices were assessed. The sub-project concerning the economic aspects was conducted by the University of Helsinki.

This report presents only the environmental impact assessment results obtained by the life cycle assessment. A combined examination and report of the environmental and the economic perspective is reported in Finnish in the LCA-WASTE method report Myllymaa et al. 2005: Menettely jätehuoltovaihtoehtojen ympäristö- ja kustannusvaikutusten elinkaaritarkasteluun, Finnish Environment 750.

The authors wish to thank the steering group and the co-operating organisations for contributing their assistance and providing data for the LCA-WASTE study. Also several other persons and organisations have kindly answered our questions and provided data, which is very much appreciated. Ms. Tuula Mäkinen (VTT) and Mr. Juha Grönroos (SYKE) are appreciated for the constructive and helpful comments given on this report. Finally, the financial contribution of the National Technology Agency (Tekes) to the LCA-WASTE project is gratefully acknowledged.

Helsinki, May 2005

The authors

Contents

Introduction

1.1 Background

Initially, solid waste management practices were applied in order to safeguard public health. Safety and health are still important aspects but, in addition to these, waste management should be environmentally, economically and socially sustainable. The environmental aspects include an emphasis on both resource conservation and pollution concerns. Especially, waste prevention or minimisation and material or energy recovery are emphasised. Due to increased recycling and energy recovery of waste materials, the influence of waste management on the sustainable management of natural resources has grown. By choosing appropriate waste management practices, the overall sustainability of the use of natural resources can be enhanced.

In the waste policy of the European Union, waste prevention has been set as the first priority of waste management. Prevention is hierarchically followed by material recycling, recovery as energy and, as the last option, safe final disposal. All of these options have different effects on the life cycle of products. Consequently, the choice of appropriate waste management practices for different products or materials can enhance the overall sustainability of natural resource use. Discussion on the Finnish waste policy has hitherto mostly dealt with the question of how to achieve maximal recovery rates and how to minimise the disposal of wastes to landfills. It is, however, noteworthy that the priority list given above is not always the most preferable. By contrast, it appears that the overall sustainability of waste management solutions may vary depending on the materials studied and on the region in question (e.g. population densities and transport distances). Comparison of the overall sustainability of alternative waste management solutions is therefore a demanding task which calls for life cycle assessment (LCA) of products and case by case studies.

1.2 Life cycle assessment (LCA) and integrated waste management

The main aim of integrated waste management (IWM) is to develop more sustainable waste management systems. It is an approach that emphasises the environmental effectiveness, economic sustainability and social aspects of a waste management system. IWM tends to take into consideration all the circumstances and individual characteristics of a region or a community. This particular region can then constantly seek improvements in its waste management. (McDougall 2001).

Life cycle assessment (LCA) can be applied as a tool to promote IWM (e.g., Clift et al. 2000, Ekvall 1999, Ekvall and Finnveden 2000, Eriksson 2003, Finnveden 1999, Finnveden and Ekvall 1998, Finnveden et al. 2000, Harrison et al. 2000, McDougall et al. 2001, Sundqvist et al. 1999). Life cycle assessment is an environmental management tool and it is used to predict and compare the environmental impacts of products or services. Life cycle assessment is a systematic framework for the identification, quantification, interpretation and evaluation of the environmental interventions (emissions, resource extractions and land use), caused by a product, service or function, and it follows a "cradle-to-grave" approach (Berg et al. 1995). The International Organization for Standardization (ISO) has published four standards concerning LCA (Table 1). According to the ISO standard 14040 (ISO 1997), LCA consists of four phases: goal and scope definition, inventory analysis, impact assessment and interpretation of results (Fig. 1).

Table 1. Life cycle assessment standards.

Standard	Subject	Year
ISO 14040	Environmental management. Life cycle assessment. Principles and framework	1997
ISO 14041	Environmental management. Life cycle assessment. Goal and scope definition and inventory analysis	1998
ISO 14042	Environmental management. Life cycle assessment. Life cycle impact assessment	2000
ISO 14043	Environmental management. Life cycle assessment. Life cycle interpretation	2000

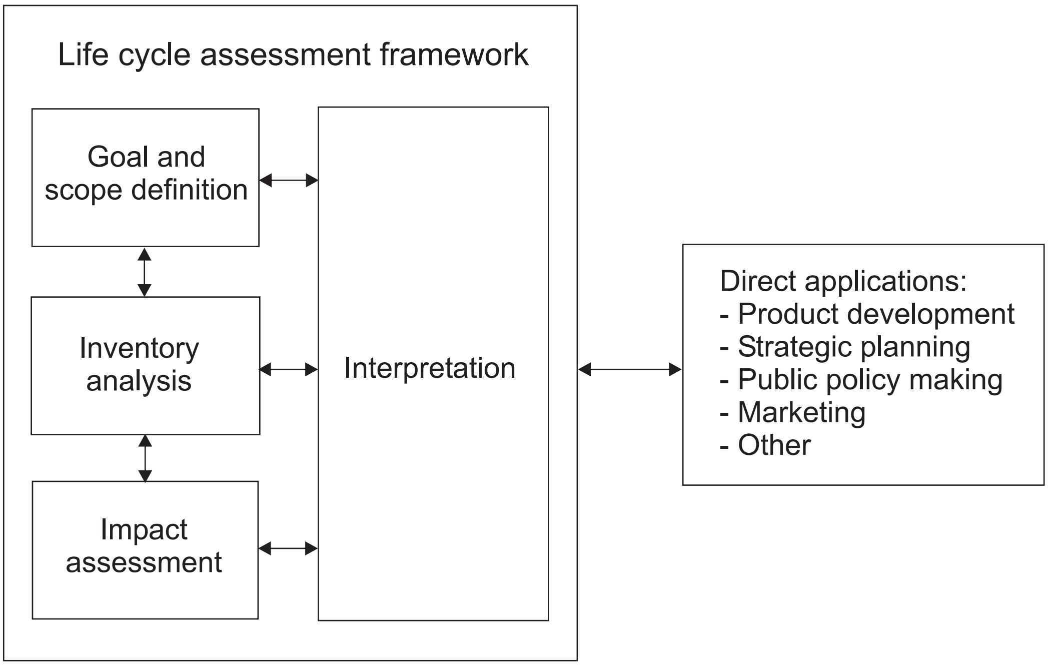

Figure 1. Life cycle assessment framework (ISO 1997).

One of the goals of an LCA on IWM is to assess the environmental performance and economic costs of an IWM system. Another aim is to analyse the whole waste management system, focusing especially on the interactions between different factors and parts of the system. LCA offers a possibility to carry out hypothetical calculations concerning different waste management systems, and in this way helps to identify the most applicable alternatives. (White et al. 1995)

An LCA on waste management comprises several steps. The first step consists of the depiction of the system and choosing the possible waste treatment options. The second step (inventory analysis) consists of the data (inputs and outputs) calculations in which the fixed data of processes is applied. Technology and equipments influence the fixed data, and the lack of quality data is a recognised problem (White et al. 1995). The most relevant inputs and outputs of a waste management system include (White et al. 1995):

- the net energy consumption of the system,
- water and air emissions,
- landfill volume, especially if land use aspects are involved in the research,
- recovered materials (issues such as the re-processing capacity of industry and the market situation of recovered materials), and
- the volume and quality of compost.

In impact assessment, the inventory data are compared and aggregated from the point of view of environmental impacts. In the last step, interpretation, the inventory and impact assessment results are analysed against the aims of the study.

In order to identify the most sustainable integrated waste management system the current waste management system can be used as the basic situation, and the other alternatives can be compared to this. The choice of optimal waste strategy should be based on local conditions. LCA has been successfully applied to optimise waste management systems, for example, in Europe, North America and Latin America (McDougall 2001). Integrated sustainable waste management offers, especially for the developing countries, new possibilities to improve their waste management and find solutions that do not degrade the environment (Klundert 2001).

1.3 The LCA-WASTE study

This report is based on the life cycle assessment (LCA) carried out in a project called "Life cycle approach to sustainability of waste management – A case study on newspaper (LCA-WASTE)". In the LCA-WASTE study, a complete life cycle assessment was performed on newspaper with special attention to the waste management solutions. The modelled area was the Helsinki Metropolitan Area (HMA).

The objectives of the LCA-WASTE project were, firstly, to develop a generally applicable methodology for assessing the ecology and costs of alternative waste management solutions and, secondly, to provide information on the impacts of different waste management targets for waste policy making. Accordingly, in addition to the environmental impacts included in the LCA, the costs of the waste management alternatives were assessed. The economic analysis conducted consistently with the LCA complements the LCA in a way that can be expected to make the results and the study more feasible for the decision-makers. The process and results of combining the two perspectives are reported in Myllymaa et al. (2005) and Dahlbo et al. (2005b).

Newspaper was selected for the case study on the grounds of paper being one of the largest municipal solid waste components and a material/product originating in Finland's most important renewable natural resource, forest. The newsprint studied is manufactured by the UPM-Kymmene Group Kaipola Mill in Central Finland (UPM-Kymmene Group 2003). The main raw materials used for newsprint are thermo-mechanical pulp (TMP, processed from spruce pulpwood and chips) and de-inked pulp (DIP, processed from separately collected newspapers and magazines). The Kaipola Mill uses over 50% (180 000 tons in the year 2000) of the total amount of separately collected paper (newspapers and magazines) in Finland.

This study was conducted in the Helsinki Metropolitan Area, which includes four cities: Helsinki, Espoo, Vantaa and Kauniainen on the south coast of Finland.

The Helsinki Metropolitan Area is the most densely populated area in Finland. The area accounts for 0.2% of the whole country, but 18.5% of Finland's population lives in the area. The acreage of the Helsinki Metropolitan Area is 764 $km^{2,}$ and the total population was approximately 965 600 in 2002 (YTV-alue 2005). Roughly one million tons of waste are produced annually in the Helsinki Metropolitan Area. Of all the waste, 55% is reused or recovered and the remaining 45% are currently landfilled.

The YTV (Helsinki Metropolitan Area Council) Waste Management has the overall responsibility for household waste management in the Helsinki Metropolitan Area. Its functions are general planning, transport and treatment of solid waste, taking care of closed landfills, collecting recyclable and hazardous wastes, and intensive public information services. There are several research reports and briefings on the waste management of the Helsinki Metropolitan Area (e.g., Tanskanen 2000b, Pelkonen et al. 2000, Mäkinen et al. 2000) and a large amount of monitoring data on the waste management sector is available along with statistical data.

The current municipal solid waste (MSW) management system in the HMA is based on separation at source, and includes the separate collection of various waste fractions from private households and office premises, as well as from local drop-off collection points. The most significant separately collected waste fractions are biowaste, paper, board, glass, metals, electronics scrap and hazardous wastes. The separate collection of paper in the area is primarily taken care of by Paperinkeräys Oy. Paperinkeräys Oy is also one of the organisations contributing to the LCA-WASTE project. Paperinkeräys Oy is a company owned by six forest industry enterprises. Its key operations are procurement, processing and supply of recovered paper (Paperinkeräys Oy 2002).

The waste management alternatives formulated for the case study were based on the current MSWM system in the HMA and on the future plans on developing it.

The goal and scope definition 2

2.1 The goals of the LCA-WASTE study

The first phase of an LCA study is the goal and scope definition. The goal definition states the purpose of the study, why the study is carried out and for whom the results are meant. (ISO 1998, Berg et al. 1995)

The objectives of the LCA-WASTE study were, firstly, to develop a generally applicable methodology for assessing the ecology and costs of alternative waste management solutions. The methodology should give guidance for researchers and consultants on performing an LCA study (such as the LCA-WASTE) on various waste fractions and in various regions. Decision-makers should find the method useful in identifying the aspects influencing the performance of different waste management alternatives and hence helping them to interpret the results of LCA studies.

Secondly, the objective of the LCA-WASTE study was to provide information on the impacts of different waste management targets for waste policy making.

2.2 The scope of the LCA-WASTE study

The scope definition phase of an LCA study includes defining the functional unit and the system boundaries for the product and the specification of data quality requirements. The scope definition should also include the allocation procedures, stated assumptions and limitations of the study. (ISO 1998)

2.2.1 The functional unit

The functional unit serves as a reference unit in the inventory. All the inputs and outputs of the product system are calculated against the functional unit. The functional unit of an integrated waste management system is different from that of a product LCA. The functional unit in a waste management system is the waste coming in to the system and, normally, the waste in question is from some certain geographical area. The functional unit can also be, for example, the management of the waste of one household. (White et al. 1995)

The aim of the LCA-WASTE study was to compare different waste management systems for newspaper waste, thus the functional unit of the product system was defined as one ton of newspaper delivered to consumers. This is compatible with the functional unit used in several LCA studies focusing on waste management, which is one ton of waste entering the waste management system (e.g., Finnveden et al. 2000, Edwards and Schelling 1999).

2.2.2 System boundaries and life cycle phases of the study

The product systems of the study consisted of the whole life cycle of newspaper. The systems included the main life cycle phases and sub-processes within the life cycle of newspaper, namely forestry, paper mill, newspaper printing, waste recovery and treatment, transportations and by-products (i.e., avoided emissions from energy recovery of waste) (Figures 2 and 3). Energy generation, fuel production and chemical manufacture were taken into account in each life cycle phase whenever information was available.

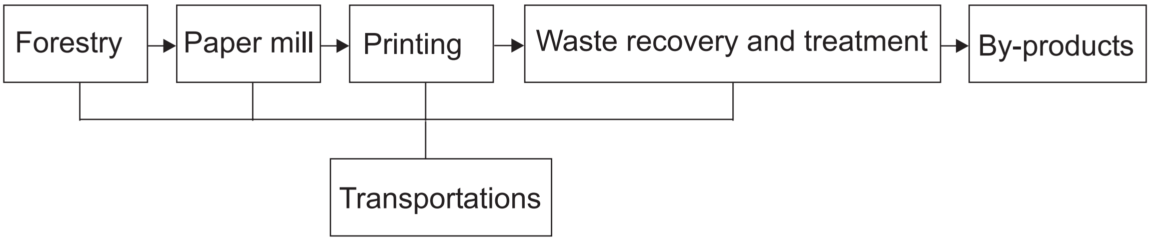

Figure 2. The life cycle phases of newspaper.

In principle, when different waste management systems are compared, their boundaries have to be identical. The boundaries of the product systems in our study differ, however, from the ones used in the other studies, since typically the systems having one ton of waste as the functional unit exclude the manufacturing of the discarded products. By including the manufacturing of newspaper in the product systems of this study, we were able to assess the relative significance of the different life cycle phases.

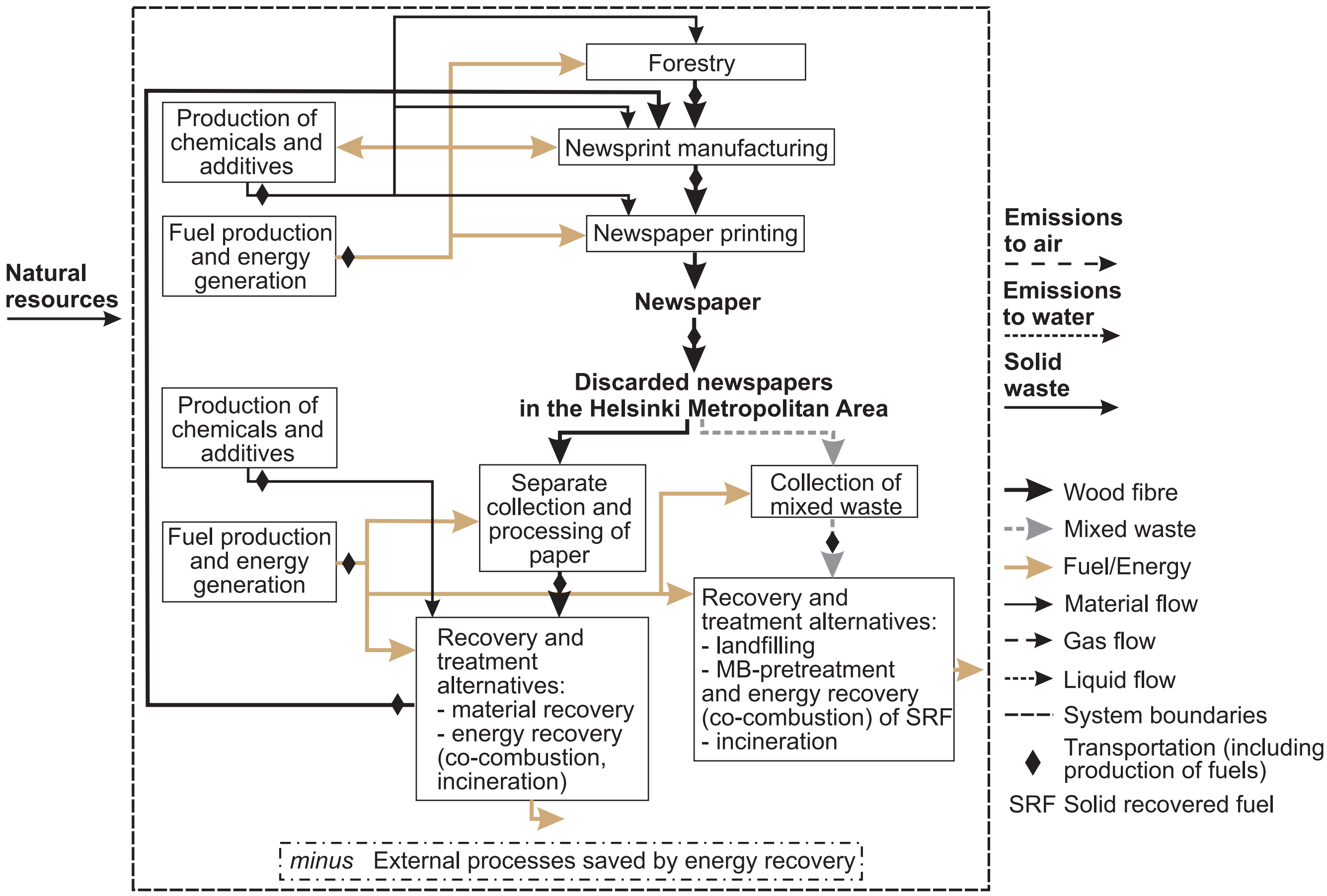

Figure 3. The system boundaries used in the LCA-WASTE project.

The first phase of the life cycle of newspaper is forestry. Forestry includes all the necessary activities concerning wood growth, the first and second thinning and regeneration felling for both fibre wood and logs. A sawmill was also included in the product systems, since sawmill chips are used for newsprint manufacturing in addition to pulpwood.

The second phase is the newsprint manufacture. In this study, the data on newsprint manufacture were obtained from the UPM-Kymmene Group Kaipola Mill in Central Finland (Hukkanen 2002). The production process at this mill can be considered representative of the newsprint technology in Finland. The newsprint is manufactured from a mixture of thermo-mechanical pulp (TMP) processed from spruce pulpwood and chips, and de-inked pulp (DIP) processed from separately collected newspapers and magazines. The paper mill includes the following sub-processes: debarking of fibre wood, chip screening, thermo-mechanical pulping, de-inking process and newsprint manufacture. In addition, power generation and transmittance were included. Also the water plant, waste water treatment plant, demineralisation plant and the pumping of cooling water were included in the system as they are relevant processes in the paper mill.

The third phase is newspaper printing. Printing consumes energy and raw materials, such as printing plates and inks. The manufacture of printing inks was included in the systems, but the manufacture of raw materials for the printing inks was not. Aluminium production for the manufacture of printing plates was taken into account. However, the manufacture of all printing materials was not included in the product systems, because proper data were not available and their effects were estimated to be insignificant.

The fourth phase is the management of newspaper waste. Five different waste management options were studied. The product systems for the options are presented in Figure 3. The cases consist of different recovery and treatment technologies, which are described in Chapter 2.3. Basically, the waste management includes different combinations of the following recovery and treatment methods: processing of separately collected newspapers, gasification and co-combustion of newspapers, incineration of newspapers, landfilling of mixed waste, mechanical-biological pre-treatment of mixed waste, gasification and co-combustion of solid recovered fuel (SRF) and incineration of mixed waste.

Transportations throughout the life cycle of newspaper were considered as one life cycle phase. Basically, all transportations concerning the life cycle of newspaper were included. However, transportation of employees was excluded.

The energy recovered from waste within the product systems can be considered as a by-product of waste recovery and treatment (Figures 2 and 3). By-product allocation was avoided by attributing all interventions to the product system and by giving credits for the production of by-products, assuming that their production replaces other forms of producing similar products ("the system expansion method") (ISO 1998). The credits were taken into account as avoided emissions. The fuel that is assumed to have been required for the external energy production determines the amount of emissions avoided. For example, natural gas is a more environmentally sound fuel than coal when considering emissions to air. Thus, the energy generated from waste provides relatively larger reductions in emissions when it replaces coal than when it replaces natural gas.

For further details on the life cycle phases and the processes included, see Chapter 3.6.2.

2.2.3 Limitations of the study

The relevant material and energy flows and emissions to water and air throughout the life cycle of newspaper were considered in the inventory, but emissions to soil were not included. Noise and vibration nuisances were not examined, since no good quantitative estimates existed for them. Construction of buildings, manufacture of vehicles, working machines or machines in factories and their maintenance were not included. General energy consumption for lighting and heating at the paper mill, printing plant, printing ink factory and landfill was considered. Construction of infrastructure such as roads and electrical networks were not included in the product system. On the other hand, constructing and restoring the forest roads was included.

Treatment of waste from forestry, printing process, fuel production and chemical or additive manufacture was not included in the inventory. The major waste flows from the paper mill, namely de-inking sludge, paper machine sludge, waste water sludge and bark, are used as fuels at the power plant of the mill and the emissions from their combustion were taken into account. Minor fibre-containing waste flows, namely debarking waste and paper machine waste, which are currently landfilled, were not included in the inventory. The treatment of waste waters from newsprint manufacturing and landfilling were included but that from other processes was not.

Treatment of ashes (from the power plant of the paper mill, the SRF gasification plant and the incineration plant) was not included in the study.

Fuel production was included in the study. The inventory contains the production data of petrol, diesel, heavy fuel oil, light fuel oil, natural gas, coal, energy wood and peat. In general, these data include the inputs and outputs of the extraction of natural resources and refining. The transportation of fuels was also considered.

Manufacture of chemicals was included in the study whenever data was available (for details see Chapter 3.6.2). Chemicals are mainly used for newsprint manufacture but some are also needed in newspaper printing and waste management. All the chemicals were not followed back to the cradle. There are a few chemicals that are used only for the manufacture of other chemicals.

The packaging of materials and products was not included in the inventory. Many of the materials are not packed at all, or they are transported in containers that can be recycled.

2.3 The basic waste management options studied

2.3.1 Overall description of the basic waste management options

Five basic waste management options were formulated for the LCA-WASTE study. These five options are described in the following Chapters 2.3.2 – 2.3.6. The grounds for choosing these options were:

- to include the current MSW management system of the HMA (Case 1),
- to include the future plans of YTV Waste Management for developing the HMA MSW management system and building new waste treatment facilities by the year 2010 (Case 2a) (in the course of this study, however, the plans have been changed),
- to study incineration as an alternative energy recovery option, because it is commonly included in the MSW management schemes of other Finnish regions (Case 3a), and

- to study a hypothetical situation in which the paper mill was unable to use all the recovered newspaper provided by the HMA and thus a part of the separately collected paper would be combusted or incinerated (Cases 2b and 3b).

The five basic alternatives include various recovery and treatment methods applicable to the newspaper in the separately collected paper fraction and to the newspaper in the mixed waste. The methods considered for the separately collected paper fraction were 1) material recycling, 2) gasification and co-combustion, and 3) incineration. The methods considered for newspaper in the mixed waste were 1) landfilling, 2) mechanical-biological pre-treatment followed by gasification and co-combustion, and 3) incineration (Fig. 4).

In the current situation, an estimate of 76% was used for the collection rate of newspaper in the separately collected paper fraction (comprising principally newspapers (60%), but also magazines and other paper). The estimate was based on the composition of MSW in the HMA (Tanskanen 1997) and the total amount of paper collected separately in the HMA in 2001 (Löfström 2002). The information on the amount of paper collected separately focused on the whole paper fraction, which mainly consists of newspapers and magazines. However, it is not known whether the separation efficiency for newspapers is higher than that for magazines. Here, it was assumed that the separation efficiency is the same for both.

Of the newspapers delivered to consumers, 21% were estimated to enter the mixed waste stream. The remaining 3% were assumed to end up in small-scale recycling (e.g., as kindlings, biowaste bags or wrappings, Appendix 1), and it was excluded from the product systems due to its minor relevance.

The five options for the waste management of newspaper (i.e., Cases 1, 2a, 2b, 3a and 3b) were as follows (Fig. 4):

Case 1 describes the current system in the HMA:

Separately collected paper: material recycling into newsprint manufacturing.
Mixed waste: landfilling without pre-treatment.

Cases 2a and 2b are based on the plans to build new treatment facilities in the HMA by 2010:

a) Separately collected paper: material recycling.
Mixed waste: gasification and co-combustion of SRF (solid recovered fuel, containing newspaper and various other materials) sorted from the mixed waste by mechanical-biological (MB) pre-treatment. The co-combustion concept here consists of gasification of SRF, purification of the product gas and co-combustion of the purified gas with pulverised coal and natural gas in a combined heat and power (CHP) plant.

b) Identical to Case 2a except that 50% of the separately collected newspapers are gasified and co-combusted.

Cases 3a and 3b are, for the present, theoretical in Finland:

a) Separately collected paper: material recycling.
Mixed waste: incineration with energy recovery. Incineration is considered as burning mixed waste in a plant built especially for waste treatment.

b) Identical to Case 3a except that 50% of the separately collected newspapers are incinerated.

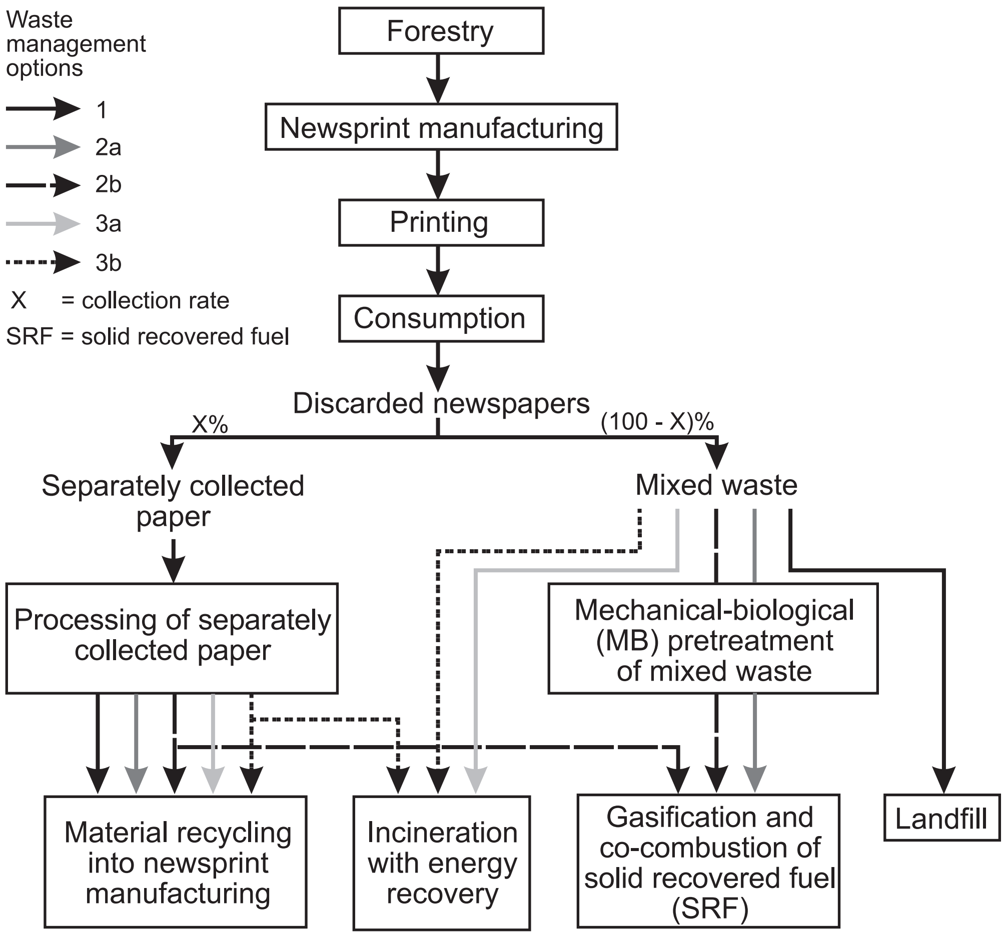

Figure 4. The waste management options studied.

2.3.2 Detailed description of Case 1

Case 1 describes the current waste management system in the Helsinki Metropolitan Area (Fig. 5): discarded newspapers are collected either separately or with mixed waste. The separately collected newspapers are recycled as material for the manufacturing of newsprint and the mixed waste is landfilled. The separately collected newspapers are first transported to the processing plant of Paperinkeräys Oy, where they are loaded into lorries either baled or loose, and then transported further to the Kaipola mill for newsprint manufacturing. Newspaper in the mixed waste is collected and transported to the Ämmässuo landfill maintained by the YTV Waste Management.

Newspaper in the mixed waste is in the present situation landfilled in the only operational landfill in the HMA, the Ämmässuo landfill. This landfill for non-hazardous waste became operational in 1987. The anaerobic degradation of organic material produces landfill gas which is collected with drainage and suction well systems. In 2002, 75% of the landfill gas was collected and flared off without energy recovery at the Ämmässuo landfill (Kopalainen 2003). Energy recovery of the landfill gas was started, however, in the end of 2004. The gas is currently used for producing heat for district heating. In modelling the landfill gas utilization process in the LCA-WASTE study, however, available data from a Swedish study were used. Hence, for modelling landfilling in Case 1 it was assumed that 60% of the energy of methane was converted into heat, 30% into electricity, and in addition there was a loss of 10% (Finnveden et al. 2000).

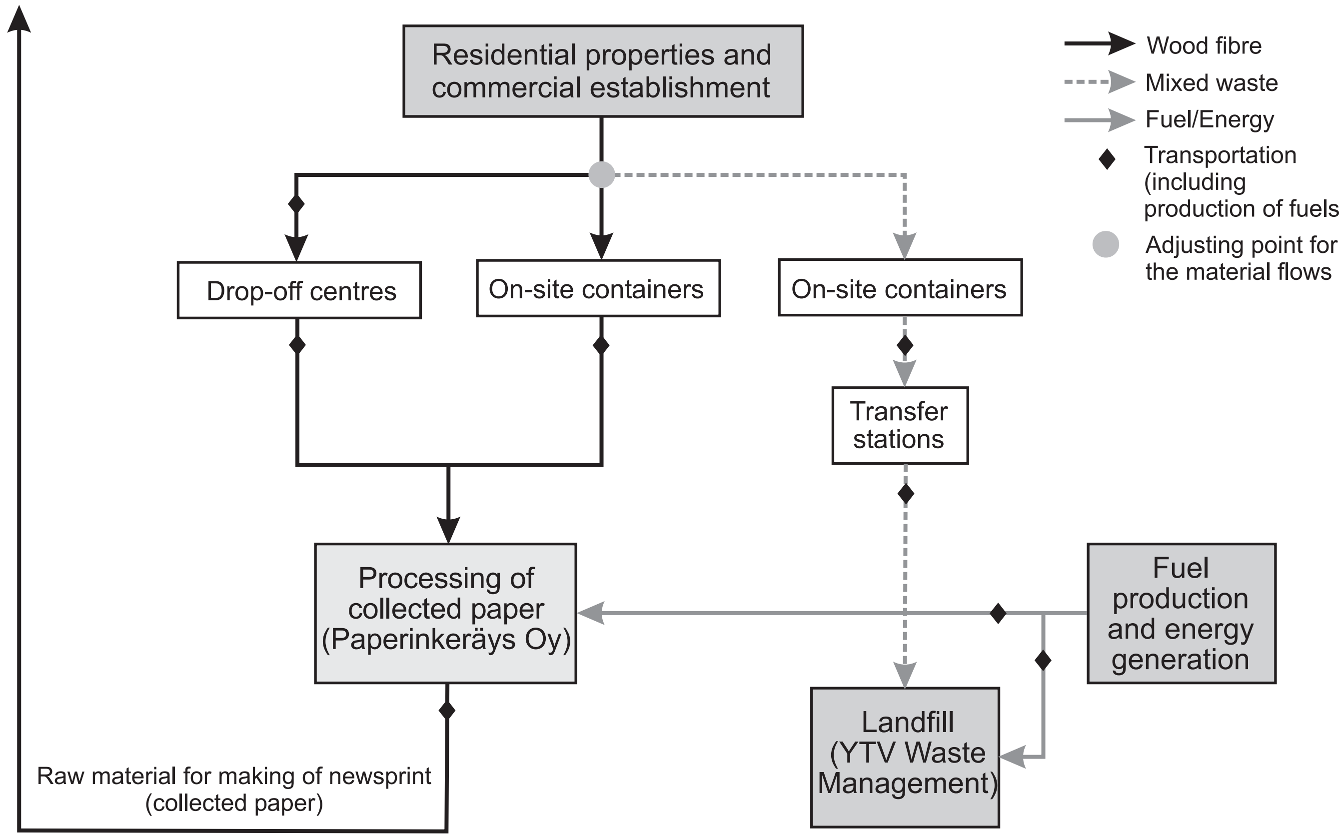

Figure 5. The waste recovery and treatment phase in the product system of Case 1.

Leachate is generated at the landfill due to waste decay and rain infiltrating through the waste. The quantity of leachate depends on the amount of rainfall, which varies seasonally. Landfill management practices, on the other hand, have a great influence on the leachate quality. The leachate collection system consists of a network of perforated pipes. The leachate from the landfill and the contaminated surface water from landfill roads and waste treatment areas are collected into an equalizing basin. From the basin, the waste water is led to the Suomenoja waste water treatment plant for purification. Clean surface water from the Ämmässuo landfill is led to an open ditch, from where it flows further to a nearby lake. At the Suomenoja plant, the waste water treatment is based on biological and chemical treatment methods, and the purified water is finally led to the Gulf of Finland (Espoon vesi 2003, YTV 2003). The waste water sludge is treated anaerobically, dried and composted. The treatment of waste water sludge was not, however, included in the study.

2.3.3 Detailed description of Case 2a

Case 2a describes the future plans for developing the MSWM system in the HMA. The separately collected newspapers are recycled as material for the manufacturing of newsprint (as in Case 1, see Chapter 2.3.2). The mixed waste is first processed in a mechanical-biological (MB) pre-treatment plant. The combustible fraction (including the newspaper) produced here is used as SRF and gasified and co-combusted in a pulverised coal power plant (Fig. 6). The YTV Waste Management plans included three alternatives for the MB pre-treatment plant. The one chosen for the LCA-WASTE study was the alternative that would most probably be chosen for implementation. Data for this alternative were available from similar plants already operating in Europe.

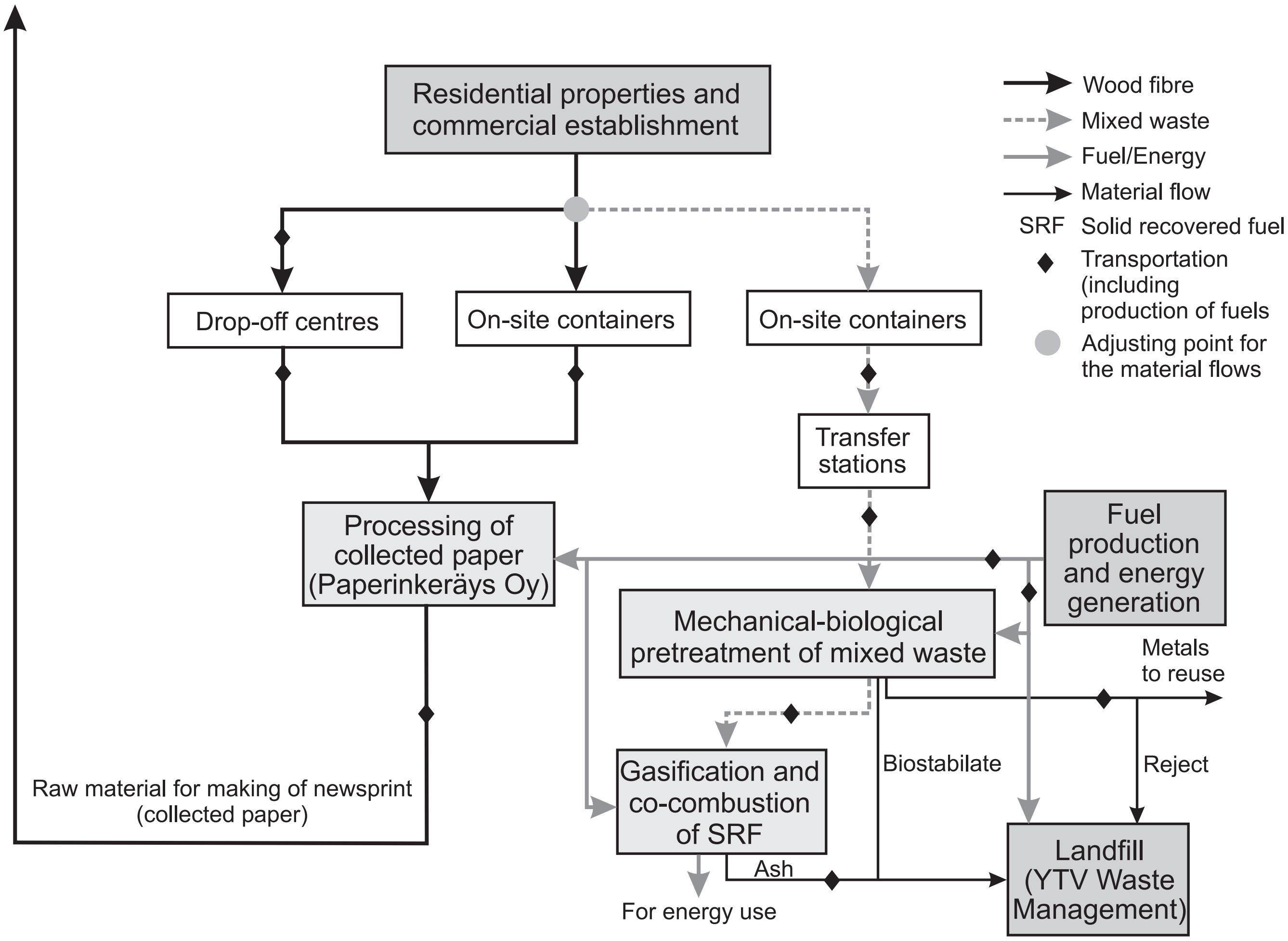

Figure 6. The waste recovery and treatment phase in the product system of Case 2a.

With MB pre-treatment, the mixed waste can be divided into the following fractions:

- unsuitable materials for the treatment,
- magnetic metals,
- non-magnetic metals,
- inert materials (e.g., stone, glass),
- organic materials, and
- SRF (mainly paper, plastic and wood).

The SRF is baled and packed with plastic wrappings. The bales are transported to power plants for energy recovery. Metals sorted out in the mechanical pre-treatment are recycled by the metal industry. Inert materials, such as stone or glass, are landfilled or utilised in landfill constructions. The organic fraction is aerobically composted. (YTV 2003)

The mechanical part of the MB pre-treatment consists of several processes. The selection and sequence of processes varies among different processing facilities, but the following processes are considered here (Fig. 7):

- a receiving hall for the unloading of mixed waste,
- feeding of the waste to the process with a wheel loader,
- preliminary shredding of the waste with a slowly rotating crusher,
- screening of the waste in which the fine and heavy organic fraction is separated from the light and coarse fraction,
- separation of magnetic metals with a magnet separator,

- separation of non-magnetic metals based on a quickly changing magnetic field (eddy current),
- additional shredding with a fast rotating and cutting crusher,
- drying of SRF in a drum, and
- baling and wrapping of SRF.

Belt and other conveyors are used in transferring the materials between different processes.

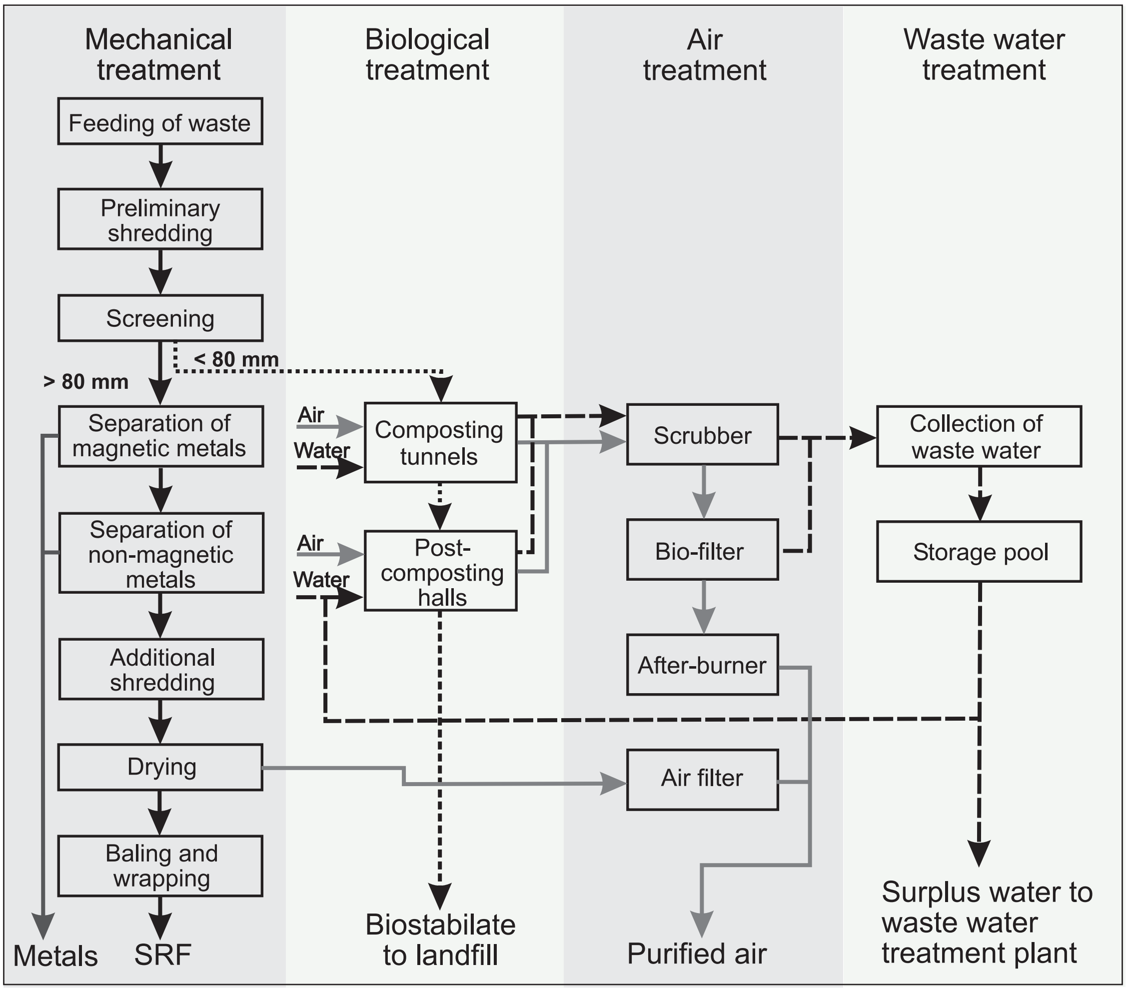

Figure 7. Processes of the mechanical-biological pre-treatment plant (adapted from Loikala 2001).

In the biological part of the MB pre-treatment the organic fraction is treated aerobically in a closed composting system. The aim is to produce composted waste that does not degrade significantly or cause any harmful emissions in a landfill (YTV 2003). In this study, however, the composting process was not included in the product system, because all newspapers were assumed to be sorted out into SRF. This assumption of a 100% separation efficiency was given support by practitioners of the waste management sector, according to whom approximately 90% of newspaper is in practice sorted into SRF.

The MB pre-treatment of mixed waste causes emissions to air. The outgoing air is treated in order to decrease the emissions. In mechanical treatment, the dust from the outgoing air is removed by dust filters. In addition, the outgoing air is thermally afterburned. This reduces the amount of organic compounds.

In Case 2a, the SRF produced by MB pre-treatment is gasified. Gasification can be defined as the thermo-chemical conversion of a solid carbon-based material into a combustible gaseous product. The high temperature in thermo-chemical conversion changes the chemical structure of the material (here SRF). When an oxidant gasification agent is used to partially oxidise the carbon-based material, it is called direct gasification. Here the gasification agent was assumed to be air.

Generally, a gasification system consists of three basic elements (Fig. 8). The first element is a gasifier which produces the combustible gas. The second element is the gas cleanup system needed to remove harmful compounds from the gas. The third element is the energy recovery system. (Belgiorno et al. 2003)

The purified combustible gas produced from SRF is co-combusted in a power plant. In this study, the gasification was assumed to take place in boiler 2 of the Vantaa Energy Martinlaakso power plant in the Helsinki Metropolitan Area (Vantaa Energy 2003). The fuels used in boiler 2 were the following in 2001: 97.6% coal and 2.4% natural gas. SRF compensates pulverised coal in the process. Of the total energy produced by boiler 2, 30% was electricity and 70% district heat (Vahti 2003). The efficiency of energy production in boiler 2 was 65%.

Ash from co-combustion of SRF, reject from MB pre-treatment and compost from the biological treatment are disposed of in the Ämmässuo landfill.

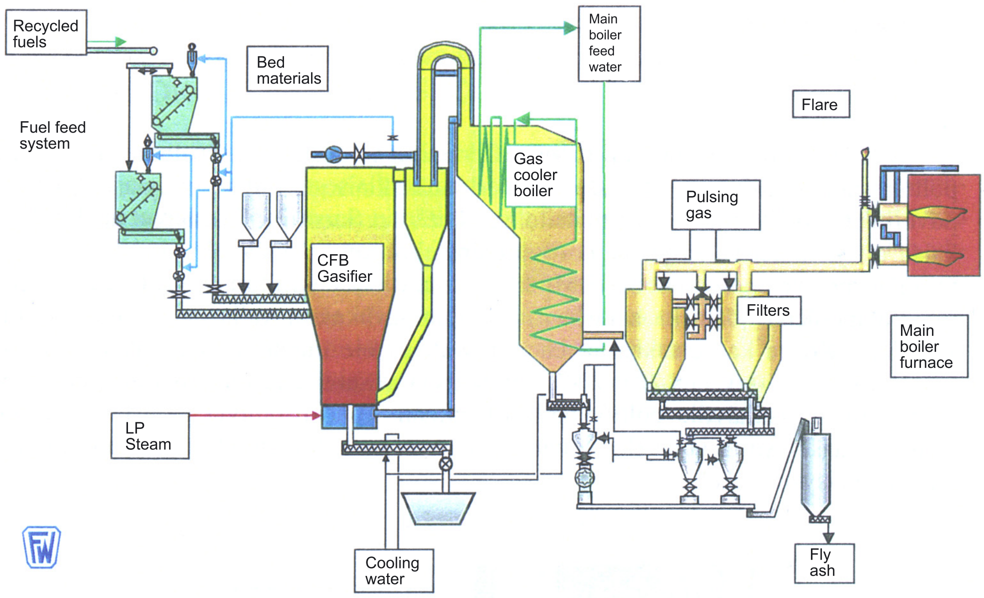

Figure 8. Gasification of solid recovered fuels with hot gas filtering, Foster Wheeler (Mäkinen et al. 2000).

2.3.4 Detailed description of Case 2b

In Case 2b (Fig. 9), mixed waste is treated identically with Case 2a (see Chapter 2.3.3). The separately collected newspapers are divided into two flows: 50% are used for newsprint manufacture and 50% are gasified and co-combusted together with the SRF produced from mixed waste by MB pre-treatment.

2.3.5 Detailed description of Case 3a

Case 3a (Fig. 10) is a combination of material recycling and incineration. Separately collected newspapers are processed at the processing plant of Paperinkeräys Oy and used for newsprint manufacturing. Mixed waste is incinerated without pre-treatment, but with energy recovery. The ashes from incineration are disposed of in the landfill.

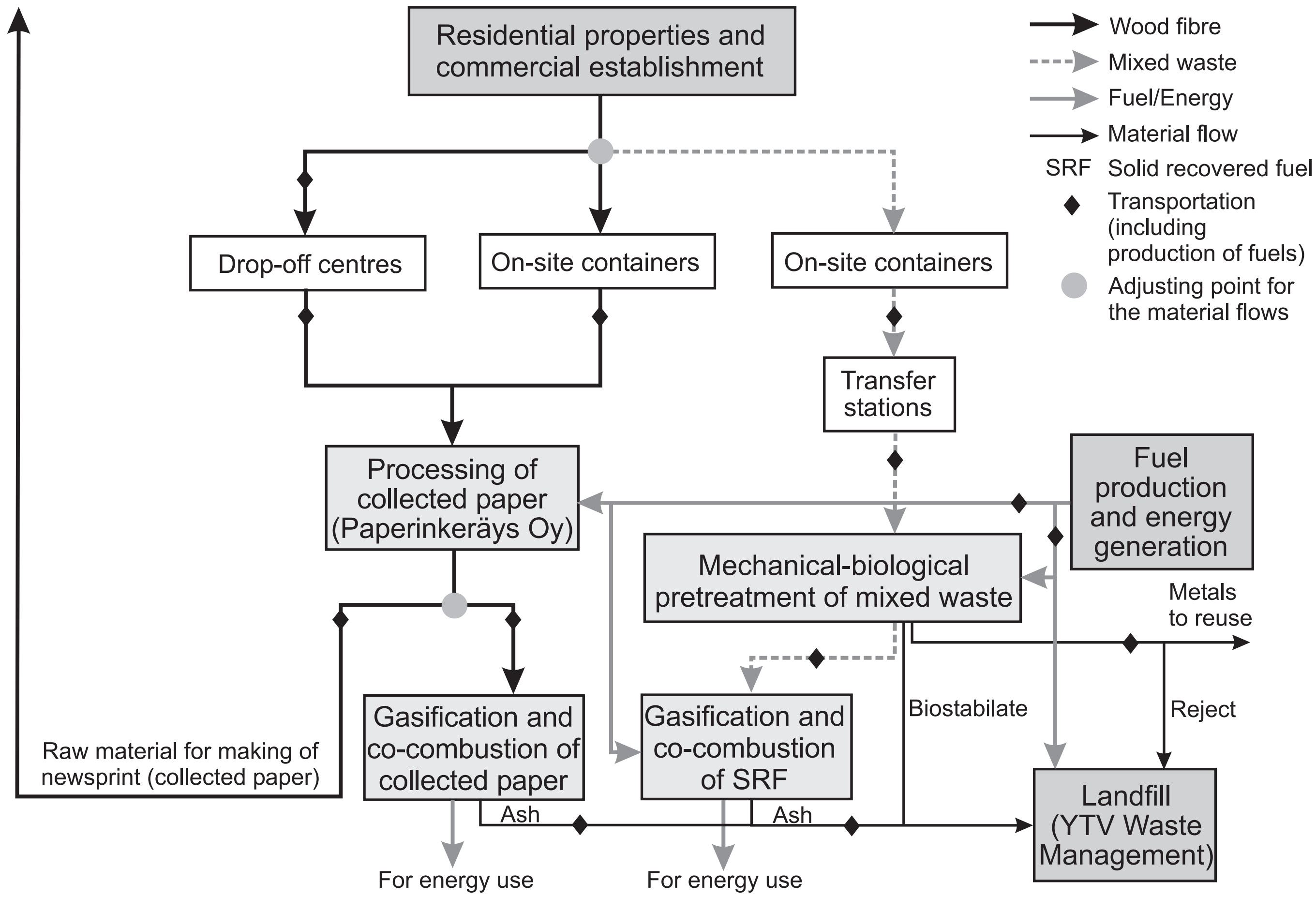

Figure 9. The waste recovery and treatment phase in the product system of Case 2b.

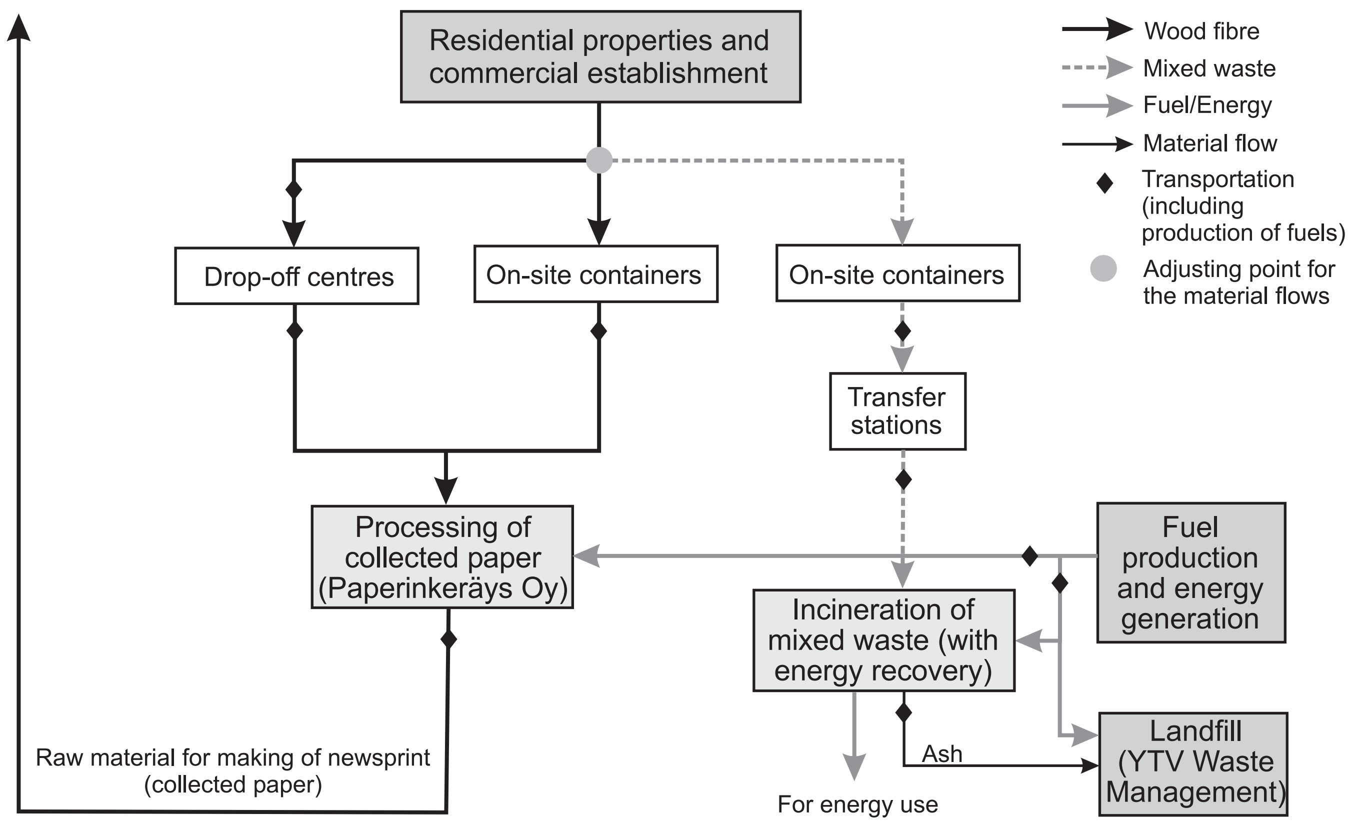

Figure 10. The waste recovery and treatment phase in the product system of Case 3a.

Incineration is a form of thermal waste treatment and it can be considered to have four objectives: reduction of the waste volume, stabilisation of waste, recovery of energy from waste and sterilisation of waste. Incineration can be divided into the following stages: incineration process, energy recovery, emission control and treatment of solid residues. (McDougall et al. 2001)

In Figure 11, a schematic representation of an MSW incinerator is presented. The mixed waste delivered into the reception hall is fed into the furnace feed hopper using a mechanical grab. The moving grate conveys the waste through the furnace as it burns. The waste passes through a drying stage and continues then to burn slowly. After the burnout stage, the unburned residues are deposited into a quench tank at the end of the grate. Primary air needed in incineration is blown through the grate and secondary air is pumped into the gas phase over the fire. After the furnace, the hot gases are transmitted into the energy recovery boiler. (McDougall et al. 2001)

The Stockholm Högdalen incineration plant represents the incineration facility modelled in Case 3a. The plant consists of three incinerators with a total capacity of 310 000 tons per year. The first two boilers of the plant were built in 1970 and the last one in 1986. Of the total energy produced at the Högdalen plant, 96.5% is heat and 3.5% electricity (Björklund 1998). The total efficiency of energy production is 85%. In the course of the study it became evident, however, that this type of an incineration facility would not be applicable to the HMA due to the non-existing possibilities of utilising the heat load produced.

The Högdalen incineration plant consists of a kiln, which generates outputs of slag and raw gas, and an air emission system. To meet with the strict environmental requirements placed on incineration plants, an advanced flue gas cleaning equipment has been built. It is made up of a particle filter, deSO_x-system and deNO_x-system. In particle filtration, the gas flows through a number of filter bags placed in parallel, and the fabric captures the dust from the gas. A deSO_x-system applies dry scrubbing and it works by injecting an alkaline reagent into the flue gas. A deNO_x-system is used to ensure low emission of NO_x and it applies selective non-catalytic reduction technology. In a deNO_x-system, ammonia is injected directly into the kiln as a gas. (McDougall et al. 2001, The Heat Supply of Stockholm 2003)

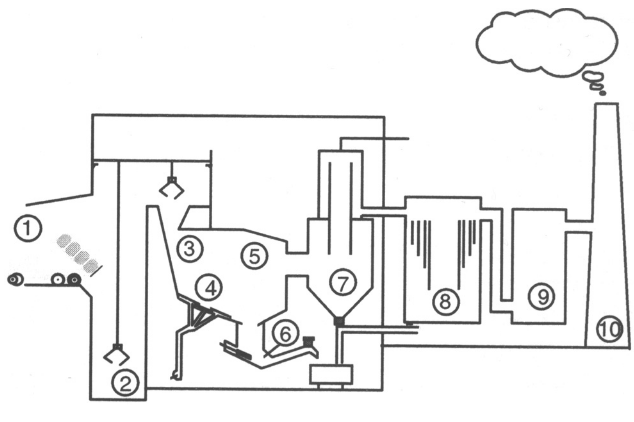

Figure 11. Schematic representation of an MSW incinerator (McDougall et al. 2001). Key: 1) reception hall; 2) waste pit; 3) incinerator feed hopper; 4) combustion grate; 5) combustion chamber; 6) quench tank for bottom ash; 7) heat recovery boiler; 8) electrostatic precipitator; 9) acid gas scrubbing equipment; 10) incinerator stack.

2.3.6 Detailed description of Case 3b

In Case 3b (Fig. 12), mixed waste is treated identically with Case 3a (see Chapter 2.3.5). Separately collected newspapers are divided into two flows: 50% are used for newsprint manufacture and 50% are incinerated together with the mixed waste.

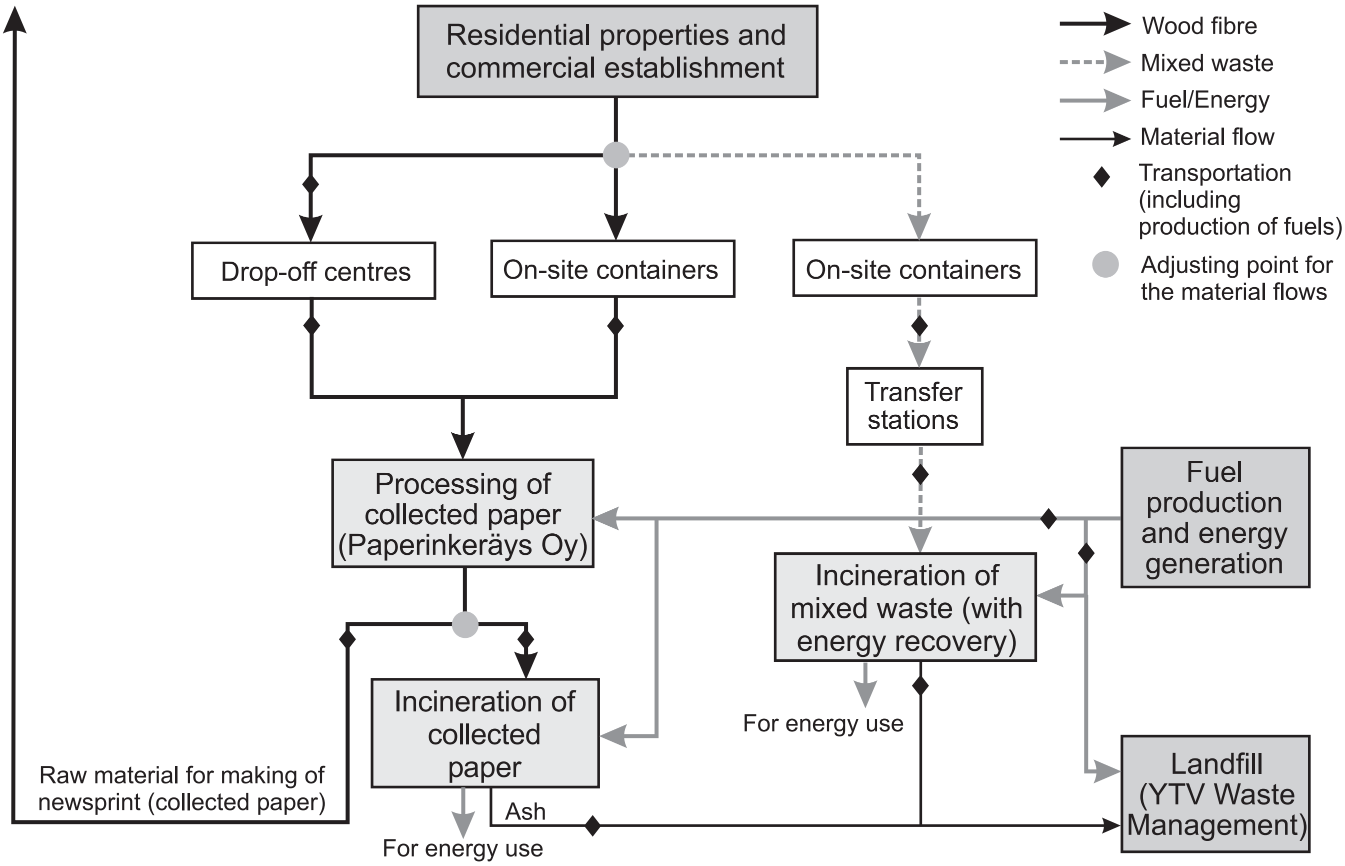

Figure 12. The waste recovery and treatment phase in the product system of Case 3b.

2.4 Modifications of the basic waste management options

2.4.1 Modifications for performing sensitivity analyses

For assessing the sensitivity of the studied systems on various assumptions, several modifications were performed on the basic waste management options described in Chapters 2.3.2 – 2.3.6. These modifications are described in the following Chapters 2.4.2 – 2.4.5. Modelling was conducted

a) using other collection rates than the current for newspaper in the separately collected paper fraction (that is 0%, 42%, 82% and 96%) (Chapter 2.4.2),
b) using the data of an alternative incineration plant for the incineration option (Chapter 2.4.3),
c) varying the fuel used for producing the energy compensated with energy from waste (Chapter 2.4.4), and
d) varying the transportation distances for the fibre wood used for newsprint manufacturing (Chapter 2.4.5).

The results of these sensitivity analyses are presented in Chapters 5.4.1 – 5.4.3.

2.4.2 Modelling the product systems with different collection rates

By varying the collection rate within each of the five product systems, the impacts of the collection rate on the environmental interventions of the waste management options were analysed. In the current situation, an estimate of 76% was used for the collection rate of newspaper in the separately collected paper fraction (see Chapter 2.3.1).

The two variables affecting the collection rate of paper are (Tanskanen 2000a):

- the coverage of the paper collection system, i.e., in a given area, the ratio of the amount of discarded paper generated in those properties in which a collection system is available to the amount of paper generated in all properties in that area, and
- the separation activity rate in the area, i.e., the share of paper that is correctly separated in those properties where a collection system is available.

In the HMA, the collection systems in use are on-site and drop-off collection. According to the YTV waste management regulations, all residential properties comprising more than five separate households are required to have their own paper collection container. This is the on-site obligation limit. For commercial establishments, the on-site obligation limit is a minimum of 50 kg of discarded paper per week. Discarded paper generated in smaller properties must be taken to a drop-off collection point.

The product systems were modelled for the 0%, 45%, 76% (current), 82% and 97% (maximum possible in practice) collection rates. For each collection rate, the environmental interventions of the waste collection and transportation system were calculated using a methodology developed for analysing MSW management based on source separation (Tanskanen 2000a and 2000b; Tanskanen and Melanen 1999). These results were used as input data for the waste collection and transportation module of the product systems. On the basis of these calculations, the above-mentioned percentages were chosen to illustrate the trend in emissions arising from the waste collection system with collection rates ranging from 0% to 97%.

For modelling the various collection rates in the product systems, the following steps were carried out:

- The collection and transportation systems for both the separately collected paper and the mixed waste were adjusted to meet the collection rate in question. The measures used for this adjustment were not only possible, but also the ones most likely to be taken into practice, namely altering (in the order they were used) 1) the on-site obligation limit for residential properties, 2) the on-site obligation limit for commercial establishments and 3) the separation activity rate in the area.
- The recipe for newsprint manufacturing was modified to meet the different collection rates by compensating the decreasing or increasing flow of separately collected newspapers with an increasing or decreasing flow of virgin wood. The increase in the use of virgin wood in the thermo-mechanical pulp (TMP) process increased the demand of purchased electricity at the paper mill.
- The processes of the paper mill's power plant were modified to first use all the biofuels arising from the processes connected to the newsprint manufacturing at the mill, and subsequently to produce the rest of the energy needed using fossil fuels.

2.4.3 Alternatives for the incineration option

The energy recovery solution in Cases 2a and 2b consists of gasification of SRF, purification of the product gas and co-combustion of the purified gas with pulverised coal and natural gas in a combined heat and power (CHP) plant. In this concept the consumption of the primary fuel (coal) in the main boiler can be reduced, thus leading to reduced greenhouse gas emissions. The emissions avoided by this concept can thus directly be calculated from the emissions of the primary fuel that would have been used in the process instead of this gas if no waste energy recovery would have taken place. The assumptions used for the co-combustion concept were 40% efficiency for electricity production and 90% efficiency for heat production. Of the overall energy produced 30% was electricity and 70% heat and thus the total energy efficiency was approximately 65% (Vahti 2003).

In contrast to Cases 2a and 2b, the issue of substitution is more complicated in Cases 3a and 3b, where incineration of mixed municipal solid waste is assumed to take place. No incineration facility exists in the HMA currently, thus the decision on whether this facility would produce heat or electricity, has not been made in reality. Therefore alternative solutions for the incineration concept were investigated.

First, for Cases 3a and 3b, the incineration facility was modelled as producing mainly heat (97%) using the data for an incinerator in Stockholm from Björklund (1998, Appendix 4). For the utilisation of this heat, there are in theory two possibilities, namely to use the heat 1) in the municipal district heat network in the HMA, or 2) to produce steam for the industrial use, e.g., in pulp and paper production. In practice there is, however, no need for an additional heat load in the municipal district heat network in the HMA. This is due to the fact that the existing energy network is based on combined heat and power production, where compensating the current heat production with heat from waste would result in shifting the electricity generation towards marginal power production, which in the Finnish energy system is mainly coal-condensing power (Lehtilä and Tuhkanen 1999). Thus the latter alternative, using the heat generated by waste incineration for industrial purposes, would be the preferable one. There is, however, no industrial need for steam close to Helsinki. This concept would thus lead to long transfer distances for the heat load. In practice, also this concept has to be considered as a hypothetical one. It was, however, studied for the purpose of the sensitivity analysis of the study. This hypothetical concept could be considered as the best possible one for incineration, giving the maximum of avoided impacts, because of the high efficiency (85%) of the plant producing heat and the possibilities for utilising the total heat load.

Second, for Cases 3a and 3b, it was assumed that the heat load from the heat producing incineration facility could not be utilised at all. Incineration used as merely a disposal method would, however, not be in accordance with the waste policy of Finland. This concept is thus considered as the worst option for incineration, producing no avoided impacts.

Third, for Cases 3a and 3b, a generic incineration facility was modelled as producing electricity with 9.4% efficiency and heat with 19.6% efficiency (Ecoinvent data v1.1. 2004, Doka 2003). The Ecoinvent data used for this concept, represent the average of 28 current municipal solid waste incineration plants in Switzerland (Appendix 4). Both the electricity and the heat were assumed to replace energy produced with coal and natural gas in a CHP plant. This is, however, also considered as a highly unlikely solution for the HMA.

2.4.4 Varying the fuel used for producing the energy compensated with energy from waste

The performance of an energy recovery option is dependent on the possibilities to connect the waste-to-energy facility into the existing energy production system. In the sensitivity analysis of this study two types of incineration facilities were modelled: one producing mainly heat and one producing mainly electricity. In practice, however, heat from incineration would not be utilised in the municipal district heat network in the Helsinki Metropolitan Area (HMA), since the existing energy network is based on combined heat and power production. Thus there is no demand for a heat producing facility. Only if there were a demand for heat in the industrial sector, would incineration with the production of heat be a realistic option. On the other hand, electricity from incineration could be utilised, but there are two facts acting against an electricity producing facility in the HMA: the efficiency of the facility is low and the capital expenditure is high. Drawing on the previous discussion, if an incineration facility were built in the HMA, it would most probably act as a waste treatment facility rather than as a form of energy recovery, unless the industry could use the heat load from incineration.

In this study, two ways of assessing the emissions avoided by energy recovered from wastes were studied, namely using the fuel mixture 1) used for the average Finnish electricity and heat production (Appendix 5), and 2) that used in a local coal-powered CHP plant (Appendix 6). The saved processes were taken into account in the product systems as negative emissions (Fig. 3). For comparison also an assessment was made without any credits, which can be considered representative of a situation where waste would compensate for biofuels.

2.4.5 Transportations

The fibre wood needed for newsprint manufacturing was assumed to be acquired from the Central Finland, from the forests quite close to the Kaipola mill (see Table 8 for the distances). This assumption is valid for the current situation, where 76% of newspaper is recycled into newsprint manufacturing. It would not, however, be valid for the extreme situation, where 0% newspaper was assumed to be recycled into paper manufacturing. Hence, for this extreme case, the fibre wood was assumed to be acquired from Russia and transported to Kaipola Mill (Table 2). The estimates for these transport distances were given by the UPM-Kymmene Group experts.

Table 2. Data for the modified transportations of fibre wood to the paper mill.

Transported material	Desti-nation	Transportation equipment and proportion (%) of the transported amount, distance (km)			
		Full trailer timber lorry	Timber floating	Barge for wood	Train (electr.)
Fibre wood	Paper mill	(60%) 80	(6%) 210	(4%) 210	(30%) 860

Inventory analysis

3

3.1 Inventory analysis in general

Data collection and calculation procedures are the main activities in an inventory analysis. The scope definition of an LCA study defines the unit processes included in the study and the associated data categories. Data collection procedures may vary according to unit processes in different systems, and data collection thus requires knowledge about each unit process. All the inputs and outputs are calculated against the functional unit of the product system. Validation of the data should be done during the data collection and it may involve creating mass balances or comparing emission factors. (ISO 1998)

3.2 The life cycle inventory tool KCL-ECO

The primary tool applied for the inventory in this study was the KCL-ECO 3.01 software, which is a calculation programme suitable for life cycle assessments (KCL 2003). The KCL-ECO 3.01 software was developed by the Finnish Pulp and Paper Research Institute. The core of the programme is to calculate the material and energy requirements and emissions for a specified production and recycling system. In the KCL-ECO programme, it is possible to create flow charts by constructing the whole product system graphically (see Appendix 2). (KCL 1999)

Modules containing unit processes are the basic elements of the flow chart and they are joined together by flows. The modules contain equations concerning the data for unit processes, and they can be solved in order to obtain the results in the form of a report. Equations can be added and modified and they are shown as a graphic flow chart on the screen (KCL 1999). In other words, the KCL-ECO software serves as a tool for composing the product system and for calculating the inputs and outputs against the defined functional unit.

All the inputs and outputs in modules were categorised into 13 main categories (Fig. 13) specified in the KCL-ECO software. One category can contain both inputs and outputs because the same variable can be an input in one module and an output in another module.

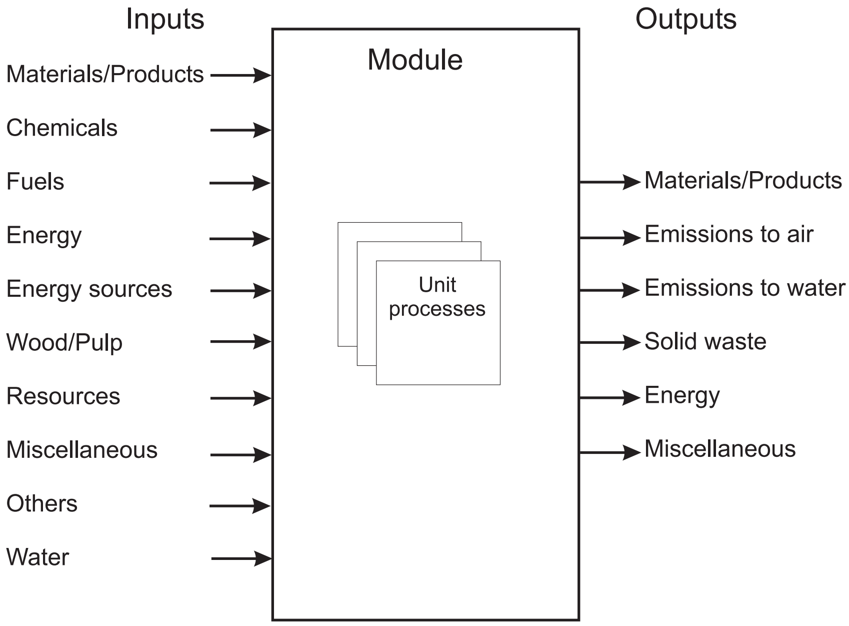

Figure 13. Example of a module with main categories.

3.3 Closed-loop recycling for discarded newspapers

Recycling of newspaper has a significant role in the product systems, since in addition to virgin wood materials, such as fibre wood and chips, separately collected newspaper is used as raw material in newsprint manufacturing. In the product systems studied, recycling was modelled as closed-loop recycling. In other words, all newspapers collected separately for material recycling in the HMA were returned to the Kaipola Mill for de-inking and recovery in the newsprint manufacturing. In each of the five cases, all separately collected newspapers were used either for material or energy recovery. The amounts of the other raw materials used for newsprint manufacturing were adapted to the amount of recovered newspaper available for material recovery. In Cases 1, 2a and 3a, all separately collected newspaper was used for material recovery but in Cases 2b and 3b, 50% were used for material recovery and 50% for energy recovery. Correspondingly, more virgin wood material was used in Cases 2b and 3b, since it was assumed that virgin wood would compensate for the decrease in the flow of discarded newspapers to the paper mill.

3.4 Electricity and heat generation

In the inventories, the energy inputs and outputs are expressed as electricity (MWh) and heat energy (MJ). The average Finnish electricity and heat generation (in the grid) were used as the supply of electricity and heat for the whole product systems. The paper mill makes an exception, since here the power plant of the mill produced a significant share of the energy needed. The additional energy needed and purchased was, however, assumed to be from the grid.

The electricity model used in the inventories is based on the average Finnish electricity generation and includes the net imports from Russia and Sweden (Appendix 3) (Heikkinen 2003). The calculation of the environmental interventions was based on the fuel mixture used in Finland in the years 2000 – 2002 (Appendix 5). This approach was chosen in order to balance the differences between the years. Net imports were assumed to have been produced with nuclear power, hydro power and natural gas. For each year, the emissions from electricity generation were calculated, and the average of the years was used in the inventory. The electricity generation data also includes the production of fuels and heavy metal emissions, even though they are not presented in Appendix 5.

For heat production, the fuel mix used for the average district heat production in Finland in 2000 was used (Tattari 2003). The emissions of heat generation are averages for the whole country (Appendix 5). Despite the fact that the heat generation is very local and based on local circumstances, the average of the whole country was chosen because the comprehensive local data were not available. The heat generation model includes the production of fuels and the transmittance losses.

3.5 Criteria for the inclusion of inputs and outputs

Most of the chemicals used in the product systems were used at the paper mill. For the chemicals used for both newsprint manufacture and water treatments at the paper mill an inclusion limit of 0.5% (mass) was used. Hence the manufacture and transportation of chemicals with a mass percentage of under 0.5% of the total mass of chemicals used at the paper mill were excluded. This was done because the chemical proportion of under 0.5% can be considered to have a rather small role in the whole life cycle of newspaper. Some chemicals exceeding the inclusion limit were, however, excluded due to the lack of proper data.

3.6 Modelling the product systems

3.6.1 Data sources

The data were collected from companies and organisations, literature and different databases. The data on paper processing were obtained from Paperinkeräys Oy and the data on newsprint manufacture were provided by the UPM-Kymmene Group. The data on different waste management cases were gathered mainly from reports produced by or for the YTV Waste Management and the Vantaa Energy.

The following databases were used as data sources: KCL EcoData maintained by the Finnish Pulp and Paper Research Institute (KCL), Lipasto maintained by VTT (Technical Research Centre of Finland) and IISI database (International Iron and Steel Institute). In addition, the Hertta and Vahti Environmental Data Management Systems maintained by the Finnish Environment Institute were used. The waste collection and transportation data applied for the waste management system were produced using the method by Tanskanen (2000a). Generally, the data were based on either calculated, measured or estimated values. The references for the inventory data are documented in Chapter 3.6.2.

3.6.2 Description of the modules and unit processes

In the following, the modules of the KCL-ECO flow charts are briefly described. The modules are grouped to the six life cycle phases identified in the product systems (see, e.g., Appendix 2):

– Forestry
– Paper mill
– Printing
– Waste treatment
– Transportations
– By-products

Forestry

The modules and unit processes comprising the forestry phase are: silviculture, forest growth, sawmill, fuel production and electricity generation (Table 3). Information on the forestry modules was mainly based on the KCL EcoData database.

Table 3. The forestry modules.

Module	Unit processes	Data from the year	Source
Growth of spruce	Binding of CO_2 into wood (use of fertilisers and emissions to water due to fertilisers were excluded in this study).	1989	KCL EcoData (Finnish Forestry Statistics*) modified
1st commercial thinning (fibre)	Clearing of harvested area, harrowing, mechanical seeding, planting and plant transportation, nursery, restoring of young forest, fertilisation and ditching. Constructing and restoring forest roads. All transport of machines in the forest during harvesting operations, hauling and transports of the employees. Harvesting of wood is based on Finnish technology: 1st thinning: chain saw 19%, harvester 81%. 2nd thinning: chain saw 8.5%, harvester 91.5% Regeneration felling: chain saw 3.7%, harvester 96.3% Technology level: typical Finnish, 1999	1999	KCL EcoData (Metsäteho 2000*)
2nd commercial thinning (fibre)	See 1st commercial thinning (fibre).	1998	KCL EcoData (Metsäteho 2000*)
Regeneration felling for fibre wood	See 1st commercial thinning (fibre).	1998	KCL EcoData (Metsäteho 2000*)
1st thinning for logs	See 1st commercial thinning (fibre).	1998	KCL EcoData (Metsäteho 2000*)
2nd thinning for logs	See 1st commercial thinning (fibre).	1998	KCL EcoData (Metsäteho 2000*)
Regeneration felling for logs	See 1st commercial thinning (fibre).	1998	KCL EcoData (Metsäteho 2000*)
Sawmill	Activities of the sawmill industry: production of sawn timber (in this study, the data were allocated for the production of sawmill chips based on the mass principle).	1998	KCL EcoData (LCA Sawmill*) modified
Diesel production	Diesel production, which includes crude oil production and transportation, refining of crude oil and the transportation of diesel to the end user. Typical density is 835 kg/m^3.	2002	Fortum Oil and Gas Oy 2002
Electricity generation	Electricity generation is based on the mean values of the fuel mix for Finland's average electricity in 2000, 2001 and 2002 and the mean values of emissions within Finland. Includes the production of fuels and net imports.	2000, 2001 and 2002	Heikkinen 2003 IVO 1998 Adato Energia Oy 2003 Petäjä 2003
Petrol production	Petrol production, which includes crude oil production and transportation, refining of crude oil and the transportation of petrol to the end user. Typical density is 745 kg/m^3.	2002	Fortum Oil and Gas Oy 2002
Chain oil production	Chain oil production was assumed to be similar to heavy fuel oil production, which includes crude oil production and transportation, refining of crude oil and the transportation of heavy fuel oil to the end user.	2002	Fortum Oil and Gas Oy 2002
Hydraulic oil production	Hydraulic oil was assumed to be similar to heavy fuel oil production, which includes crude oil production and transportation, refining of crude oil and the transportation of heavy fuel oil to the end user.	2002	Fortum Oil and Gas Oy 2002

* These data sources were identified in the modules of the KCL EcoData database. They are not specified in the references of this report.

The module for the growth of spruce (KCL EcoData) is the same for both fibre wood and logs. The module includes CO_2 bound into the wood but not CO_2 bound into the undergrowth. The inputs and outputs are given as a function of 1 000 kg of spruce. The use of fertilisers was excluded because it is currently insignificant (see, e.g., Metla 2002).

The modules of thinning and regeneration felling were based on the following information. In Finland, the first thinning occurs when the wood is approximately 30-50 years old. The second thinning takes place when the wood is 50-80 years old and the regeneration felling is carried out when the wood is over 80 years old. In the regeneration felling, also called final felling, most of the trees in a particular stand are cut in a single operation (KCL EcoData). It was assumed that the fibre wood used at the paper mill was obtained from the three forestry operations in proportions given in Table 4. Forestry modules include the emissions from working machines.

Table 4. Proportions of wood originating from different forestry operations (Metsäteho 2003).

Forestry operation	Proportion (%) of fibre wood (spruce) from the operation	Proportion (%) of log (spruce) from the operation
First thinning	7	1
Second thinning	24	12
Regeneration felling	69	87

The sawmill module represents the average data on all sawmills in Finland, and the technology level is typical for Finland in the year 1999. The main product of the sawmill module is sawn timber but in addition sawmill chips are produced. Sawmill chips are used as raw material for newsprint manufacturing. The sawmill input and output data were allocated to the sawmill chips based on the mass of the chips (846 kg) and the sawn timber (1000 kg).

All the wood inputs and outputs in the forestry modules are given as dry masses. In order to assess the transportations of the materials in the field conditions, the following dry matter contents were used: the dry matter content of fibre wood (spruce) is 48% and that of sawmill chips is 45% (Hukkanen 2002).

The forestry phase also includes some fuel production modules. Many of the fuels are oil-based and the data concerning them were obtained from the Fortum Oil and Gas Oy. The data on oil-based fuels include the transportation of the product to the end users.

Paper mill

The data on newsprint manufacture were obtained mainly from the UPM-Kymmene Group, and were based on the newsprint manufacture at the Kaipola Mill in the year 2001. The paper mill phase also includes the Kaipola Mill energy production and water treatment and the manufacture of chemicals used at the mill, the production of fuels and the generation of heat and electricity (Table 5). The main output is air dry newsprint with a dry matter content of 91% (Hukkanen 2002). Separately collected newspapers with a dry matter content of 90% are used as raw material for the newsprint (Hukkanen 2002).

Data for some of the chemicals were obtained directly from the manufacturing industry and these sources are confidential (Table 5). All chemicals were not followed back to the cradle. A few of the chemicals are used in the manufacturing of other chemicals needed in the paper mill phase.

Table 5. The paper mill modules.

Module	**Unit processes**	**Data from the year**	**Source**
Debarking plant	Debarking of fibre wood, chipping of fibre wood.	2001	Hukkanen 2002
Chip screening	Screening of purchased sawmill chips.	2001	Hukkanen 2002
TMP	Thermo-mechanical pulping of chips.	2001	Hukkanen 2002
De-inking plant	De-inking of recovered newspaper.	2001	Hukkanen 2002
Paper machine	Manufacture of newsprint (paper machine 7 at the Kaipola mill).	2001	Hukkanen 2002
Newsprint	General heat and electricity consumption of the paper manufacture.	2001	Hukkanen 2002
Power plant	Energy generation for the Kaipola Mill. Power production includes four boilers (K1,K3,K4, K5) and an electric turbine.	2001	Hukkanen 2002
Power transmittance	Transmittance of electricity. Purchased electricity comes to this module.	2001	Hukkanen 2002
Heat transmittance	Combines the heat coming from the heat recovery (TMP) and the power plant.	2001	Hukkanen 2002
Cooling water	Pumping of the cooling water. The power consumption includes the power used for water treatment.	2001	Hukkanen 2002
Water plant	Chemical purification of water (process water purification). The power consumption includes the power used for water treatment.	2001	Hukkanen 2002
Demineralisation plant	Demineralisation of water.	2001	Hukkanen 2002
Waste water plant	Waste water treatment.	2001	Hukkanen 2002
Fatty acid manufacture	Manufacture of fatty acid from talloil and H_2SO_4. Technology level: Finnish average, 1996	1996	KCL EcoData
Kaolin manufacture	Kaolin manufacture includes the emitted CO_2 emissions and chemical consumption concerning extraction and refining. Technology level: European site	2001	Confidential
Bentonite manufacture	No data (only transportation)		
Talc manufacture	Mining, refining and transports which are needed in production process.	2000	Confidential
CO_2 manufacture	Manufacturing of gaseous CO_2 from liquid CO_2 by evaporating (on-site). Average transport of the product distance 200 km. Technology level: Finnish average, 1996	1996	KCL EcoData
SO_2 manufacture	Manufacture of liquid SO_2 from gaseous SO_2.	1996	Confidential
Na_2SiO_3 manufacture	Manufacture of sodium silicate from SiO_2 and Na_2CO_3. Emissions from heat production included. Technology level: Finnish average, 1992	1992	KCL EcoData
NH_3 manufacture	Mining, refining and transports needed in production process. Technology level: European average, 1992	1992	KCL EcoData (VTT/ IIASA*)
$NaBH_4$ manufacture	Manufacture of $NaBH_4$ from Na, H_3BO_3 and H_2. Technology level: Finnish average, 1996	1996	KCL EcoData
H_2O_2 manufacture	Mining, refining and transports which are needed in production process, chemical manufacturing and energy production. Technology level: European average, 1992	1992	KCL EcoData (VTT/ IIASA*)
$CaCO_3$ manufacture	Manufacture of $CaCO_3$ includes mining, transports and refining. Technology level: European average, 1992	1992	KCL EcoData
CaO manufacture	Process for manufacturing CaO by calcination. Transport data or energy production not included. Technology level: European average, 1995	1995	KCL EcoData (NordPap agrofiber-study*)

$Ca(OH)_2$ manufacture	Manufacture of $Ca(OH)_2$ from CaO. Includes electricity and water consumption. Technology level: European site, 2000	2000	Confidential
NaOH manufacture	Mining, refining and transports needed in production process. Technology level: Finnish average, 1996	1996	KCL EcoData (VTT/ IIASA*)
S manufacture	Manufacture of sulphur (S). Technology level: Finnish average, 1994	1994	KCL EcoData (CB/ Finnboard*)
Fixative manufacture	Process for manufacturing fixative.	2002	Confidential
Na_2CO_3 manufacture	Na_2CO_3 manufacture includes chemical and energy consumption of Na_2CO_3 manufacture and air emissions. Technology level: Finnish average, 1994	1994	KCL EcoData (CB/ Finnboard*)
H_2SO_4 manufacture	Process for manufacturing H_2SO_4 from sulphur. Transport data or energy production are not included. Technology level: European average, 1993	1993	KCL EcoData (NordPap agrofiber-study*)
NaCl manufcature	Manufacture of NaCl by mining salt rock. Transport data or energy production are not included. Technology level: European average, 1993	1993	KCL EcoData (NordPap agrofiber-study*)
Energy wood production	Data include collecting and chipping wood residuals from regeneration fellings. Transportation from forest to road included. Module excludes the data on silviculture. Technology level: Typical Finnish, 1999	1999	KCL EcoData (Metsäteho2000*)
Coal production	Hard coal production. Mining: underground 85% and surface 15% Technology level: 1994 Emissions from electricity production are included.	1994	IISI/Ecobilan 1998/LC
Natural gas production	Natural gas production, which includes natural gas mining, processing and pipeline transportation (4 000 km). Technology level: 1991 Emissions from electricity production are included.	1991	IISI/Ecobilan 1998/LC
Heavy fuel oil production	Heavy fuel oil production, which includes crude oil production and transportation, refining of crude oil and the transportation of heavy fuel oil to the end user. Typical density is 970 kg/m^3.	2002	Fortum Oil and Gas Oy 2002 Kara et al. 1999
Heat generation	Average district heat generation in Finland in 2000. The data include also the production of fuels and transmission and distribution losses.	2000	Tattari 2003
Peat production	Peat production. Emissions to air and water in peat exploiting areas, emissions to air from machinery and transportation. Heating value of dry peat is 20.07 MJ/kg	1999	Leijting 1999 Hukkanen 2002
Electricity generation	see Table 3		
Hydraulic oil production	see Table 3		
Diesel production	see Table 3		

* These data sources were used in the modules of the KCL EcoData database.

Printing

The printing phase includes modules for newspaper printing, printing ink manufacture, aluminium slab production for the printing plates and the manufacture of printing materials such as developers, films, fixatives and printing plates (Table 6).

The printing plant module is based on the data obtained from a Finnish printing plant (confidential) and the Hertta Environmental Data Management System (Hertta 2002). The printing plant printed only newspaper during the year 2001 and therefore no data allocations were needed. The data on ink manufacture was allocated for the manufacture of newspaper inks. There were no significant differences between the emissions from the manufacture of colour inks and black inks (Yliharsila 2002).

Table 6. The printing modules.

Module	Unit processes	Data from year	Source
Printing plant	Printing plant module includes printing of newspaper, transfer of newsprint rolls and newspapers, cleansing of the machines, lighting and heating of the buildings. Technology level: Finnish site	2001	Confidential Hertta Environmental Data Management System 2002
Ink manufacture	Manufacture of printing inks (black, colour) for the newspaper. This module includes lighting and heating of the buildings. Excludes the manufacture of raw materials for the printing inks.	2001	Yliharsila 2002 Hertta Environmental Data Management System 2002
Aluminium (slab) production	Primary aluminium is obtained by fusion electrolysis of aluminium fluoride and aluminium oxide. Casting of primary aluminium. Technology level: European site	1991	IISI/Ecobilan 1998
Solvent manufacture	Includes the emissions of crude oil production, crude oil transportation and refining.	1997	Fortum Oil and Gas Oy 2002
Light fuel oil production	Light fuel oil production, which includes crude oil production and transportation, refining of crude oil and the transportation of light fuel oil to the end user. Typical density is 845 kg/m^3.	2002	Fortum Oil and Gas Oy 2002
Printing plate manufacture	No data. Only transportation was considered.		
Printing film manufacture	No data. Only transportation was considered.		
Fixative manufacture	No data. Only transportation was considered.		
Developer manufacture	No data. Only transportation was considered.		
Heat generation	Table 5		
Electricity generation	Table 3		

Waste recovery and treatment

The waste recovery and treatment phase was divided into several modules, which contain the data needed in cases 1, 2a, 2b, 3a and 3b (Table 7). For landfilling, the data from the Ämmässuo landfill were used. The data include the emissions from the landfill and working machines and the consumption of electricity and fuel. The emissions from the landfill were considered within an infinite time scale, assuming that all the materials landfilled in newspaper would finally be discharged as emissions into air or water (see Appendix 4). Landfill fires were excluded, since they have not occurred at the Ämmässuo landfill.

In 2002, 75% of the landfill gas was collected and flared off without energy recovery at the Ämmässuo landfill (Kopalainen 2003). In 2004, however, energy recovery from the gas was started. For modelling Case 1, it was assumed that 60% of the energy of methane was converted into heat, 30% into electricity, and in addition there was a loss of 10% (Finnveden et al. 2000). Also, it was assumed that the landfill gas contains 54% of methane and 46% of carbon dioxide (YTV 2002). Other possible gas components were disregarded due to their small proportions. The concentration of, e.g., nitrous oxide is negligible in landfill gas (McDougall et al. 2001).

The leachate from the landfill is treated at the Suomenoja waste water treatment plant. It was assumed that all leachate from the landfill is collected and treated. The electricity consumption of the purification equipment was included in the study but the consumption of chemicals was not (Alapoti 2002)(Appendix 4).

The MB pre-treatment of mixed waste is based on the data obtained from the YTV Waste Management. The SRF produced in the MB pre-treatment is gasified and the purified gas is co-combusted in a pulverised coal combined heat and power (CHP) plant. The purified gas was assumed to be co-combusted in a boiler equipped with a electrostatic precipitator and desulphurisation (Appendix 4). No data were available for the emissions from the combustion of newspaper alone, thus the data for SRF were used. A comparison was, however, performed concerning the sulphur contents of SRF and paper. On the basis of literature it was estimated that the content of sulphur in SRF is 0.091% whereas that of paper is 0.086% (Pelkonen et al. 2000). According to measurements of the sulphur contents of recycled fuels in the power plants using them, the content varies between 0.06% and 0.18% (Mäkinen 2003). Hence, it can be considered that no major errors should arise from using the SRF emission data.

The incineration of mixed waste was assumed to take place in an incinerator similar to the Högdalen plant in Stockholm. The mixed waste is incinerated without any pre-treatment. The emissions from newspaper incineration were calculated using the elemental composition of newspaper and the partitioning coefficients of elements between the different outputs of the incineration reported by Björklund (1998) (Appendix 4).

Transportations

Basically, the emission factors of vehicles were obtained from the Lipasto database maintained by the VTT (VTT Lipasto 2002). In addition to these, however, a few other information sources were used. The data on fuel production, based on the eco-balances of Fortum Oil and Gas Oy for different oil-based fuels, were added to the transportation modules. The waste collection and transportation data applied for the waste management system were produced using the method by Tanskanen (2000a). The modules for the different transportation forms were used for modelling the transportations anywhere in the product systems (Table 8). More detailed information on transportations is provided in Chapter 3.6.3. The age distribution of the transport equipment is presented with the EURO classification (see Table 10).

Table 7. The waste recovery and treatment modules

Module	Unit processes	Data from the year	Source
Landfill	Landfilling of newspaper in mixed waste at the Ämmässuo landfill in the Helsinki Metropolitan Area. This also includes the emissions from working machines and their fuel consumption. Burning of the landfill gas in a flare. 75% of the landfill gas is collected to the flare. 15% of the uncollected methane is oxidised to CO_2 by the top soil. No energy recovery.	2000 and 2002	Pelkonen et al. 2000 Kopalainen 2003 YTV 2002 Fliedner 1999 Finnveden et al. 2000
Leachate purification	Landfill leachate purification at the Suomenoja waste water treatment plant in the Helsinki Metropolitan Area. Excludes the treatment of waste water sludge. Includes the reduction of BOD, COD and nitrogen.	2002	Espoon vesi 2002 Pelkonen et al. 2000 Valve 2003 Finnveden et al. 2003 Alapoti 2002
Processing of collected paper	Processing of separately collected newspaper in the processing plant. 1/3 of the collected paper is baled and 2/3 are not (electricity consumption of baling). Loading into lorries (emissions from working machines).	2002	Tuunainen 2002 VTT Lipasto 2002
MB-plant	Mechanical-biological pre-treatment of mixed waste. Allocated for the mechanical treatment. For the separation processes of metals only the energy consumption is included. Composting is not included.	2003	Suunnittelukeskus Oy 2003
Gasification	Gasification of SRF. Includes the flue gas treatment.	2003	Vesanto 2003 IPROy 2001
Incineration	Incineration of mixed waste. Allocated to newspaper. Includes the flue gas treatment.	1998	Björklund 1998
Gravel production	Production of gravel. Includes excavation.	2003	Vares 2003
NH_4OH manufacture	NH_4OH manufacture from NH_3. Includes NH_3 and water.	2003	Own calculations
Heavy fuel oil production	Table 5		
Hard coal production	Table 5		
Heat generation	Table 5		
Electricity generation	Table 3		
NH_3 manufacture	Table 5		
Diesel production	Table 3		
Natural gas production	Table 5		
$Ca(OH)_2$ manufacture	Table 5		
CaO manufacture	Table 5		
$CaCO_3$ manufacture	Table 5		

Table 8. The transportation modules.

Module	**Unit processes**	**Data from the year**	**Source**
Cargo ferry	Emissions of a cargo ferry and emissions of heavy fuel oil production. (ro-ro, lo-lo, storo)	2002	VTT Lipasto 2002 Fortum Oil and Gas Oy 2002
Electric train for paper	Emissions of an electric train for paper. One-way electric hauling. Emission factors for long distance hauling also include losses in transformer, contact wire and transmission. Emissions from electric locomotives are a share of emissions in power stations corresponding to the use of electricity by locomotives.	2001	VTT Lipasto 2002
Full trailer	The emissions of a full trailer and diesel oil production. EURO 3 (1999 →) emission level. Full loaded. Gross vehicle mass 60t, pay load capacity 40t. Highway driving.	2002	VTT Lipasto 2002 Fortum Oil and Gas Oy 2002
Car, urban, average	The average emissions of a diesel-driven car and a petrol-driven car and, in addition, emissions of diesel and petrol production. The Finnish, average motor vehicle stock in 2001: 14,7% were diesel-driven cars and the rest were petrol-driven cars. Urban delivery driving. The delivered mass has been calculated according to the average mass of one newspaper in the Helsinki Metropolitan area (400g) and the number of delivered newspapers per one deliverer (400 newspapers/deliverer).	2002	VTT Lipasto 2002 Fortum Oil and Gas Oy 2002 Kuronen 2002 Grönlund and Rannikko 1999
Full trailer timber lorry	The average emissions of a full trailer timber lorry and diesel oil production. EURO 2 (1996-1998) emission level. Full loaded. Gross vehicle mass 60t, pay load capacity 40t. Average line includes empty returning. Load 40t one-way and 0t for return. The total share of empty driving is 55%. Distance 96 km per direction, of which 1 km forest lorry road, local road 3 km and the rest greater roads with very little urban driving.	2002	VTT Lipasto 2002 Fortum Oil and Gas Oy 2002 UPM-Kymmene Group 2002
Diesel van	The emissions of a diesel van and diesel production. Average of EURO 1, EURO 2 and EURO 3 emission levels. 50% load. Gross vehicle mass 2.7t, pay load capacity 1.2t. Delivery driving (share of highway driving 30%)	2002	VTT Lipasto 2002 Fortum Oil and Gas 2002
Small delivery lorry	The emissions of a small delivery lorry and diesel oil production. Average of EURO 1, EURO 2 and EURO 3 emission levels. 50% load. Gross vehicle mass 6t, pay load capacity 3.5t. Delivery driving.	2002	VTT Lipasto 2002 Fortum Oil and Gas Oy 2002
Barge for wood	Emissions of a barge for wood and emissions of light fuel oil production. EURO 2 (1996-1998) emission level. Fuel consumption of a barge is 200 l/h and speed is 26 km/h, full load is 2 500 m^3.	2002	Immonen 2002 Fortum Oil and Gas Oy 2002
Timber floating	Emissions from timber floating (barge) and light fuel oil production. EURO 2 (1996-1998) emission level. Fuel consumption of a barge is 0.00341 l/m^3km.	2002	Purhonen 2002 Fortum Oil and Gas Oy 2002
Separate collection and transportation of discarded newspaper	Collection and transportation of discarded newspaper from consumers to the sorting plant. This does not include the emissions of fuel production.	2000	Tanskanen 2000a
Collection and transportation of newspaper in mixed waste	Collection and transportation of newspaper in mixed waste from consumers to the landfill. This does not include the emissions of fuel production.	2000	Tanskanen 2000a

3.6.3 Allocation and calculation procedures

Allocation principles

Primarily, the mass principle was used for the allocation of data, which means that the inputs and outputs of a certain module were multiplied with a coefficient based on the mass percentage of the examined product. This procedure was applied in the modules in which there are more than one product. In some cases, allocation based on chemical composition was used.

In the forestry phase, allocation was needed in the sawmill module. There are two products in the sawmill module: sawn timber (the main product) and sawmill chips. Sawmill chips are used as raw material in newsprint manufacture and therefore the inputs and outputs of the sawmill module were allocated to the sawmill chips using the mass principle.

In the printing phase the manufacture of printing inks was allocated to the printing inks according to the mass principle. The variables that were not connected to printing inks were excluded. The procedure was carried out with assistance from the printing ink manufacturer.

In the waste recovery and treatment phase the data concerning the MB pre-treatment were allocated to the mechanical treatment part because it was assumed that 100% of the paper is separated into the SRF fraction. Hence, the data concerning the biological treatment were excluded. The allocation of MB pre-treatment for the mechanical part was carried out by assuming that the dust emissions, the consumption of electricity and heat and half of the diesel consumption were caused by the mechanical pre-treatment.

Calculating the transportations

Basically, all the relevant transportation stages were included in the inventory. In a few cases, however, the data on transportation were aggregated with other data. The transported materials, transport equipment and distances are presented in Table 9. In some cases, several transportation equipment were used for the same material. If no percentages are given for different equipment, the whole amount of material is transported with the same transport equipment. Transportations were considered for one-way trips. The only exception was a full trailer timber lorry, for which the emission data include the return trip.

Transportation of logs to the sawmill is presented in Table 9. Transportations of machines, saplings and employees are included in the modules as aggregated. Transportations of fuels, such as diesel and petrol, and lubricating oils are combined with the data for their production.

The transportations of the following chemicals to the paper mill are included in the inventory: bentonite, kaolin, talc, fixative, $NaBH_4$, SO_2, H_2O_2, fatty acids, Na_2SiO_3 and $Ca(OH_2)$. They are not presented in Table 9 because of confidential data. The transportations of other chemicals were assumed to be insignificant due to very small amounts. Only transportations from the chemical factory to the paper mill were specified. The manufacturing data for some chemicals included the transportations of the raw materials needed for the production.

The transportations of fuels and raw materials to the paper mill were taken into account. The transportation data of oil-based fuels and natural gas are as aggregated in their modules (Table 3).

Some of the material transportations to the printing plant were included in the study. Transportation of printing plates to the printing plant was included but transportation of aluminium slabs to the printing plate manufacture site was not. Newspaper delivery to consumers was divided into two parts: 1) the delivery from the printing plant to the drop-off boxes and 2) the final delivery to consumers.

Data on the collection and transportation of mixed waste and separately collected paper were obtained with the approach by Tanskanen (2000a). The modelling of waste collection and transportation requires making choices about variables such as the size and age of the vehicle, load size, and the share of urban and highway driving. The calculation of emissions was carried out with the help of operating time. The emptying time for the containers depends on the number and type of containers per property. The volume of containers for mixed waste and separately collected paper was 600 l in residential properties and commercial establishments. In drop-off centres the paper container volumes were 4 m^3.

Separately collected paper is transported from drop-off centres, residential properties and commercial establishments to the processing plant of Paperinkeräys Oy. The average distance was 20 km (Pelkonen et al. 2000). The same distance was also applied for the mixed waste transported to the Ämmässuo landfill. The same vehicles were assumed to be used both for the collection and transportation of mixed waste, without unloading. The chosen collection and transportation vehicle was a delivery lorry (VTT Lipasto 2002). Its gross vehicle mass is 15t and pay load capacity is 9t, but the load was assumed to be 6.5t (72.2% of the maximum load). The same vehicle was used for both on-site and drop-off centre collections. The delivery driving was assumed to be as follows: 70% consists of urban driving and the rest is highway driving.

The data on transportation vehicles for mixed waste and separately collected paper are mainly from the year 1999 in the Helsinki Metropolitan Area. The vehicles used for the collection of paper and mixed waste were assumed to have the same age distribution: 50% of EURO 2 and 50% of EURO 3 (Table 10). Even if the load was 6.5t, the emission factors for the full load (9t) were applied in order to take into account the extra emissions caused by lifters and free running.

Waste management systems include also other transportations than collection and transportation of mixed waste and discarded paper. In Cases 2a and 2b, the SRF is transported from the MB pre-treatment plant to the Martinlaakso power plant, where the gasification takes place. Additionally, in Cases 2b and 3b, 50% of the processed newspapers are transported from the processing plant of Paperinkeräys Oy to the Martinlaakso power plant or the incineration plant accordingly. Some transportations of chemicals to the gasification and incineration plants are also included.

Table 9. Specified transportations in the product systems including the transported material, destination, transportation equipment, the proportion of the transported amount and distance. The data given in this table excludes the transportation of chemicals to the paper mill.

Transported material	**Destination**	**Transportation equipment and proportion (%) of the transported amount, distance (km)**										**Ref.**
		Barge for wood	**Timber floa-ting**	**Cargo ferry**	**Train (electr.)**	**Full trailer**	**Full trailer timber lorry**	**Small deli-very lorry**	**Diesel van**	**Car urban average**	**Others, no emis-sions**	
Logs	saw mill						70					a
Pulp wood	paper mill	(6%) 210	(9%)				(85%) 80					a
Saw mill chips	paper mill					170						a
Processed newspapers	paper mill				(24%) 304	(76%) 241						a
Energy wood	paper mill					70						a
Peat	paper mill					130						a
Coal	paper mill			730		277						b, c
Printing plates	printing plant			1776		410						d, e, f
Printing films	printing plant			1776		130						d, e, f
Printing inks	printing plant					165						b
Fixative	printing plant			1776		130						d, e, f
Solvent	printing plant					198						b
Developer	printing plant			1776		130						d, e, f
Newsprint	printing plant					211						b, f
Newspapers (delivery)	drop-off boxes							(80%) 28.5	(20%) 28.5			g, h
Newspapers (delivery)	consumers									(71%) 24.5	(29%) 24.5	g, h
Coal	CaO manufacture			730		31						b, c
$Ca(OH_2)$	gasification					60						b
REF	gasification					20						i
Processed newspaper	gasification					20						i
Processed newspaper	incineration					20						i
$Ca(OH_2)$	incineration					41						b
coal	the boiler 2			782		20						c, i
CaO	the boiler 2					60						b

References:
a) UPM-Kymmene Group 2002
b) Tiehallinto 2002
c) Lloyd's Maritime Atlas 1999
d) Salo 2002
e) Iso karttakirja 1995
f) Hartikainen 2002
g) Grönlund and Rannikko 1999
h) Kuronen 2002
i) own estimation

Table 10. EURO classification of the vehicles (VTT Lipasto 2002).

Pre-EURO , models ➔ 1991. This includes all pre 1992 models.
The mileages of these vehicles are so small (20-40 % of lorry mileage) that a more detailed grouping is needless.
EURO 1, models 1992 – 1995
EURO 2, models 1996 – 1998
EURO 3, from model 1999 onward

3.6.4 Assessing the credits from energy recovery of wastes

Waste-to-energy concepts were included in all the five newspaper waste management options studied. Case 1 included energy recovery of the landfill gas, Cases 2a and 2b included co-combustion of the gas produced from SRF and Cases 3a and 3b included incineration of mixed waste. The energy recovered from waste within the product systems can be considered as a by-product of waste recovery and treatment. In the LCA-WASTE study it was assumed that with the production of these by-products some other forms of producing similar products can be replaces. Thus the products systems gained credits from producing the by-products, i.e., energy from waste. The credits were taken into account as avoided emissions.

For the basic waste management options, the avoided emissions were assessed either using the fuel mixture 1) used for the average Finnish electricity and heat production (Appendix 5), or 2) that used in a local coal-powered CHP plant (Appendix 6). All the five options were assessed with the same approach.

3.6.5 Modelling the waste collection system

In this inventory, the waste collection and transportation were modelled using the approach by Tanskanen (2000a) for evaluating the effects of source separation on municipal solid waste management (MSWM).

The approach has been designed for analysing municipal solid waste management based on source separation. The approach consists of formulation, analysis, and comparison of various MSWM systems in six stages (Fig. 14). It also includes the calculations of the amounts of materials that can be collected for recovery with different separation strategies.

The first stage is to formulate potential separation strategies for recoverable waste materials. This is based on the coverages of different collection systems. Waste producers are grouped into residential properties and commercial establishments in order to differentiate between the amounts of materials produced by different waste producers. The second stage is to calculate the recovery rates of individual materials and the total recovery rate. If the recovery rate is too low, the separation strategies need to be altered. The third stage is to calculate the accumulation of waste types and the sizes of waste streams. These calculations are done for each waste producer group. (Tanskanen 2000a)

The fourth stage is to plan the collection systems, which means defining the types and numbers of bins and containers and collection frequencies for each waste type, waste producer group and separation strategy. The fifth stage is to determine the unit costs and unit emissions. Each waste component of a waste stream has its own unit emissions. Finally, in the sixth stage, the costs and emissions of the MSWM system are calculated for the whole year as an outcome of the sizes of waste streams, unit costs and unit emissions. As a result, it is possible to modify municipal solid waste management systems in order to achieve reductions in costs and emissions. (Tanskanen 2000a)

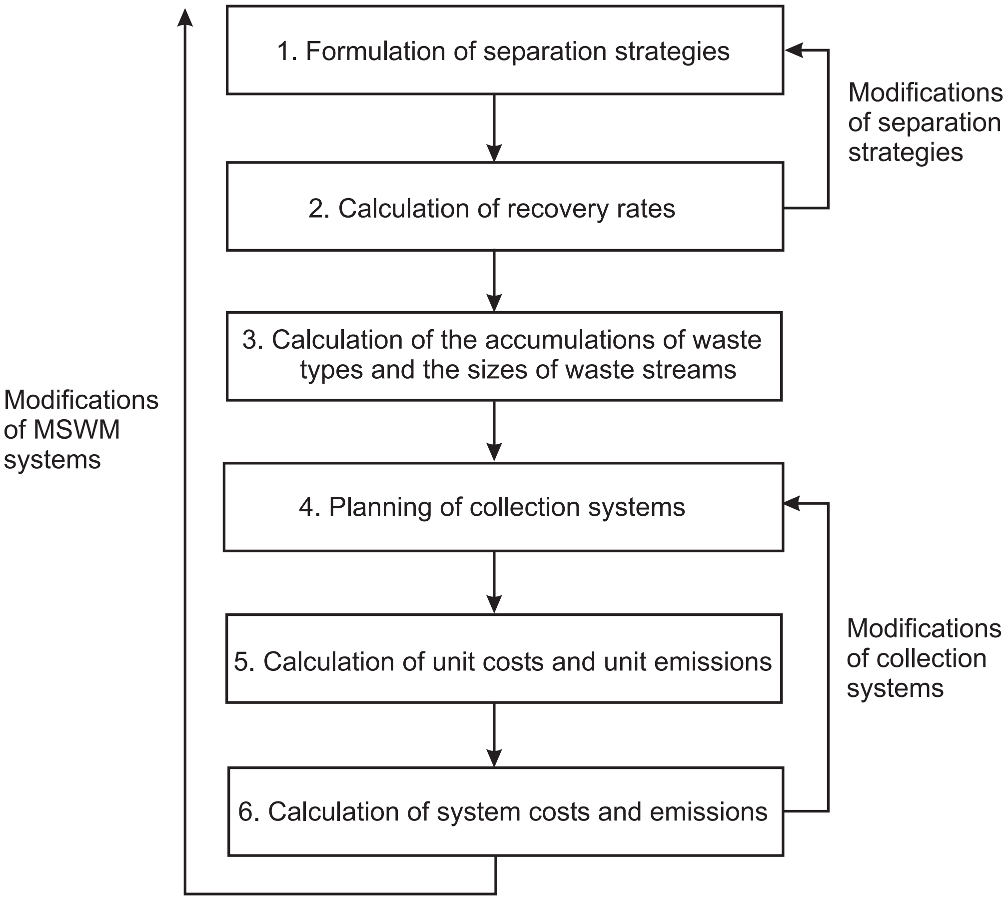

Figure 14. Stages of the MSWM modelling approach (Tanskanen 2000a).

3.7 Quality and reliability of the inventory data

The life cycle inventories of newspaper were carried out as case studies in the Helsinki Metropolitan Area. The data concerning this area were the basis for the inventory calculations especially concerning the waste management. Most of the data are from the year 2001. The data on newsprint manufacture, ink manufacture and newspaper printing are also from the year 2001. The data concerning the current waste management system (Case 1) are as new as possible.

The sources and thus the reliability and quality of the data used for the inventory analysis varied to some extent. On the one hand, reliable and site-specific data from existing plants were available for newsprint manufacture, ink manufacture, newspaper printing and the current waste management system. Generic data from commonly available databases were used for the chemical and raw material production and transportations.

On the other hand, however, the data used for the waste management leads to more uncertainties in the results for a number of reasons. For example, no data from existing plants were available for the energy recovery option comprising gasification of SRF and co-combustion of the purified gas, hence the data were taken from pilot studies. For the theoretical incineration option, data from a Swedish plant were used, which may not be valid for a plant potentially constructed in the future.

No data were available from existing MB pre-treatment plants for assessing the efficiency of the plant to separate newspaper from mixed waste into the SRF fraction. In this study the efficiency was assumed to be 100%. In practice, however, some of the newspaper might end up in the organic waste fraction and in turn be composted, but at least with the current collection rate this flow would be very small. According to an estimate given by some practitioners of the waste management sector, approximately 90% of newspaper is, however, in practice sorted into SRF.

4 Life cycle impact assessment

4.1 The general framework

The third phase of an LCA is life cycle impact assessment (LCIA), which aims to assess the environmental significance of a product's life cycle. An LCIA applies impact categories and category indicators connected with the LCI results in order to provide environmental information on the product system (ISO 2000a).

The first steps in the impact assessment are the definition of impact categories and the classification. Firstly, the appropriate impact categories (climate change, acidification etc.) and category indicators (e.g., H^+ releases in acidification) are defined. After defining the categories, the interventions (emissions, resource extractions and land use) obtained from the inventories are assigned to the categories on the basis of cause-effect relationships.

The third element, characterisation, is the quantification of the interventions in the chosen impact categories of the newspaper system in terms of category indicators. In characterisation environmental interventions are multiplied by the corresponding characterisation factors and the results are summed up as category indicator results. The three steps described above are the mandatory steps of an LCIA (ISO 2000a). It is sometimes possible to evaluate the alternatives on the basis of the characterisation results.

Usually, however, a fourth element, normalisation, is needed in LCIA. Normalisation relates the magnitude of the effects in the different impact categories to reference values (e.g., the impact category indicator results caused by human activities throughout Finland). Normalisation can point out the significance of different impact categories and offer an answer to the evaluation.

The fifth element, weighting, includes valuation and aggregation of different environmental impact category indicator results in order to obtain single value scores for each alternative, i.e., in order to compress multi-dimensional information into decision making. In the LCA-WASTE study, weights obtained from previous LCIA studies (e.g., Seppälä et al. 1998, Seppälä et al. 2000 and 2001) were used. Normalisation and weighting are optional elements in an LCIA (ISO 2000a). According to ISO standard 14042 (ISO 2000a), weighting shall not be used for comparative assertions disclosed to the public.

4.2 The models used in the LCA-WASTE study

The impact assessment phase of LCA, life cycle impact assessment (LCIA), is still under development (e.g., Udo de Haes et al. 2002, ISO 2000a). Several LCIA methodologies with diverse approaches exist and are used, and different results may be obtained with the different methods. A question for LCA practitioners arises: which method is appropriate to the specific aim of the study? Unfortunately, there is no unambiguous answer because different methods have their strengths and weaknesses (see e.g., Guineé et al. 2002).

The life cycle inventory data of each waste recovery and treatment option were interpreted with three impact assessment methods, DAIA (Decision Analysis

Impact Assessment) (Seppälä 1999, Seppälä 2003), Eco-indicator 99 (Goedkoop and Spriensma 2001) and EPS 2000 (A systematic approach to environmental priority strategies in product development, Steen 1999a, Steen 1999b). These three models differ from each other in several aspects (Table 11). The differences of the methods and the results they produce were compared in the LCA-WASTE study. The results of this comparison have been reported in detail in Dahlbo et al. (2005c).

Table 11. Basic features of the environmental impact assessment methods used in the study.

Impact assessment method	Approach	Impact categories	Damage categories / safeguard subjects	Basis for reference system in normalisation	Weighting factors
DAIA (Seppälä 2003, Seppälä 1999)	Midpoint, sitedependent	Climate change Acidification Aquatic eutrophication Oxygen depletion Tropospheric ozone formation Ozone layer depletion [1]		Finnish emissions	Finnish, panel method
Eco-indicator 99 (Goedkoop and Spriensma 2001)	Endpoint	Carcinogenic effects on humans Respiratory effects caused by organic substances Respiratory effects caused by inorganic substances Damage caused by climate change Effects caused by ionising radiation [1] Effects caused by ozone layer depletion [1]	Human health	European interventions	European (Swiss), panel method
		Damage caused by ecotoxic effects Damage caused by the combined effect of acidification and eutrophication Damage caused by land occupation and land conversion	Ecosystem quality		
		Damage caused by extraction of minerals Damage caused by extraction of fossil fuels	Resources		
EPS 2000 (Steen 1999a, Steen 1999b)	Endpoint	Life expectancy Severe morbidity Morbidity Severe nuisance Nuisance	Human health	Normalisation is avoided. The spatial extension of EPS can be considered as global.	Willingness to pay (WTP) to avoid changes
		Crop growth capacity Wood growth capacity Fish and meat production capacity Soil acidification Production capacity for irrigation water [1] Production capacity for drinking water [1]	Ecosystem production capacity		
		Depletion of oil reserves Depletion of coal reserves Depletion of natural gas reserves Depletion of elemental or mineral reserves	Abiotic stock resource		
		Species extinction	Biodiversity Cultural and recreational values [2]		

[1] Impact categories not included in this study, since interventions causing such effects do not exist in the LCI data.
[2] Indicators should be defined when needed.

4.3 The impact categories and environmental interventions included in the models

The basic difference between the methods is in the impact aspects taken into account. In this case study, the DAIA application was restricted to the impact categories that have scientific-based characterisation factors from the point of view of Finnish emissions (climate change, acidification, aquatic eutrophication, oxygen depletion and tropospheric ozone formation). (Note that DAIA is an open framework for all kinds of impact categories that have even subjective characterisation factors. The only requirement is that all stages of impact assessment shall follow the rules of multiattribute value theory (see Seppälä 2003)).

In Eco-indicator 99 there are altogether eleven impact categories and the aim is to cover all important cause-effect chains related to three damage categories (human health, ecosystem quality and resources), whereas in the EPS 2000 method there are 16 impact categories related to five safeguard subjects (Table 11). Furthermore, the difference between impact categories leads to a different number of interventions included in the methods. In our application 12 interventions were included in DAIA, whereas 33 were included in Eco-indicator 99 and 26 in EPS 2000 (Appendix 11).

4.4 Characterisation

The methods also differ from each other in characterisation, i.e., in the modelling of environmental impacts. In DAIA different impact category indicators (e.g., algal growth in aquatic eutrophication) were determined for each impact category and the category indicator results were calculated by multiplying the amounts of interventions with the corresponding characterisation factors (Appendix 11). In the case of climate change, the characterisation factors correspond to global warming potentials (GWP_{100}) determined by the Intergovernmental Panel on Climate Change (IPCC) (Ramaswamy et al. 2001). In the context of acidification, tropospheric ozone formation, aquatic eutrophication and oxygen depletion, site-dependent, Finnish-specific characterisation factors were used (Seppälä 1999, Seppälä et al. 2004). The characterisation in DAIA is based on the midpoint approach, meaning that the impacts are modelled at a midpoint level in the environmental mechanism between emissions and damages. In contrast, Eco-indicator 99 and EPS 2000 use the end-point approach aiming at modelling damages.

In EPS 2000, category indicator types representing end-point effects have been determined and the environmental interventions are aggregated into category indicator results with the help of global-specific characterisation factors (Appendix 11). The indicator types in EPS 2000 are such as years of lost life (YOLL), severe morbidity, morbidity, severe nuisance, nuisance, production capacity (of crop, wood, fish and meat, irrigation water or drinking water), base cation capacity, abiotic resource in the reserve and the normalised extinction of species (NEX) (Steen 1999a). The characterisation factors consist of several pathway-specific characterisation factors which have been determined by three types of models (for a more detailed description see Steen 1999b). The category indicators used in Eco-indicator 99 are surplus energy needed for future extraction (for damage to mineral and fossil resources), percentage of vascular plant species per km^2 per year (for damage to ecosystem quality) and disability adjusted life years, DALY (for damage to human health). The characterisation factors are called damage factors that directly aggregate interventions to damage category indicator results (Appendix 11). The foundations for the damage models of ecosystem quality and human health are mostly based on the cause-effect chains related to the environmental conditions in Central Europe. (Note that ozone layer depletion and radiation categories were omitted from this study because interventions causing such effects do not exist in the LCI data.)

4.5 Normalisation and weighting

The bases of normalisation in the three LCIA methods used are also different. The reference system of normalisation in DAIA represents the impacts of Finnish emissions. In Eco-indicator 99 the reference systems are calculated by European environmental interventions. In EPS 2000 the normalisation has been avoided because of monetary weighting and the global spatial extension (Appendix 11).

The weighting factors used in DAIA and Eco-indicator 99 have been produced by a panel method, whereas EPS 2000 uses monetary weighting (Appendix 11). In the DAIA application the weighting factors of the impact categories represent the average opinions of about 40 Finnish experts working in the field of environmental issues in 1996 (Seppälä 1999). The experts were asked to state their opinion about the importance of the impact issues. In the valuation, the focus was only on the effects caused by the Finnish emissions. In Eco-indicator 99 the weighting factors for the three damage categories were obtained using a questionnaire sent out to 365 members of the Swiss discussion platform on LCA in order to derive weights that reflect the views of the European society. However, only 82 answers were received. The respondents were asked to rank the damage categories in the order of decreasing importance and also to give weights to the categories directly (Goedkoop and Spriensma 2001). The default version, the hierarchist perspective with average weighting set (H,A), of Eco-indicator 99 was used in this study.

In EPS 2000 the default weighting indicator is the willingness to pay (WTP) to restore impacts on the safeguard subjects, as measured amongst today's OECD inhabitants. The weights for safeguard subject human health are based on the WTP for preserving lives referred to as the value of statistical life (VSL). The weights for abiotic stock resources are based on market scenarios where the production costs of, e.g., a sustainable alternative for fossil oil, namely vegetative oil, are assessed. The WTP for avoiding one NEX is estimated from Swedish figures on governmental and private expenses for preservation measures (Steen 1999a, Steen 1999b).

In summary, the basic DAIA version was developed for assessing the environmental impacts of the Finnish emissions and it has been used in several Finnish life cycle assessment applications (Seppälä et al. 1998, Tenhunen and Seppälä 2000, Grönroos et al. 2001, Seppälä et al. 2001, Seppälä et al. 2002). The spatial extension of Eco-indicator 99 is Europe, whereas in EPS 2000 it is the world.

4.6 Presentation of the impact assessment results

In the impact assessment results reported here, the methods have been applied in accordance with the respective methodology reports and publications (Goedkoop and Spriensma 2001, Seppälä et al. 2004, Seppälä 2003, Seppälä et al. 2001, Seppälä 1999, Steen 1999a, Steen 1999b). The assessment has been carried out up to the point of producing one aggregated impact value for each waste recovery and treatment case studied. Characterisation, normalisation and weighting have been carried out using the factors readily available in the respective reports and publications (Appendix 11). The three LCIA methods all have their own terms for the final results of the LCIA, which represent the overall impacts on the environment. In DAIA the term impact score or value is used, whereas in EPS 2000 the results are given as environmental load units (ELUs) and in Eco-indicator 99 as ecoindicator value or ecopoints.

According to ISO standard 14042 (ISO 2000a), weighting shall not be used for comparative assertions disclosed to the public. In this study, however, weighting was performed in order to allow comparability of the results received with the three methods. For compatibility with the ISO 14042 standard, the overall results are presented both as divided into the impact categories included in each method and as the overall impact assessment results.

5 Results and discussion

5.1 Life cycle interpretation

The aims of life cycle interpretation are to analyse completeness, sensitivity and consistency of the results, make conclusions, define limitations and give recommendations. Life cycle interpretation should be done in a systematic and iterative way, like all the other life cycle phases. The interpretation should include identification of the significant issues, such as the implications of the methods used and assumptions made in the preceding phases. (ISO 2000b)

In the following chapters the results of the life cycle inventory (Chapter 5.2) and the life cycle impact assessment (Chapter 5.3) are presented. The waste management options examined are the basic waste management options with one exception: the LCIA results for Cases 3a and 3b are reported using the generic incineration facility modelled with the Swiss Ecoinvent data (see Chapter 2.4.3). This choice was made during the LCIA phase considering that in the energy system of the HMA, an incineration facility generating electricity would be more likely than an incineration facility generating district heat.

In Chapter 5.4 the results of the sensitivity analyses are presented.

5.2 Results of the life cycle inventory phase

5.2 1 Mass flow chart of fibres in the product systems

In Figure 15, the mass flow chart of fibre products in the product systems of newspaper is presented. The chart is not a mass balance chart and it presents only the main products of the sub-processes. In the forestry phase, the main flows consist of fibre wood and logs. Fibre wood ends up at the paper mill without processing. Meanwhile, logs are first transported to the sawmill for debarking and sawing. The sawmill chips are used for newsprint manufacture.

In the paper mill phase, the fibre wood is debarked and the bark is used as a fuel at the power plant of the paper mill. This causes a reduction in the amount of wood going out from debarking. Similarly there is a reduction in the amount of sawmill chips when they are screened at the paper mill. Saw dust from screening is used at the power plant. Chips from debarking and screening are used as raw materials in the TMP process. The raw material used for the newsprint manufacturing, in addition to wood, consists of separately collected newspaper. Newspaper is de-inked and the de-inking sludge is combusted at the power plant of the paper mill. Part of the de-inking sludge is utilised in landfill constructions. Other minor waste flows from the paper mill are debarking waste, de-inking reject and waste from the paper machine. They contain insignificant amounts of fibres and they are landfilled.

The paper machine uses both TMP and DIP for the newsprint manufacture. In Cases 2b and 3b, there is 50% less DIP available compared with Cases 1, 2a and 3a due to the energy recovery option applied for separately collected newspaper in Cases 2b and 3b. The same amount of newsprint is however produced in each case and therefore in Cases 2b and 3b more virgin wood material is used compared with Cases 1, 2a and 3a.

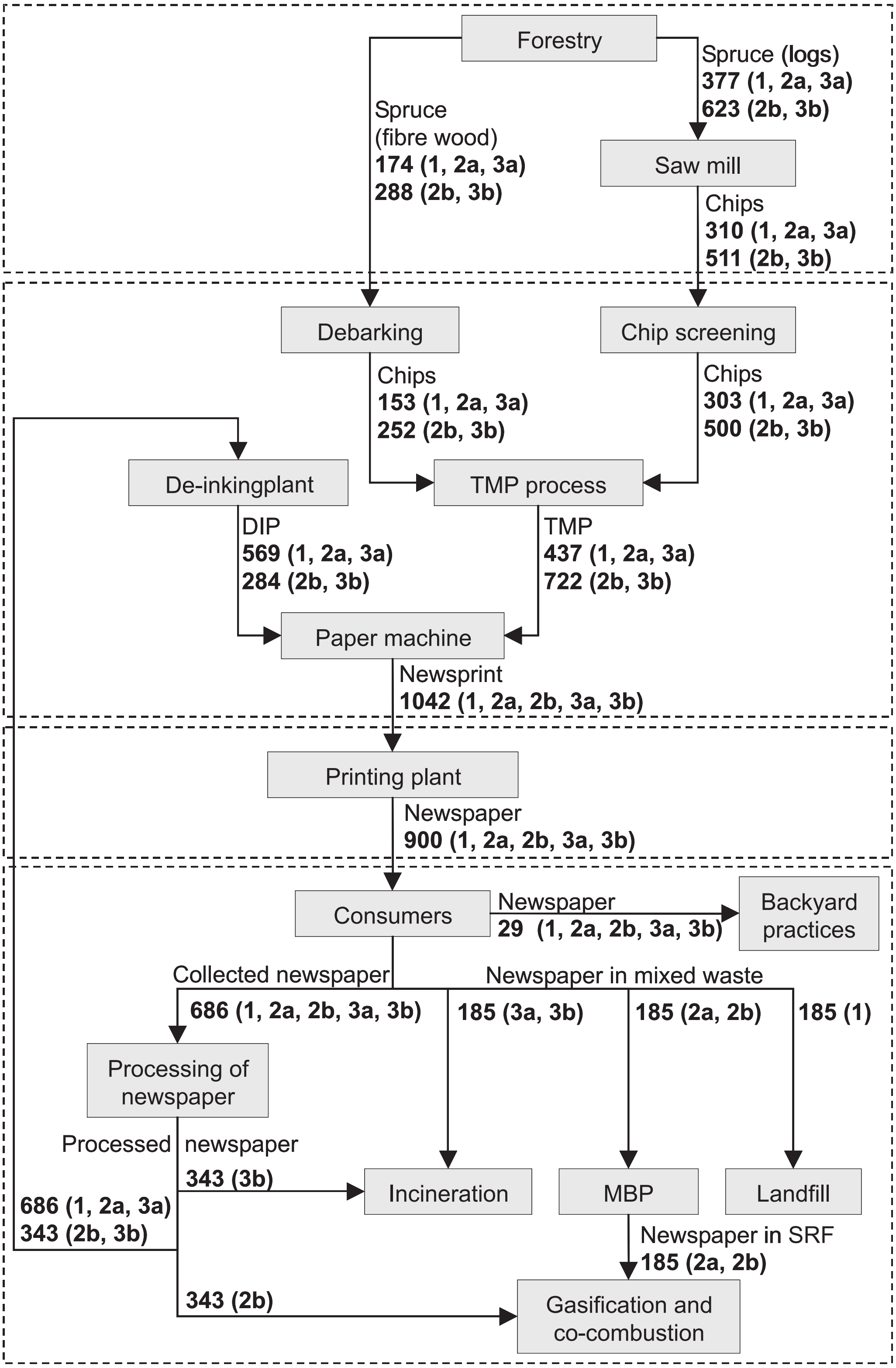

Figure 15. Mass flow chart of the main fibre products in the product systems of newspaper. Figures are given as kilograms of dry weight per the functional unit (1 ton of newspaper delivered to consumers). The codes in brackets refer to Cases 1, 2a, 2b, 3a and 3b in which the mass flow appears. The figures are valid only for the current recovery rate of newspaper, 76%.

The same amount of newsprint is used at the printing plant in each waste management option. The main losses are caused by the printing machine. Before printing, a new paper roll has to achieve a certain rotation speed and this causes some paper losses. In addition, the printing quality has to obtain a certain level, which causes losses.

After printing, the newspapers are delivered to consumers. 76.2% of the newspapers delivered to consumers are collected separately and 20.6% enter the mixed waste stream. The remaining 3.2% are used as kindlings, biowaste bags, wrappings, etc.

Newspaper in mixed waste is treated differently in the different cases. Separately collected newspapers are baled and loaded into lorries at the processing plant. In Cases 1, 2a and 3a the processed newspapers are used for material recovery. In Cases 2b and 3b, 50% of the processed newspapers are recovered as energy, and 50% as material.

5.2.2 Emissions to air

The overall emissions to air from the product systems

In the following figures (Fig. 16 and 17), the emissions to air of methane, fossil carbon dioxide, nitrogen oxides and sulphur dioxide from the product systems are shown. Emissions of other components (that were included in the impact assessment) are presented in Appendix 10. Two ways of assessing the emissions avoided by energy recovered from wastes were studied, namely using the fuel mixture 1) used for the average Finnish electricity and heat production (Fig. 16), and 2) that used in a local coal-powered CHP plant (Fig. 17). The saved processes were taken into account in the product systems as negative emissions.

There are no major differences in emissions to air between the cases (Fig. 16) if avoided emissions are not taken into account. Only methane emissions in Case 1 are drastically higher than in the other cases.

The life cycle phase paper mill has a significant effect on the total amount of emissions to air. Thus the differences between the cases result primarily from the differences in the raw material composition of newsprint. The use of virgin wood material is higher in Cases 2b and 3b (due to more energy recovery of newspaper) than in Cases 1, 2a and 3a. The more virgin wood is used, the more the emissions from the forestry phase increase. The same amount of newsprint is produced in each case regardless of the proportion of material recovery. Therefore emissions from the printing phase are the same in each case.

When more virgin wood material is used at the paper mill, the electricity consumption of the TMP process increases. In Cases 2b and 3b, the amount of electricity purchased by the paper mill is higher compared with Cases 1, 2a and 3a. The change in the material composition affects the fuel mixture used at the power plant of the mill. When using more virgin wood materials, more biofuels are produced at the paper mill and thus the need for fossil fuels for the power generation at the paper mill decreases. As a result, fossil CO_2 and SO_2 emissions from the power plant decrease.

In Case 1, the methane emissions are caused by landfilling (Fig. 16). Of the methane produced at the landfill, 75% was assumed to be collected, and 15% of the uncollected methane was oxidised into carbon dioxide by the top soil. The methane emissions from the landfill comprised the fraction that is not collected and is not oxidised by the top soil (Kopalainen 2003, Finnveden et al. 2000).

The methane emissions in Cases 2b and 3b are slightly higher than in Cases 2a and 3a. This is caused by the higher electricity consumption of the paper mill in Cases 2b and 3b. The electricity consumption of the paper mill in Cases 1, 2a and 3a causes

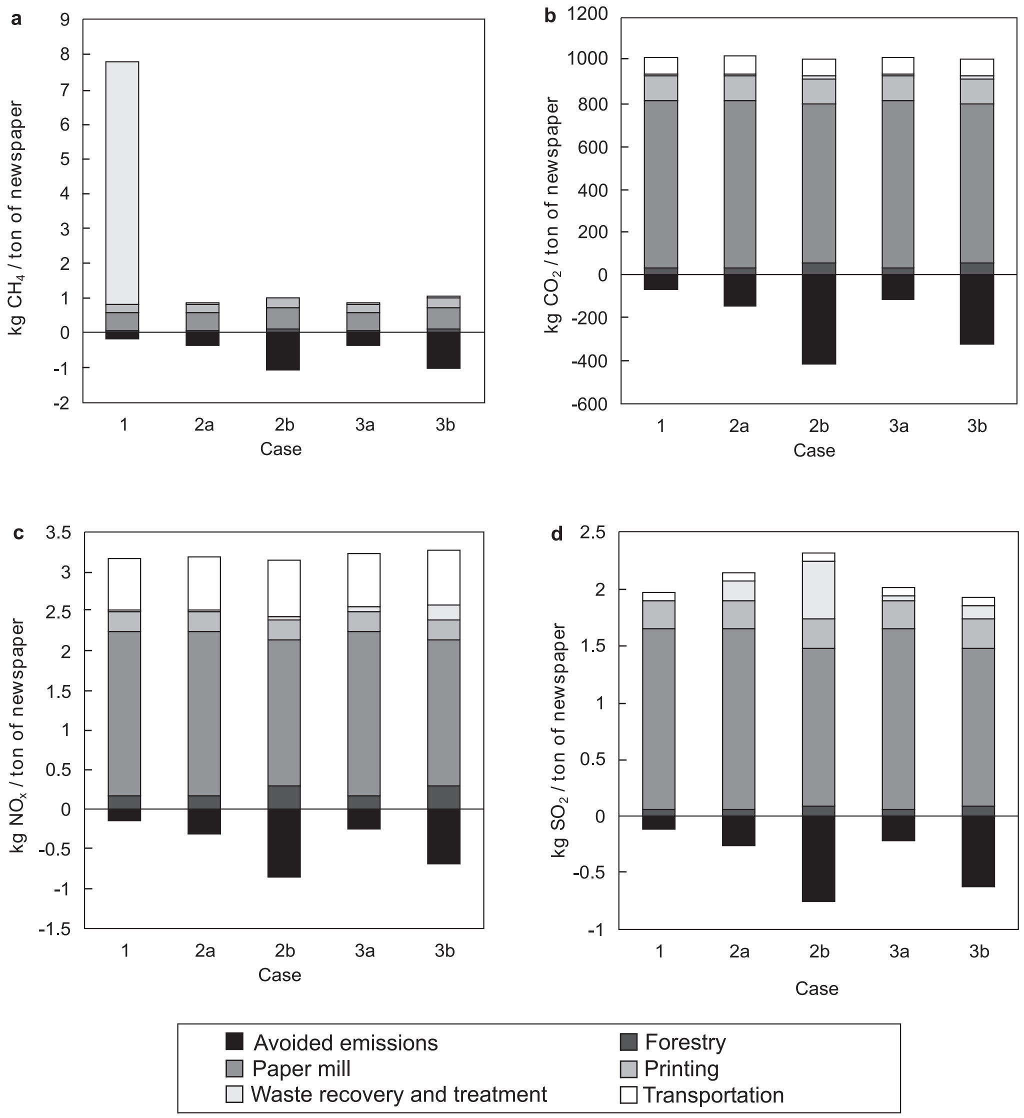

Figure 16. a) Methane (CH_4), b) fossil carbon dioxide (CO_2), c) nitrogen oxide (NO_x) and d) sulphur dioxide (SO_2) emissions to air throughout the life cycle of newspaper in Cases 1, 2a, 2b, 3a and 3b. The avoided emissions are based on the Finnish average heat generation (the year 2000) and the Finnish average electricity generation including net imports (the years 2000-2002). The recovery rate of newspaper is 76%.

81.8%, and peat production 6.1% of the methane emissions from the paper mill phase. By contrast, the electricity consumption produces 93.4% of the methane emissions in the paper mill phase of Cases 2b and 3b. In the forestry phase, the highest methane load is produced by the sawmill. Generally, the methane emissions of the other life cycle phases compared with the landfilling in Case 1 are insignificant.

When the avoided emissions are considered, Case 3b produces the least methane emissions. In Cases 2b and 3b, there are higher avoided emissions than in Cases 2a and 3a because 50% of the separately collected newspapers are used for energy recovery. Hence Cases 2b and 3b produce more energy, which substitutes for other forms of energy production. The avoided emissions differ between the cases. The two assumptions that influenced the magnitude of avoided emissions were 1) the fuel mixture used for the compensated energy production and 2) the ratio of electricity and heat production in the incineration and co-combustion processes. In Cases 2a and 2b, 30% of the produced energy is electricity and 70% heat, and in Cases 3a and 3b, 3.5% is electricity and 96.5% heat.

Generally, there are no differences in the total CO_2 emissions between the cases. However, in Cases 2b and 3b the forestry phase produces more CO_2, but the paper mill phase less, compared with Cases 1, 2a and 3a. This is caused by the increased use of virgin wood materials at the paper mill. The fossil CO_2 load from forestry increases because of increased harvesting and sawmill activities.

The fossil CO_2 emissions from the paper mill phase dominate in each case. In Cases 1, 2a and 3a the power plant of the mill produces 36.9%, and the purchased electricity 56.5% of the fossil CO_2 emissions in the paper mill phase. But when the use of virgin wood materials is higher in Cases 2b and 3b the power plant produces only 11.9%, and the purchased electricity 84.5% of the fossil CO_2 emissions in the paper mill phase. The use of virgin materials consumes more purchased electricity but decreases the fossil CO_2 emissions of the power plant of the mill.

The waste recovery and treatment does not have a great influence on the total fossil CO_2 emissions. In Case 1, the landfilling of mixed waste causes slightly smaller fossil CO_2 emissions than the other waste recovery and treatment. When taking into account the avoided emissions, Case 3b generates the least CO_2 emissions. The avoided emissions depend, however, on the chosen energy production system and the ratio between electricity and heat generation.

The NO_x emissions to air are quite similar in each case (Fig. 16). The emissions in Case 3b are slightly higher than in the other cases. In Cases 2b and 3b, the emissions of the forestry phase are higher but the emissions of the paper mill phase are lower compared with Cases 1, 2a and 3a. In Cases 1, 2a and 3a, the power plant of the paper mill and the purchased electricity used in the paper mill phase produce NO_x emissions almost equally. In Cases 2b and 3b, however, the purchased electricity produces 64.1%, and the power plant 30.5% of the NO_x emissions of the paper mill phase. The paper mill phase has a relatively small contribution to the total NO_x emissions, whereas the forestry and transportation phases have a more significant role. When the avoided emissions are considered the NO_x emissions produced by Cases 2b and 3b very similar .

Case 2b produces the highest SO_2 emissions if the avoided emissions are not taken into account (Fig. 16). The paper mill phase produces the highest SO_2 load in each case. In Cases 2b and 3b, the paper mill phase causes less SO_2 emissions than in Cases 1, 2a and 3a. In the forestry phase, the situation is the opposite. In Cases 1, 2a and 3a, the power plant of the paper mill produces more SO_2 emissions than the purchased electricity in the paper mill phase. The power plant of the paper mill uses less fossil fuels in Cases 2b and 3b compared with Cases 1, 2a and 3a, and thus the emission coefficient of SO_2 is smaller for the power plant in Cases 2b and 3b. Gasification and co-combustion of the purified gas produce more SO_2 emissions in Cases 2a and 2b than incineration in Cases 3a and 3b.

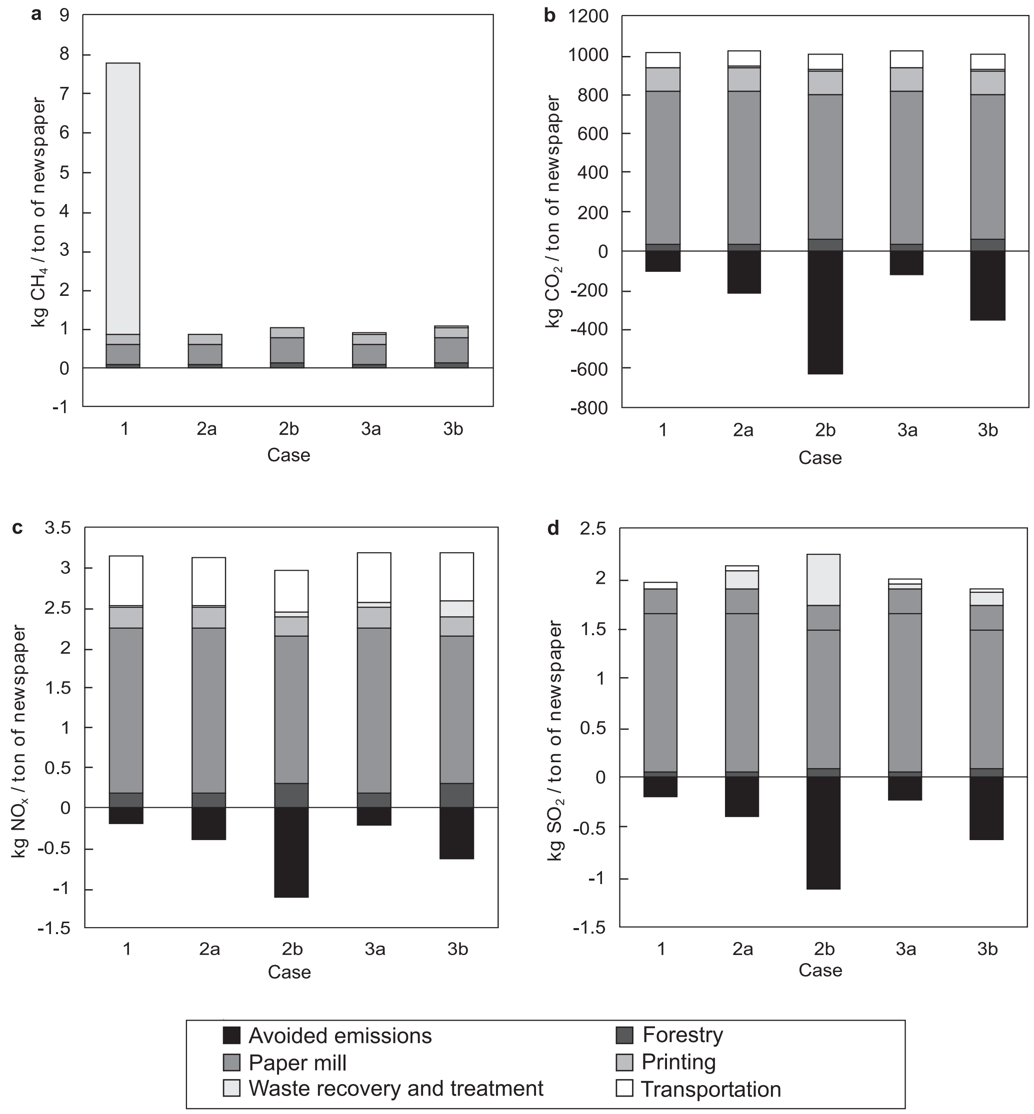

Figure 17. a) Methane (CH_4), b) carbon dioxide (CO_2), c) nitrogen oxides (NO_x) and d) sulphur dioxide (SO_2) emissions to air throughout the life cycle of newspaper in Cases 1, 2a, 2b, 3a and 3b. The avoided emissions are based on the emissions of the coal-powered CHP plant (Appendix 6). The recovery rate of newspaper is 76%.

For comparing the different ways of compensating the energy recovered from waste, the avoided emissions are assessed based on the coal-powered CHP plant, that is boiler 2 of the Martinlaakso power plant in Figure 17. The fuels used in this boiler in 2001 were coal (97.6%) and natural gas (2.4%). The avoided emissions to air are mainly higher in Figure 17 than in Figure 16. The energy produced with coal causes more emissions compared with the Finnish average energy production. Thus the energy recovery of newspaper gets more credits when it replaces coal than when it replaces Finnish average energy production. The only exception is methane because the data concerning boiler 2 did not include any methane emissions.

Emissions to air from transportations

The life cycle of newspaper was divided into five life cycle phases (Chapter 3.6.2). One of the phases is transportation, which includes all the specified transportations in the product systems of newspaper. In Figure 18, the transportation phase is further divided into the following six sections in order to compare the transportations of products, raw materials, fuels, waste, etc:

1. Wood materials, including
- transportation of wood materials from forest to the sawmill and the paper mill, and from the sawmill to the paper mill, and
- manufacture of fuels needed.
2. Newspaper to the paper mill, including
- transportation of separately collected and processed (baled and loaded) newspapers to the paper mill, and
- manufacture of fuels needed.
3. Other raw materials and fuels, including
- transportation of chemicals, printing materials and fuels to the paper mill, printing plant and waste recovery and treatment facilities, and
- manufacture of fuels needed.
4. Delivery of newspapers, including
- transportation of newspapers from the printing plant to the drop-off boxes and delivery of newspapers from the drop-off boxes to consumers, and
- manufacture of fuels needed.
5. Separately collected newspapers, including
- separate collection of discarded newspapers from consumers and transportation to the processing plant of Paperinkeräys Oy, the transportation of processed newspaper from the processing plant to the gasification (Case 2b) or incineration (Case 3b), and
- manufacture of fuels needed.
6. Mixed waste, including
- collection of newspaper in mixed waste from consumers and transportation to the waste management centre of YTV Waste Management, transportation of SRF from the MB pre-treatment plant to the gasification (Case 2b), and
- manufacture of fuels needed.

There are no major differences between the atmospheric emissions from transportations of the cases. The emissions from Cases 2b and 3b are either slightly higher or lower than the emissions from the other cases. The differences are primarily caused by the differences in the raw material composition of the newsprint. In Cases 2b and 3b, virgin wood materials are used more than in Cases 1, 2a and 3a. The increased use of wood produces more emissions from the transportations compared with Cases 1, 2a and 3a. When more virgin wood is used, the transportation of separately collected newspapers to the paper mill decreases. There are four factors which affect the emissions: transported distance, transported amount, transportation equipment and the age of the transportation equipment.

The methane emissions (Fig. 18) from transportations are quite equal in all cases. The major source of methane emissions to air is the delivery phase, in which relatively small loads are transported with petrol-driven cars. Petrol-driven vehicles are not used in any other transportations. The delivery does not have an effect on the differences between cases, because it is identical in each case. Generally, methane emissions from transportations are insignificant compared with the emissions from the whole product system (Fig. 16).

Cases 2b and 3b have higher CO_2 emissions to air from transportations than Cases 1, 2a and 3a (Fig. 18). The most significant reason for this is the increased transportation of wood materials to the paper mill in Cases 2b and 3b. The decreased transportation of separately collected newspapers to the paper mill is not enough to compensate for the increased transportations of wood materials. The delivery is the largest source of fossil CO_2 emissions in each case. The lowest CO_2 load comes from the collection of mixed waste.

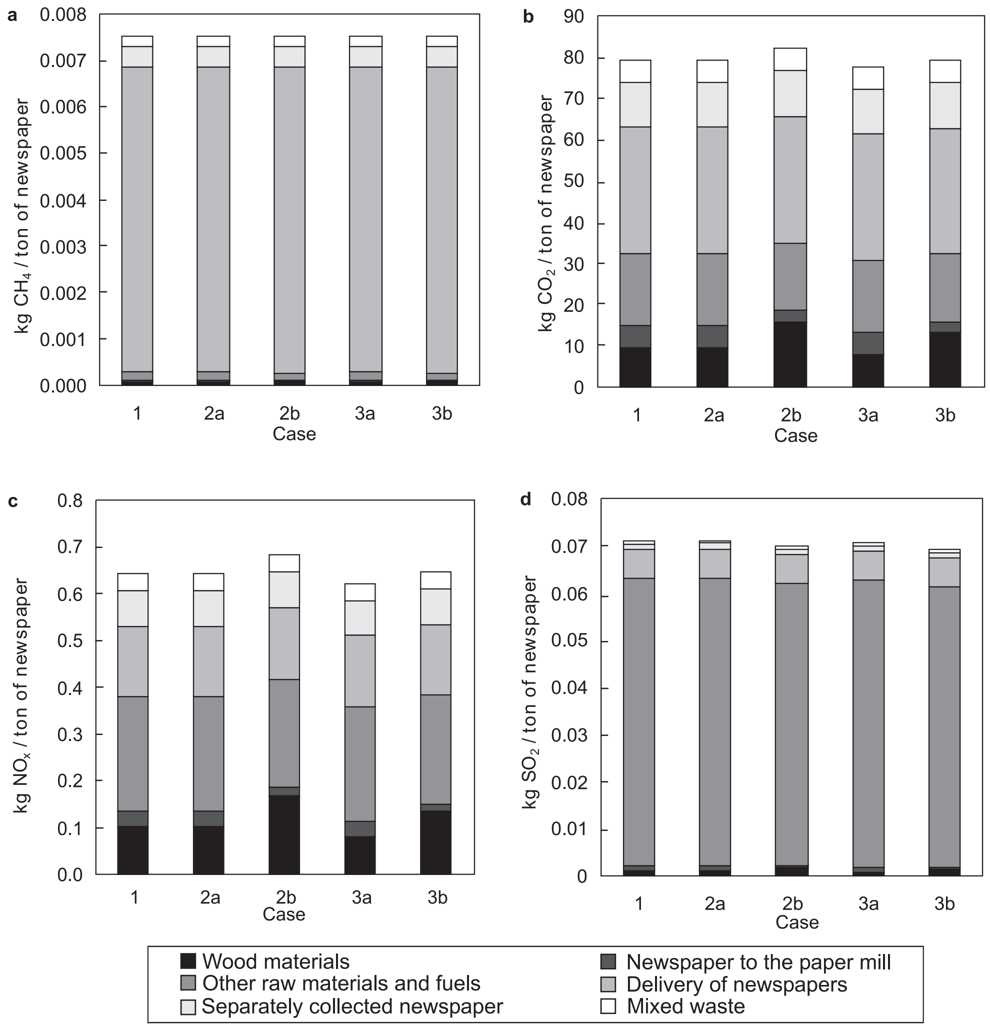

Figure 18. a) Methane (CH_4), b) fossil carbon dioxide (CO_2), c) nitrogen oxide (NO_x) and d) sulphur dioxide (SO_2) emissions to air from transportations in Cases 1, 2a, 2b, 3a and 3b. The recovery rate of newspaper is 76%.

The NO_x emissions from transportations (Fig. 18) are higher in Cases 2b and 3b than in Cases 1, 2a and 3a, because of the increased virgin wood material transportations. The transportation of other raw materials and fuels contribute most to the NO_x emissions. The transportation of kaolin mainly by ship to the paper mill causes 67% of the NO_x emissions from the transportation of raw materials and fuels. The transportation of raw materials and fuels does not include, however, the transportation of oil-based fuels because this is aggregated to the fuel manufacturing data.

The SO_2 emissions (Fig. 18) from transportations are quite similar in each case. The highest SO_2 load is evidently caused by the transportation of raw materials and fuels. The transportation of kaolin by ship causes over 90% of it. Petrol-driven cars used for delivery produce more SO_2 emissions than diesel-driven cars. Also the production of petrol causes more SO_2 emissions than the production of diesel. Hence, the delivery causes much more SO_2 emissions than the collection of newspapers and mixed waste. The total SO_2 load from Cases 2b and 3b is lower than that from Cases 1, 2a and 3a. This is due to the decreased amount of transported bentonite, which is used at the paper mill in de-inking process.

Emissions to air caused by the waste management

Figure 19 presents the methane (CH_4), fossil carbon dioxide (CO_2), nitrogen oxide (NO_x) and SO_2 emissions to air caused by the waste management phase. The avoided emissions were calculated with the Finnish average energy production. In order to be able to compare energy recovery with material recovery, the material recycling of newspaper into newsprint manufacturing was included in the life cycle phase waste management. The environmental interventions generated by material recycling were obtained by comparing the manufacturing of newsprint with the current DIP/TMP ratio with manufacturing with TMP alone.

Generally, the avoided emissions due to material and energy recovery are higher than the emissions from the waste management. Especially, Cases 2b and 3b get compensation because of the high energy recovery rate. The processing of separately collected paper causes hardly noticeable emissions. Collection, transportation and energy recovery cause most of the emissions of the waste management phase.

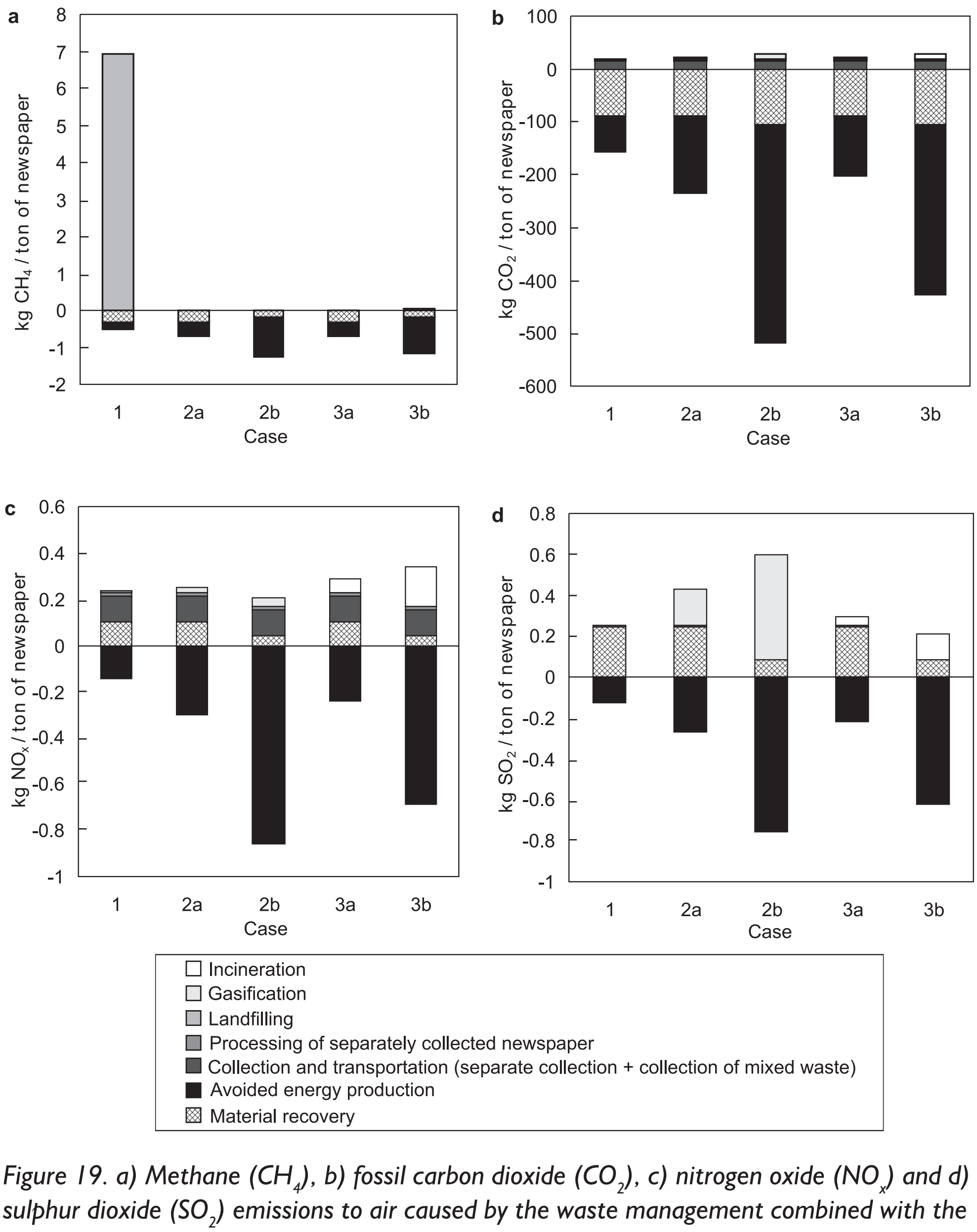

Figure 19. a) Methane (CH_4), b) fossil carbon dioxide (CO_2), c) nitrogen oxide (NO_x) and d) sulphur dioxide (SO_2) emissions to air caused by the waste management combined with the avoided emissions from material recovery and energy production in Cases 1, 2a, 2b, 3a and 3b. The recovery rate of newspaper is 76%.

The CH_4 emissions to air caused by the waste management phase (Fig. 19) resemble the methane emissions of the whole product system (Fig. 16). Case 1 causes the highest methane emissions due to landfilling, but in the other cases the methane emissions from the waste management are insignificant. The avoided emissions from the energy production are highest in Case 3b due to the high heat generation proportion in incineration compared with co-combustion in Cases 2a and 2b. This results from the fact that the methane emissions are higher in the Finnish average heat generation than in the corresponding electricity generation. The use of separately collected newspaper for material recovery causes avoided methane emissions compared with the manufacture of newsprint merely from virgin wood materials.

Cases 2b and 3b yield slightly higher fossil CO_2 emissions than the other cases, but the differences are very small. The avoided CO_2 emissions are much higher than the emissions arising from the waste recovery and treatment. The energy recovery of newspaper results in avoided CO_2 emissions in Cases 2a, 2b, 3a and 3b. In Cases 2a and 3a, the benefits from the material recovery and energy recovery are almost equal.

Cases 3a and 3b produce more NO_x emissions than the other cases. The NO_x emissions are higher from incineration than from co-combustion. The NO_x emissions from collection and transportation are slightly lower in Cases 2b and 3b than in the other cases because there are less transportations of separately collected newspapers to the paper mill due to the increased energy recovery.

Cases 2a and 2b have the highest SO_2 emissions to air. The SO_2 emissions from material recovery are positive, which means that material recycling causes more SO_2 emissions than the manufacture of newsprint merely from virgin wood materials. This results from the fuel mixture used at the power plant and the changes in the need for heat and electricity in the pulping processes. When more TMP is used, the need for fossil fuels is decreased at the power plant of the paper mill. As a result, the SO_2 emissions of the power plant decrease. Moreover, the purchased electricity is partly produced by nuclear power and hydro power, which do not produce any SO_2 emissions. Consequently, the contrary happens when more DIP is used in the newsprint manufacturing.

5.2.3 Emissions into water

Figure 20 presents the total nitrogen, phosphorus, BOD and COD emissions to water from the product systems (Appendix 10). The avoided emissions are based on the Finnish average energy production.

The paper mill and waste recovery and treatment phases cause the most significant nitrogen emissions to water (Fig. 20). The total nitrogen load is highest in Case 1 due to landfilling. The waste recovery and treatment phases of the other cases do not have any nitrogen emissions to water. The paper mill phase causes the highest nitrogen emissions to water in each case. In Cases 2b and 3b, the emissions are slightly lower than in the other cases due to a small decrease of the emissions from the paper mill phase. The nitrogen emissions from other life cycle phases are too small to be shown in Figure 20. The avoided nitrogen emissions of the Finnish average energy production are insignificant.

There are in practice no differences between the cases in the phosphorus emissions to water (Fig. 20). In each case, the majority of the phosphorus emissions to water originate from the paper mill phase. The forestry phase causes more phosphorus emissions in Cases 2b and 3b than in Cases 1, 2a and 3a. The avoided emissions are insignificant.

BOD emissions to water (Fig. 20) are very clearly caused by the paper mill and waste recovery and treatment phases. In Case 1, landfilling causes the highest BOD emissions. The emissions in Cases 2b and 3b are slightly lower than in

Cases 2a and 3a, because of the decrease in BOD emissions when more TMP is used for newsprint manufacture. The avoided emissions are insignificant. COD emissions to water are very similar to the BOD emissions (Fig. 20). The paper mill clearly dominates the emissions. In Case 1, the COD emissions are highest due to landfilling. In Cases 2a and 2b, the avoided emissions are very small. In the other cases, the avoided emissions are insignificant.

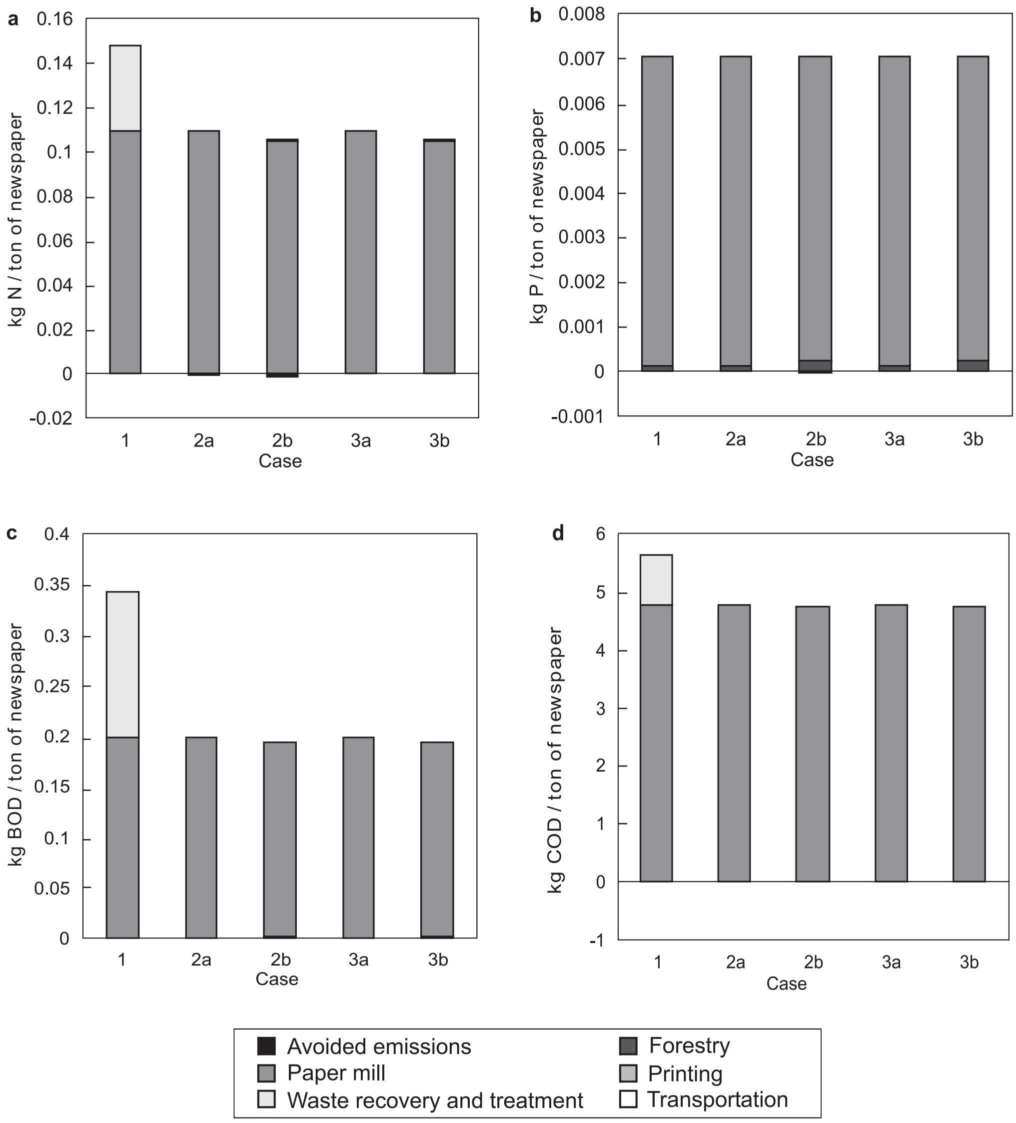

Figure 20. a) Total nitrogen, b) total phosphorus, c) BOD and d) COD emissions to water from the product systems. Avoided emissions are based on the Finnish average energy production. The recovery rate of newspaper is 76%.

5.2.4 Consumption of energy and resources in the product systems

In Figure 21 the energy consumption of the product systems are presented divided into the life cycle phases (see Appendix 8 for the data). The energy recovered from waste is here assumed to compensate for energy produced with the average Finnish electricity and heat production. The paper mill phase dominates the energy consumption. The printing and paper mill phases consume over 90% of the total energy consumption. The contribution of the forestry and transportation phases is quite small. The waste recovery and treatment phase is insignificant. The total energy consumption is higher in Cases 2b and 3b than in Cases 1, 2a and 3a.

This is caused by the increased use of virgin wood materials at the paper mill, as the material recovery rate for the separately collected newspaper is lower than in Cases 1, 2a and 3a. The TMP process consumes more electricity and thus the paper mill has to purchase more electricity in order to fill the electricity need. This causes a higher total energy consumption. The TMP process, however, generates heat recovery steam, which decreases the need of steam from the power plant of the paper mill. Because Cases 2b and 3b produce more energy from wastes, the avoided fuel consumption is also higher. Hence, the net consumption in Cases 2b and 3b is lower than in Cases 1, 2a and 3a.

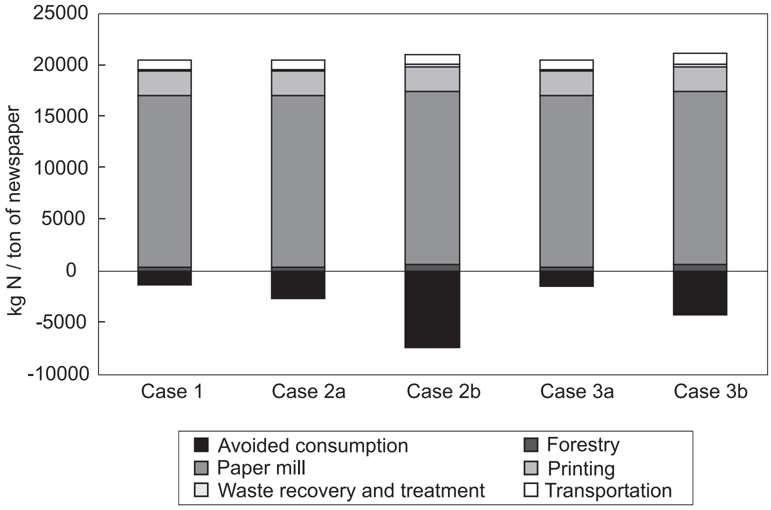

Figure 21. Energy consumption in the product systems divided according to the life cycle phases. The avoided consumption is based on the Finnish average heat generation (the year 2000) and the Finnish average electricity generation including the net imports (the years 2000-2002). The recovery rate of newspaper is 76%.

5.2.5 Production of wastes in the product systems

The majority of the wastes produced within the product systems are recovered within the systems, thus they were not reported as wastes in the LCI. Over 50% of the wastes reported in the LCI are recovered somewhere outside the product systems (Appendix 9). These wastes are mostly unqualified newsprint from the printing facility. Their recycling processes were not included in the systems because their amounts are constant in all the cases.

The small differences in the figures for the production of wastes in the five cases are due to the differences in the amounts of ashes and the amount of de-inking reject produced. The amount of ashes is dominated by the paper mill power plant, where less ashes is produced in Cases 2b and 3b compared with Cases 2a and 3a respectively (Appendix 9).

5.2.6 Comparison of the life cycle phases based on the inventory results

The life cycle phase causing the most environmental interventions was the paper mill (for example, CO_2 and SO_2 in Fig. 16), which was mainly due to the high energy consumption at the mill. The landfilling of mixed waste increased the emissions into water in Case 1, otherwise the emissions into water were dominated by the paper mill phase. The waste treatment phase contributed most clearly to the total amounts of atmospheric CH_4, NO_x , SO_2 and N_2O emissions. The largest CH_4

emissions were generated by anaerobic digestion in the landfill. The incineration and gasification processes, however, caused most of the SO_2 emissions. Incineration accounted for a major part of the N_2O and NO_x emissions, too. Additionally, the processing of separately collected paper and the manufacturing of lime for the gasification process increased the amount of the NO_x emissions in the waste treatment phase.

The waste management systems were modelled using the regional characteristics of the HMA, where the transportation distances are somewhat shorter than in the less densely populated parts of Finland. The transportations connected to the waste management stage (i.e., the collection and transportation of the separately collected newspapers and the newspapers in mixed waste) only accounted for 0 - 3% of the total emissions for various components. Longer transportation distances and especially the use of passenger cars for transportation might influence the results, as has been reported by Finnveden et al. (2000).

5.2.7 Comparison of the product systems based on the inventory results

There are many factors influencing the relative performance of the five cases, and thus it is not possible to place them in a clear rank order. The avoided emissions have a major influence on the net emissions of the cases. Two different kinds of data on the avoided emissions were applied: the Finnish average energy production and the coal-based CHP plant. They gave slightly different results.

When the Finnish average energy production was applied, the avoided consumption was higher compared with the coal-based CHP plant. In order to produce the same amount of energy, the Finnish average energy production needs more fuels and a different fuel mixture than the coal-based CHP plant. Due to the use of coal in the CHP plant, it causes more avoided emissions than the Finnish average energy production. This is especially the case for the electricity. The nuclear and hydro power decrease the emissions of the Finnish average electricity generation.

The amount of the avoided emissions in the different cases depends on the emission data used, but also on the ratio between heat and electricity generation in the considered treatment alternative. In Cases 2a and 2b, the co-combustion of the gasification gas was assumed to produce 30% electricity and 70% heat. In Cases 3a and 3b, the incineration was assumed to produce 3.5% electricity and 96.5% heat.

When the energy consumption of the cases is considered, Case 2b has the lowest net consumption (Fig. 21). However, the difference between Cases 2b and 3b is quite small, when the avoided consumption is based on the Finnish average energy production. When the avoided consumption is based on the coal-powered CHP plant, Case 2b has clearly the lowest net consumption.

When the emissions to air from the product systems with the avoided emissions based on the Finnish average energy production are examined, Cases 2b and 3b have the lowest net emissions (Fig. 22). The methane, fossil carbon dioxide and sulphur dioxide net emissions are lowest in Case 3b. The nitrogen oxide net emissions are lowest in Case 2b. The differences are, however, very small. Case 1 seems to be the worst option. When the avoided emissions are based on the coal-powered CHP plant, the lowest methane net emissions are in Cases 2a and 3a, due to the fact that the emission data for this option did not include methane. Case 2b has the lowest net emissions of fossil carbon dioxide and nitrogen oxide and Case 3b the lowest net emissions of sulphur dioxide. The energy recovery of the landfill gas does not change the situation because the avoided emissions of Case 1 do not exceed any other avoided emissions (Fig. 22).

A sensitivity analysis was carried out for the incineration facility, where the data from the Orware model on the Högdalen incineration plant and the data from the Ecoinvent database for a generic Swiss incineration plant were compared. The comparison based on the inventory results are shown in Figure 23. The Swiss facility produces electricity and heat and has a much lower total energy efficiency than the Högdalen facility. This is reflected in lower avoided emissions and hence in higher net emissions to air from the Swiss facility (Fig. 23).

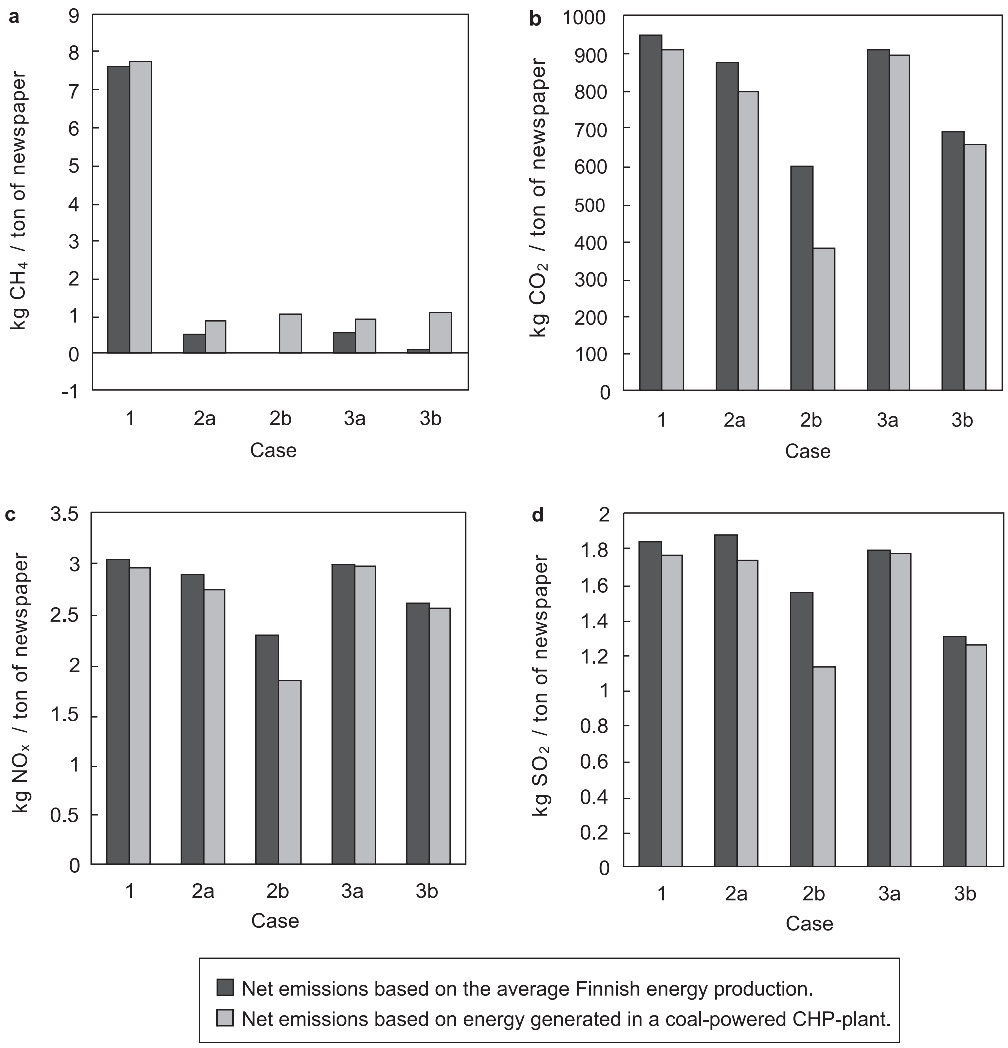

Figure 22. Net emissions of a) methane (CH_4), b) carbon dioxide (CO_2), c) nitrogen oxide (NO_x) and d) sulphur dioxide (SO_2) to air from the waste management options. The data for modelling the emissions avoided by energy recovery of waste has been varied.

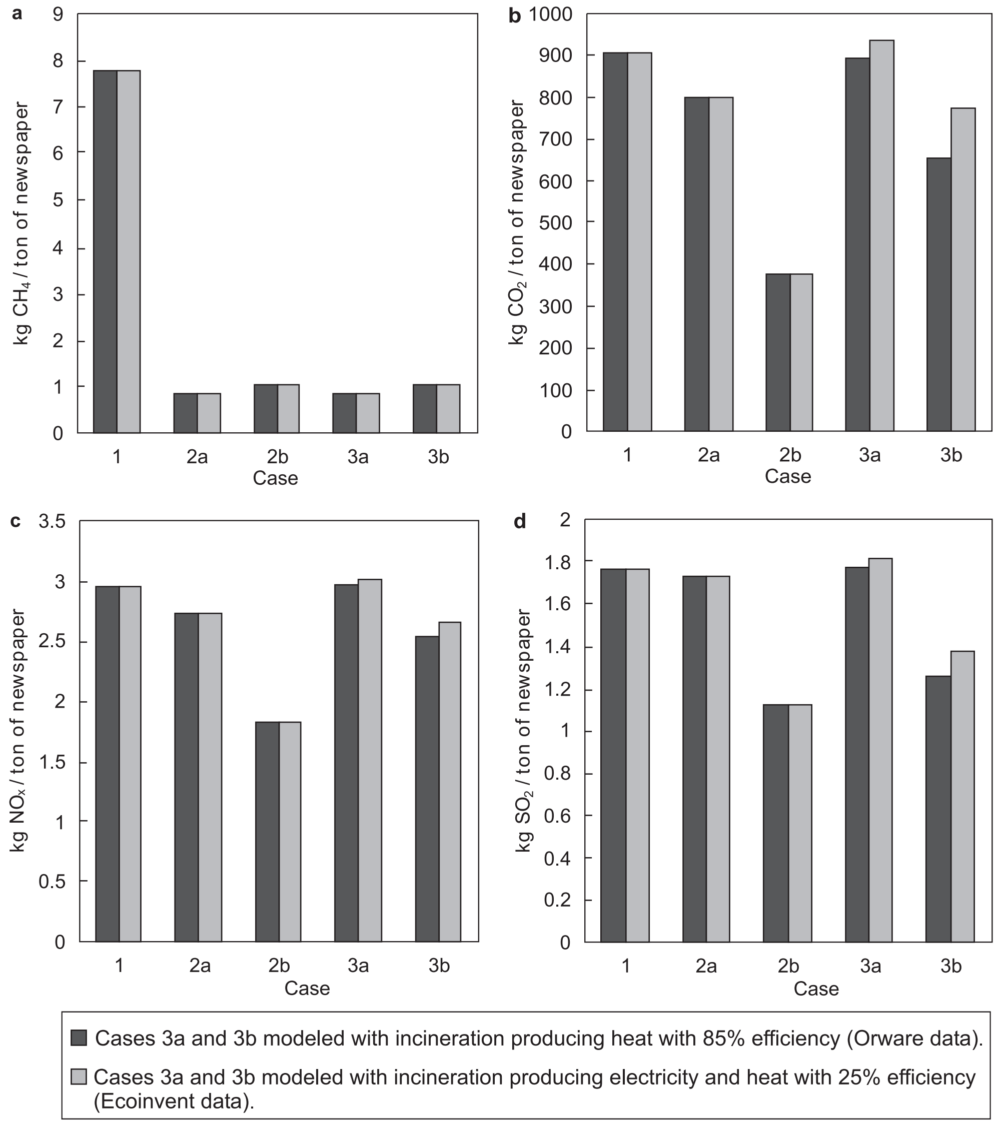

Figure 23. Net emissions of a) methane (CH_4), b) carbon dioxide (CO_2), c) nitrogen oxide (NO_x) and d) sulphur dioxide (SO_2) to air from the waste management options. The data for modeling cases 3a and 3b has been varied. Avoided emissions only calculated with energy generated in a coal-powered CHP-plant.

5.3 Results of the life cycle impact assessment

5.3.1 The life cycle environmental impact assessment results

For the life cycle impact assessment, the incineration facility in Cases 3a and 3b was modelled using the Ecoinvent data for an average Swiss incineration facility producing mainly electricity. A sensitivity analysis was, however, made, where both the two incineration facilities were compared (Chapter 5.4.2). For all cases, avoided impacts were assessed using the data for the coal-powered CHP plant.

The overall results obtained by the three LCIA methods (DAIA, Eco-indicator 99 and EPS 2000) can be given as divided into the impact categories included in the assessments (Tables 12, 13 and 14). The results thus obtained can be interpreted in two ways. First, the scores for each impact category give the same information as scores given by characterisation and normalisation. Thus the ranking of the five newspaper waste recovery and treatment cases can be obtained for each impact category individually. Second, the relative importance of the different impact categories in the three models can be analysed, since weights are included in the scores.

The impact scores given by the DAIA model (Table 12) show that for all the five impact categories included, the lowest environmental impact is given by Case 2b, when the avoided impacts are taken into consideration. The impact categories climate change and acidification reflect directly the production and consumption of energy in the product systems. The impact category oxygen depletion includes emissions into the water, which in the studied systems mainly originate from the paper mill (except for Case 1, where some emissions to water also originate from landfilling). Thus the differences in the scores for oxygen depletion only reflect the changes in the raw material composition for newsprint manufacturing. Aquatic eutrophication includes emissions to water as well as emissions to air, of which the latter reflect the production and consumption of energy in the product systems. Tropospheric ozone formation consists of emissions originating mainly from producing electricity for the grid. In the overall results obtained by DAIA the dominating impact categories are climate change, acidification and aquatic eutrophication. Hence, due to energy recovered from SRF with high efficiency and the impacts avoided by compensating coal-powered energy production with this, the alternative with gasification of newspaper in SRF (Case 2b) performs better than the other alternatives.

The ecopoints given by Eco-indicator 99 for the nine impact categories included in the assessment show that in most of the categories the lowest impact is given by Case 2b, when the avoided impacts are included in the assessment (Table 13). For the impact categories respiratory effects on humans caused by organic substances, damage to ecosystem quality caused by ecotoxic emissions and damage to ecosystem quality caused by land occupation and land conversion, the lowest ecopoints are given by Case 2a (and in the last mentioned also by Cases 1 and 3a). But when comparing the levels of ecopoints in the different impact categories, one can notice, that the three categories where Case 2b did not get the lowest ecopoints, are of minor importance for the overall results. It must be noticed, however, that in the assessment of land use impacts, only land use for forestry was included, and there were uncertainties about the number of square metres actually affected by acquisition of fibre wood for newsprint manufacturing. The three dominating impact categories in the overall results are damage to resources caused by extraction of fossil fuels, respiratory effects on humans caused by inorganic substances and damages to human health caused by climate change. These all reflect the production and consumption of energy in the product system. Hence the result is the same as given by DAIA.

The ELUs given by EPS 2000 show more heterogeneity in ranking the cases than DAIA and Eco-indicator 99. Of the fourteen impact categories included in the assessment, Case 2b has the lowest ELUs from seven, when the avoided impacts are included in the assessment (Table 14). Case 1 gets the lowest and Case 2b the highest ELUs in wood growth capacity and fish and meat production capacity, for which EPS 2000 assumes positive effects from, e.g., different forms of nitrogen emissions into air (for wood), and into water (for fish and meat). Case 2b gets the highest ELUs also in the depletion of natural gas reserves and second highest in depletion of elemental or mineral reserves. Differences between the cases in the last mentioned impact category reflect solely the use of nuclear power (i.e., uranium) for producing the electricity for the Finnish grid. Depletion of natural gas reserves also reflects the changes in the consumption of the electricity from the Finnish grid. The high ELUs for Cases 2b and 3b in these impact categories thus result from the increased demand for electricity from the Finnish grid which is a consequence of increased use of virgin fibres for newsprint manufacturing. The

ELUs for the impact category species extinction are also highest for Cases 2b and 3b, due to the impacts from landuse for forestry (assessed through the volume of wood used, which is higher in Cases 2b and 3b than in 2a and 3b respectively). The dominating impact categories in the overall results are life expectancy, severe morbidity, depletion of natural gas reserves and depletion of elemental or mineral reserves. The two first named include impacts from all the major air emission components, such as CO_2, SO_2, NO_x, CH_4, NH_3, N_2O and CO. Most of these emissions originate primarily from energy production, hence also the overall results of EPS 2000 are in favour of Case 2b if avoided impacts are included. The result is not as evident as from the other two methods. But if avoided impacts are not included the overall result is changed.

It can be summarised from the above that the results of this study indicate better environmental performance for energy recovery of newspaper with a co-combustion option compared with recycling of newspaper (Case 2b compared to Case 2a) or compared with incineration (Case 2a compared to 3a) in most of the impact categories included the LCIA methods used (Tables 12, 13 and 14 and Figure 24) if energy from waste can compensate for energy generated with coal. In most of the impact categories in the three models, the worst position is given to either landfilling (Case 1) or incineration (Case 3a or 3b). Hence, energy recovery by incineration is not a preferable option. If, however, the energy from waste does not substitute any other form of energy production or if it compensates energy from biofuels, the best alternative can not be assessed unambiguously.

Table 12. The impact assessment results by DAIA divided to impact values for each impact category.

Impact category	Impact value / one ton of newspaper (Avoided impacts included)					Impact value / one ton of newspaper (Avoided impacts not included)				
	Case 1	Case 2a	Case 2b	Case 3a	Case 3b	Case 1	Case 2a	Case 2b	Case 3a	Case 3b
Climate change	3.4259	2.5081	1.2595	3.0255	2.5413	3.7658	3.2785	3.2482	3.2832	3.2757
Acidification	1.6702	1.6155	1.0597	1.7168	1.3558	1.8321	1.9479	2.0073	1.8396	1.7058
Aquatic eutrophication	1.3597	1.2634	0.8742	1.3847	1.2295	1.4635	1.4370	1.3614	1.4512	1.4114
Oxygen depletion	0.1038	0.0546	0.0629	0.0546	0.0608	0.1038	0.0644	0.0608	0.0644	0.0608
Tropospheric ozone formation	0.7293	0.6715	0.4754	0.7368	0.6667	0.7577	0.7463	0.7117	0.7702	0.7408

Table 13. The impact assessment results by Eco-indicator 99 divided to ecopoints for each impact category.

Impact category	**Ecopoints / one ton of newspaper (Avoided impacts included)**					**Ecopoints / one ton of newspaper (Avoided impacts not included)**				
	Case 1	**Case 2a**	**Case 2b**	**Case 3a**	**Case 3b**	**Case 1**	**Case 2a**	**Case 2b**	**Case 3a**	**Case 3b**
Carcinogenic effects on humans	8.1204	0.0605	0.0579	0.0618	0.0618	8.1220	0.0632	0.0645	0.0632	0.0646
Respiratory effects on humans caused by organic substances	0.0089	0.0066	0.0086	0.0066	0.0087	0.0089	0.0066	0.0087	0.0066	0.0087
Respiratory effects on humans caused by inorganic substances	10.944	10.661	7.3393	11.238	9.0666	11.975	12.741	13.268	12.015	11.283
Damages to human health caused by climate change	5.8671	4.4758	2.1766	5.2505	4.4098	6.4580	5.6888	5.6347	5.6985	5.6869
Damage to ecosystem quality caused by ecotoxic emissions	1.4063	1.3492	1.7147	1.3667	1.7644	1.4219	1.3812	1.8058	1.3784	1.7981
Damage to ecosystem quality caused by the combined effect of acidification and eutrophication	1.4668	1.3646	0.9114	1.4971	1.2994	1.5678	1.5719	1.5023	1.5737	1.5177
Damage to ecosystem quality caused by land occupation and land conversion	0.8408	0.8408	1.3900	0.8408	1.3900	0.8408	0.8408	1.3900	0.8408	1.3900
Damage to resources caused by extraction of minerals	0.1517	0.1517	0.1517	0.1517	0.1517	0.1517	0.1517	0.1517	0.1517	0.1517
Damage to resources caused by extraction of fossil fuels	15.302	14.795	14.216	15.456	16.394	15.867	15.952	17.515	15.884	17.614

Table 14. The impact assessment results by EPS 2000 divided to ELUs for each impact category.

Impact category	ELUs / one ton of newspaper (Avoided impacts included)					ELUs / one ton of newspaper (Avoided impacts not included)				
	Case 1	Case 2a	Case 2b	Case 3a	Case 3b	Case 1	Case 2a	Case 2b	Case 3a	Case 3b
Life expectancy	107.24	91.296	54.152	99.272	77.585	119.60	116.19	125.06	108.59	104.12
Severe morbidity	37.212	27.384	13.158	32.298	27.317	40.846	34.847	34.431	35.054	35.172
Morbidity	7.5962	5.7652	2.9043	6.7092	5.6272	8.3428	7.2968	7.2702	7.2751	7.2405
Severe nuisance	0.1253	0.1218	0.1511	0.1290	0.1723	0.1294	0.1302	0.1750	0.1321	0.1811
Nuisance	1.9875	1.9337	1.2918	2.0464	1.6244	2.0266	2.1300	2.1663	2.0377	1.9128
Crop growth capacity	0.4723	0.3814	0.2403	0.4288	0.3785	0.5047	0.4479	0.4299	0.4534	0.4485
Wood growth capacity	-1.8322	-1.5991	-0.8179	-1.8550	-1.5566	-2.0273	-1.9994	-1.9582	-2.0029	-1.9779
Fish and meat production capacity	-0.1587	-0.1358	-0.1033	-0.1459	-0.1330	-0.1652	-0.1491	-0.1412	-0.1508	-0.1470
Soil acidification	0.0600	0.0570	0.0376	0.0616	0.0511	0.0651	0.0675	0.0676	0.06552	0.0622
Depletion of oil reserves	15.669	15.692	11.821	15.600	11.755	15.680	15.713	11.881	15.609	11.778
Depletion of coal reserves	2.6893	0.4877	-5.837	3.2321	2.0966	4.8218	4.8671	6.6470	4.8490	6.7058
Depletion of natural gas reserves	48.716	48.116	63.389	49.230	67.703	49.668	50.057	68.924	49.951	69.757
Depletion of elemental or mineral reserves	26.473	26.546	35.540	26.608	36.246	26.476	26.551	35.557	26.610	36.252
Species extinction	10.448	10.057	15.329	10.254	15.898	10.591	10.353	16.174	10.363	16.210

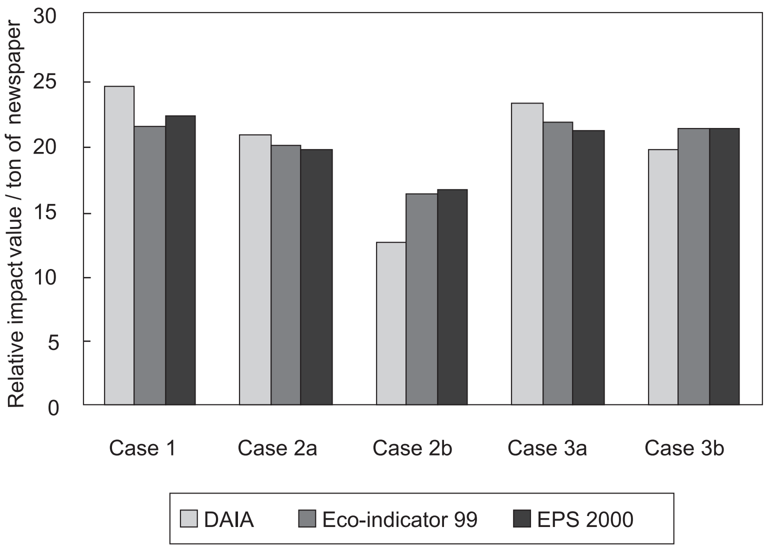

Figure 24. Comparison of the overall LCIA results given by the three impact assessment methods. Incineration facility modelled in Cases 3a and 3b as generating mainly electricity. Credits from the energy recovery of waste are assessed from a coal-powered CHP-plant. The total impact values of the alternatives calculated by each method is converted to 100 points in order to compare the results.

5.3.2 Impacts poorly covered by the LCIA models

The product systems considered in the study use both spruce fibre wood and sawmill chips as raw material for producing the TMP for newsprint. The commercial use of wood has impacts on the forest via the forestry operations, such as thinning, felling and regeneration (sometimes also fertilisation) of the forest. The emissions caused by the machinery used for the operations were included in the inventory and thus the impacts produced hereof were included in the impact assessment performed with the models.

The ecological impacts of recycling are, however, strongly related to its impacts on forest biodiversity. In the LCIA methods used in this study, the land use aspects were not included in a satisfactory manner. Both in the Eco-indicator 99 and in the EPS 2000 the land use impacts are considered to some extent. In the Eco-indicator 99, the area occupied by forestry was recorded and with the default factors given in the model, the impacts on the vascular plants (used as indicator species) were assessed. The factors have been derived from Swiss studies. Currently there is not, however, enough research to show that using a single indicator (be it vascular plants or something else) is capable of capturing all essential elements of biodiversity. Whether to use one indicator or a basket of indicators is an issue under scientific debate. In the EPS 2000, the volume of spruce used for making one ton of newspaper was recorded and hereby the impact on species extinction was assessed. The factors have been derived from estimates on how much the forestry in Finland and Sweden are responsible for the threat to species extinction. It has been assumed that the threat is the same as the contribution to extinction (Steen 1999b).

The modelling of biodiversity impacts in the Eco-indicator 99 and EPS 2000 models were not considered satisfactory. Thus other methods for assessing these impacts were studied. In a German study (Giegrich and Sturm 1999) several indicators were developed for producing a classification of the German (and Nordic) forests reflecting their closeness to the natural state of forests. The COST Action E9 “Life cycle assessment of forestry and forests products” working group 2 “Land use” reported a basket of indicators suitable for assessing the land use impacts of forestry and forest products (Schweinle 2002). None of these indicators is sufficient to be used alone, but it is not either clear, whether all of them need to be used simultaneously in order to draw conclusions on the biodiversity impacts in an LCA. This implies that the assessment of land use impacts in the LCA will also be an evolving area. The biodiversity impacts of forestry are, of course, a fundamental question when considering the management of discarded newspaper.

In the LCA-WASTE-study no specific indicators were taken into consideration in addition to the ones included in the LCIA models. Instead, the size of the forest area that would be saved by increased recycling was estimated. There were several aspects to consider when calculating the area affected by newsprint making and thus saved by increased recycling. The assumptions and data used for the calculations are given in Appendix 12. On the basis of the calculations it was estimated that if all newspaper consumed in the HMA (73 615 t/a) was produced of virgin fibre, an extra 800 hectares of forest (compared with the current situation) would be needed yearly to produce the fibre needed. The impact assessment of this would, however, need more data on, e.g., where the extra hectares would be situated and what type of forest (old, young, etc.) would be concerned. These aspects are primarily dependent on the future fibre and wood markets, which were not examined in the LCA-WASTE study. The assessment was thus not performed further in the study.

Toxicity of biocides

Biocides are used at the paper mill circulating water system to prevent slime build-up and clogging and also to protect the pulp and the filling- and coating material sludge from contaminations caused by microbes. These slimicides are used in rather small amounts, but due to their purpose of use they are biologically very active. They can be compared to pesticides used in the agriculture, which often produce even decomposing- and reaction products harmful to the environment (Jouttijärvi 1997).

The impacts of these chemicals could not be included in the LCIA, because there were no data available on the decomposition products and their concentrations in the paper mill waste water.

5.4 Results of the sensitivity analyses

5.4.1 Effects of the collection rate of newspaper on the emissions of the product systems

In addition to the current situation (76% collection rate), the product systems were modelled for 0%, 45%, 82% and 97% (maximum possible in practice) collection rates of newspaper in order to analyse the impacts of the collection rate on the environmental interventions of the waste management options. In Cases 1, 2a and 3a, the collection rate was identical to the rate of material recycling of newspaper in the product system, whereas in Cases 2b and 3b the material recycling rate was 50% of the collection rate. Figure 25 presents the modelling results for the CH_4, CO_2, NO_x and SO_2 emissions. Generally, when the collection rate increased, the emissions of the waste management option increased, except for Case 1. In Case 1, the trend of the emissions was downward as the collection rate increased, except for SO_2 emission, which rose with the increasing collection rate. This was a consequence of the increasing use of sulphur-containing fuels at the power plant of the paper mill and the increasing sea transportations of bentonite needed in the de-inking process.

With the 0% collection rate, all the discarded newspapers ended up in the mixed waste and were thus either landfilled, co-combusted or incinerated. Hence the emissions avoided by energy recovery were at their maximum. With the growing collection rate, the emissions of the cases including energy recovery grew because the avoided emissions decreased.

The credits for energy recovery can be seen in the diagrams of Cases 2a and 2b, and likewise 3a and 3b, for all four emission components. The gaps between the curves of Cases 2a and 2b and Cases 3a and 3b were caused by the emissions avoided by energy recovered from separately collected newspapers, and they grew with higher collection rates. The curves of Cases 1, 2a and 3a converge when approaching the maximum collection rate, 97%, thus indicating that the differences between the cases were caused by the differences in the treatment of the mixed waste.

The changes in the emissions were mainly linear in relation to the changes in the collection rate (Fig. 25). The only exception can be seen in the NO_x emissions, in which there was a non-linear increase caused by waste transportations as the collection rate increased from the current situation to 82%. This increase in the collection rate was obtained by lowering the current on-site obligation limit for residential properties from five apartments to one, which would mean that every single-family house in the area had its own container for discarded paper. This adjustment resulted in a major increase in the number of residential properties joining the separate collection system and thus a major increase in the number of kilometres driven for the collection of the extra newspaper tons.

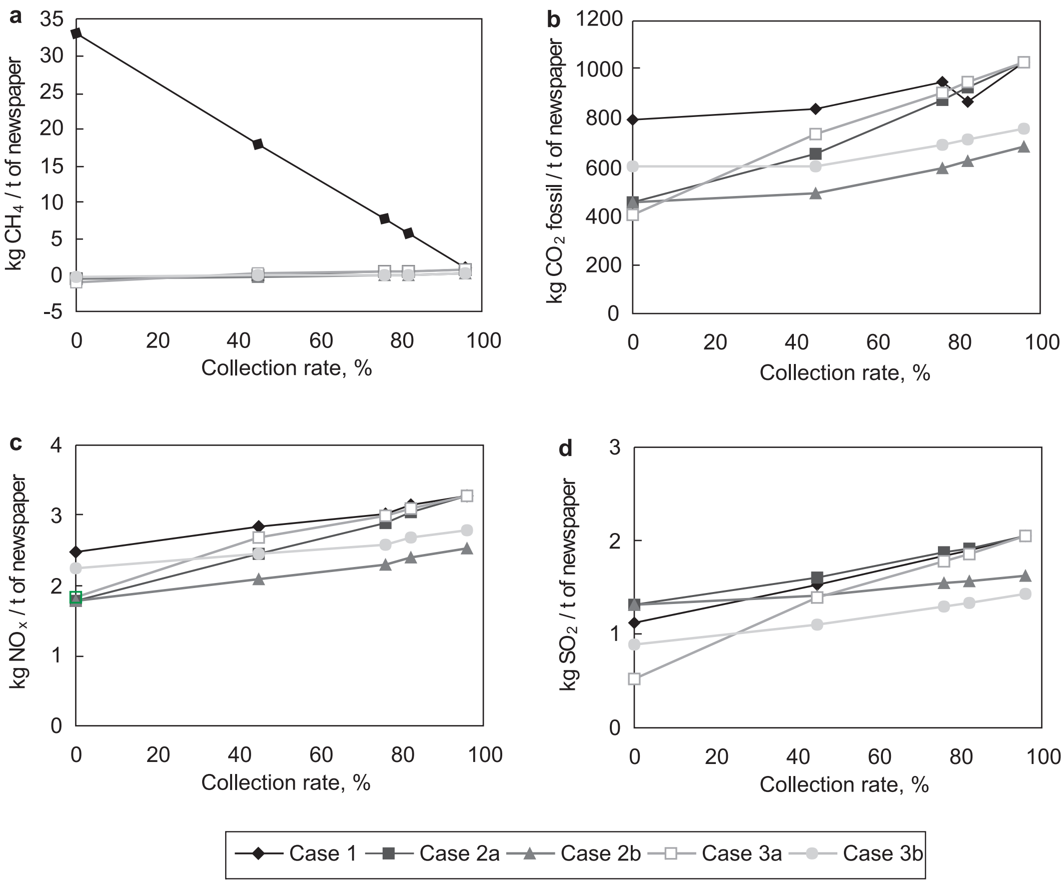

Figure 25. Net emissions of a) CH_4 b) CO_2 c) NO_x and d) SO_2 to air from the various product systems with various newspaper collection rates. The avoided emissions have been calculated with the average Finnish electricity and heat production.

5.4.2 Influence of the energy system studied

In the following the results of the sensitivity analyses performed for the incineration option and for the different ways of calculating the credits gained by energy recovery of wastes are presented.

In the sensitivity analysis of this study two types of incineration facilities were modelled: one producing mainly heat and one producing mainly electricity. Comparison of the different concepts for incineration shows that, environmentally, the best performance for the incineration option is received when incineration generates heat and the heat is utilised either for municipal or industrial purposes (Fig. 26a-c). The concept in which incineration produces primarily electricity and this electricity substitutes coal-based electricity from a CHP plant, produces only slightly higher impact values than the concept with heat generation. This is due to the lower emissions to air from this incinerator. Environmentally the worst concept is, of course, incineration producing heat which is not utilised at all.

The inclusion of the avoided impacts in the calculations has considerable effects on the results, as has been concluded also by e.g., Ljunggren Söderman (2003). The impact values for all cases are at the highest when no credits are given for energy recovery, or when biofuels are replaced with waste (Fig. 26a-c). The results obtained with DAIA show almost no differences between the four cases including energy recovery options (2a, 2b, 3a, 3b) when avoided impacts are not included (Fig. 26a). Both Eco-indicator 99 and EPS 2000 give clearly higher impacts to Cases 2b and 3b where separately collected paper is combusted if no avoided impacts are included (Fig. 26b and 26c). When avoided impacts are taken into consideration, the lowest impact values are given to Case 2b by all three LCIA methods (Fig. 26a-c).

5.4.3 Influence of the longer transport distances

For the extreme case where 0% newspaper was assumed to be recycled into paper manufacturing, the fibre wood was assumed to be acquired from Russia and transported to Kaipola Mill (Table 2). The major changes were that the use of full trailer timber lorries was reduced by 25% and compensated by electric train. Also a long distance of transport for the fibre wood by electric train was added to the basic transportations. These changes had, however, no major impacts on the emissions from the transportation phase. Only the emissions of SO_2 became slightly higher. The use of electricity was increased due to the use of electric train, but the production of electricity for the grid produces less emissions than the full trailer timber lorry. So the changes overrode each others impacts.

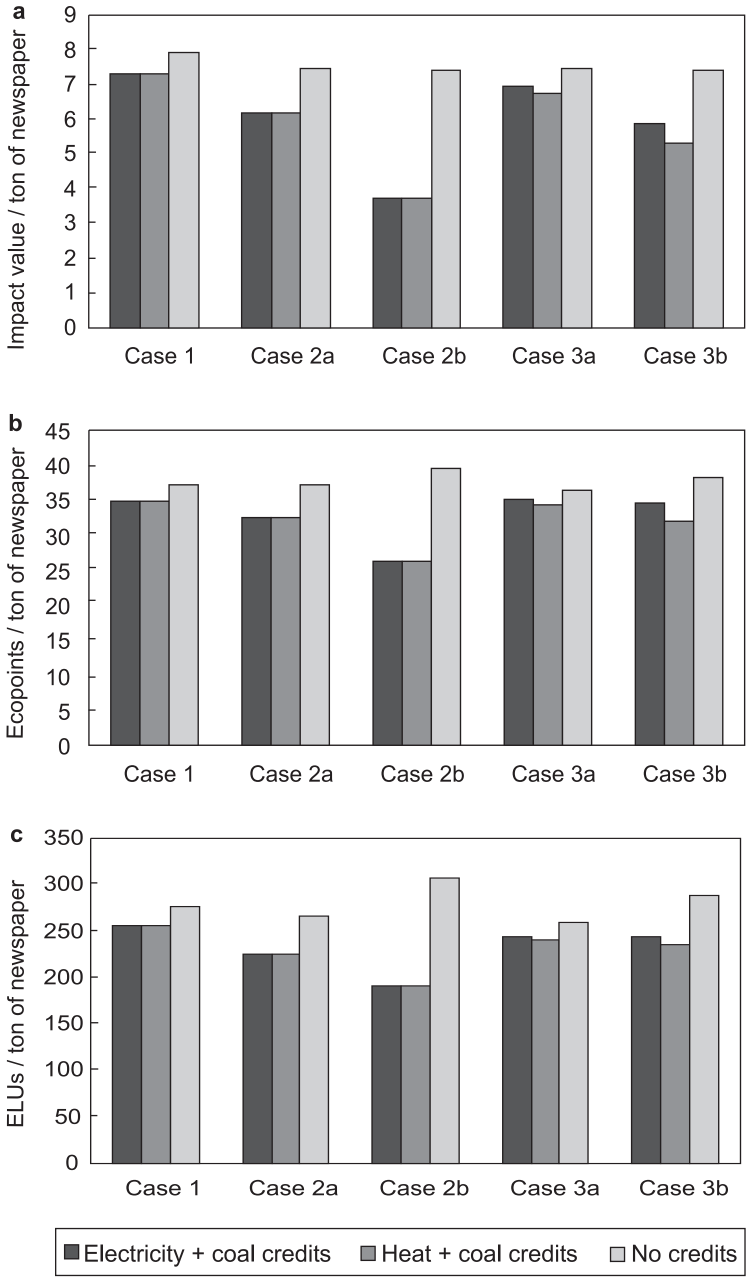

Figure 26. Comparison of different concepts for incineration and calculations of credits. Electricity + coal credits = incineration producing mainly electricity (data from the Ecoinvent data v1.1), credits assessed from coal-powered CHP-plant. Heat + coal credits = incineration producing mainly heat (data from Björklund 1998) credits assessed from coal-powered CHP-plant. Heat + no credits = incineration producing mainly heat (data from Björklund 1998), no credits given. The energy recovery concepts in Cases 2a and 2b were kept unchanged. The impacts assessed with a) DAIA, b) Eco-indicator 99, and c) EPS 2000. The recovery rate of newspaper is 76%.

5.5 Discussion on the results

When comparing the results of the LCA-WASTE study with other studies it is important to note that every LCA is unique. The comparability of the results depends on the product studied, product system, system boundaries, functional unit and local characteristics. Especially the system boundaries differ between studies. In comparing the results, the significant differences in system boundaries and life cycle phases should be described in order to make the right conclusions.

Jaakko Pöyry Consulting made an LCA study on printed materials (newspapers, magazines, books and brochures) in Finland (Tarjanne 2002). The life cycle of the printed materials was divided into six phases: forestry, pulp and paper production, electricity generation, printing, transportations including delivery, final disposal and recycling. The life cycle of the printed materials was basically the same as the one considered in the present study.

Tarjanne (2002) concluded that the pulp and paper production and electricity generation were the most significant life cycle phases. Pulp and paper production consumes a lot of electricity and thus the emissions to air were mainly caused by the energy production. The same conclusion was also made in the LCA-WASTE study. The methane emissions to air from landfilling were notable in both studies. According to Tarjanne (2000) the transportations increased the NO_x emissions to air. Similarly, in the present study, the transportations caused especially NO_x emissions whereas the other atmospheric emissions were relatively small. However, in the two studies somewhat different issues were emphasised and the system boundaries were not exactly the same. Yet the main trends in the results lend support to each other.

Lopes et al. (2003) carried out an LCA study on the Portuguese pulp and paper industry. The boundaries of the study were basically similar to this work. The greatest differences concerned the local characteristics and the product studied. In Lopes et al. (2003), the final disposal was different from the waste management options investigated in the present study. The transportation data used were also different due to the local characteristics. However, Lopes et. al (2003) presented similar results to those obtained in the present study. The results of both studies showed that the energy consumption is highest in the pulp and paper production. The energy production caused most of the emissions to air. The emissions to water were mainly caused by the pulp and paper production in both studies.

In the study by Finnveden et al. (2000), different treatment methods for municipal solid waste and its fractions were compared. The functional unit was the waste produced in Sweden during one year whereas the functional unit working the present study was 1 ton of newspaper delivered to consumers. The system boundaries in Finnveden et al. (2000) excluded the production of waste, contrary to this study in which the production of newspaper was included. Finnveden et al. (2000) concluded that the superiority of a treatment method depends on the weighing of impact categories used in impact assessment. Material recovery was the most preferable option when many impact categories were considered. For the newspaper fraction, recycling was the most superior treatment method in many impact categories, but some categories favoured energy recovery. According to the both the LCI and the LCIA results of the LCA-WASTE study, the energy recovery of newspaper seems to be more preferable than recycling if the energy from waste substitutes coal-based energy.

The waste treatment methods for six materials, one of which was newspaper, were compared in the study of Baumann et al. (1993). The worst treatment option for newspaper was landfilling, due to the loss of the energy content of newspaper. Landfilling was also the least preferable option in the present study. Baumann et al. (1993) stated that depending on the circumstances, both energy and material recovery can be environmentally sound options for newspaper. This conclusion supports the results of the present study. In both studies, the relevant aspect in newspaper manufacture is the electricity generation, because the electricity consumption is high when virgin wood materials are used for newsprint manufacture.

Previous LCA studies on the recycling and disposal of paper and cardboard products have been reviewed in a project conducted under the Environment DG of the European Commission (ETC WMF 2004). In all of the studies reviewed, landfilling was considered performing environmentally worse than recycling or energy recovery. Incineration was in general found environmentally worse than recycling. Incineration was, however, apparently the only energy recovery option used in the studies. Energy recovery by co-combustion was not studied, so no comparison to our results can be made. In the review, 15 key assumptions were considered to be decisive for the outcome of comparative LCAs on paper. In the following, some of the most important assumptions discovered in the review (ETC WMF 2004) are discussed and the choices made in our study are analysed against the choices made in the studies included in the review.

The first one of the assumptions concerns the energy and material marginals for wood and the alternative uses of wood and forest land. Alternative use of the forest area which is saved by recycling, has in previous studies been raised as one of the key variables connected to wood products (e.g., Ekvall and Finnveden 2000). The alternative uses can in theory be, e.g., no commercial use or production of fuel, pulpwood or saw-logs. In addition to these alternative uses, also use for tourism can be considered as a possible, semi-commercial, alternative use for forests. In practice, however, the question is much more complicated. Forestry involves typically joint production of saw-logs and pulpwood. Thus, harvesting produces both saw-logs and pulpwood, and sometimes also wood chips for fuel production. Hence one can question what actually would be the consequences of increased paper recycling. If the demand for pulpwood decreases due to increased recycling, but the demand for saw-logs remains constant, does this lead to new unharvested forest areas or just to a decrease in forestry practices (e.g., thinning) (Dahlbo et al. 2002).

Ecological impacts of recycling are strongly related to its impacts on forest biodiversity. However, it can be stated that the modelling of impacts on biodiversity is yet poor compared to the modelling of environmental problems caused by conventional airborne emissions. In the LCIA methods used in this study, the land use aspects were not included in a satisfactory manner. Both in the Eco-indicator 99 and in the EPS 2000 the land use impacts are considered to some extent. In the Eco-indicator 99, the assessment is performed using vascular plants as indicator species. The complexity of land use impact assessment has been discussed in several international connections. The COST Action E9 "Life cycle assessment of forestry and forests products" working group 2 "Land use" reported a basket of indicators suitable for assessing the land use impacts of forestry and forest products (Schweinle 2002). None of these indicators is sufficient to be used alone, but whether all of them need to be used simultaneously in order to draw conclusions on the biodiversity impacts in an LCA, remains to be discussed.

Nevertheless, paper and pulp industry has a crucial role considering the biodiversity of the Finnish nature, since over 85% of the forest land is currently in commercial use.

The second key issue is the assumption of the electricity marginal for virgin paper production. The assumption in favour for recycling is that the changes in electricity demand due to decreased or increased virgin paper demand are reflected in changes of electricity production with fossil fuels (marginal technology) rather than hydropower. In the LCA-WASTE project the data from the UPM-Kymmene Kaipola paper mill were used for modelling both the heat and electricity demand

and partly also the generation for the paper production. The heat and steam needed in the paper manufacturing processes are generated at the power plant of the Kaipola mill, where first the combustible wastes generated at the plant (such as waste bark, de-inking sludge, sludge from waste water treatment) are used as fuels. In addition to these, fossil fuels are used, of which peat is the dominating one. The relation of biofuels to fossil fuels used at the Kaipola mill is approximately 1:0.75. The electricity used for the paper manufacturing is to a major part purchased from the Finnish electricity grid. No exact data were received for the fuel mix of this electricity, but the average Finnish electricity generation was used for the electricity purchased by the Kaipola mill. In this mix 38% of the fuels are fossil. When recycling of paper decreases, the demand for heat (primarily needed for the de-inking process) decreases, and the demand for electricity (needed primarily for the TMP process) increases (Dahlbo et al. 2005a). The increased demand of electricity was assumed to be supplied by the electricity from the grid, which is produced with less fossil fuels than the energy at the power plant of the Kaipola mill. Thus the shift in the fuel mix for producing the energy needed leads to decreasing CO_2 emissions. This fact, in turn, is in favour of combusting newspapers compared to recycling. It can be discussed, however, whether the growing demand of electricity generated by the increased energy recovery would in practice lead to growing use of coal-condensing power instead. The latter assumption would most probably influence the ranking of the waste-to-energy options and make them less environmentally preferable than currently.

The third key issue is the assumption on the substitution of electricity from incineration of paper. This issue is studied in further details in Chapter 5.4.2 of this report.

The fourth key issue mentioned is the alternative use of incineration capacity. The assumption in favour of recycling is that an increase of paper recycling releases some incineration capacity and it is assumed that this capacity is used to incinerate waste that would otherwise have been landfilled. This was not considered in the LCA-WASTE project, since the incineration concept studied is not yet in use and thus there is no fixed capacity for the concept. Furthermore, it can be argued that the co-combustion concept studied here is more flexible than incineration in that if the SRF cannot be used, it can more easily be transported and used in other similar facilities than mixed waste.

All the above mentioned choices made in our study are reflected in the results as showing the alternatives including more combustion of newspapers (Cases 2b and 3b) principally as more environmentally preferable than the alternatives including more material recovery (Cases 2a and 3a).

Conclusions

6

6.1 The inventory results

As measured by the inventory analysis results, the material and energy recovery options (Cases 2a, 2b, 3a and 3b) were superior to landfilling (Case 1) when comparing the different waste recovery and treatment options. Although the co-combustion and incineration of newspaper produced emis-sions, they were compensated by the emissions avoided in other energy production facilities. The avoided emissions have a significant impact on the net emissions of the cases. From the five cases studied, material recycling and energy recovery can be compared by comparing Case 2a to 2b and Case 3a to 3b, of which Cases 2a and 3a represent material recycling and Cases 2b and 3b represent energy recovery. Based on the emissions to air it can be stated that the energy recovery options (Cases 2b and 3b) were more favourable than the material recovery options (Cases 2a and 3a). Material and energy recovery were actually included in all the cases, but the energy recovery ratio was higher in Cases 2b and 3b than in Cases 2a and 3a respectively, and thus the avoided emissions to air were also higher. The differences between the cases applying gasification and incineration were minor. Hence, which energy recovery method is to be preferred depends strongly on the fuel mix-ture used for the compensated energy production, on the ratio of electricity and heat production in the incineration and co-combustion processes and on the assumed total energy efficiency of the modelled plants.

When comparing the different life cycle phases of newspaper, it is evident that the paper mill phase is the phase producing the most emissions and consuming the most resources mostly due to its high energy consumption. Especially, most of the emissions to air were caused by the energy production. The more virgin materials were used, the more electricity was needed for the TMP process, thus the higher the total energy consumption. On the other hand, however, the TMP process generates heat recovery steam, which decreases steam needed from the power plant of the paper mill. Also the emissions to water are greatest in the paper mill phase. On the other hand, the methane emissions of landfilling are significantly higher than the methane emissions of the other life cycle phases.

The product systems were modelled as closed-loop systems, with virgin wood compensating for the decrease in the flow of discarded newspapers to the paper mill. This would probably not be the case in practice, as the decreasing flow of discarded newspapers from the Helsinki Metropolitan Area (HMA) would more probably be compensated by discarded paper from other areas rather than by virgin wood.

The analysis of the effects of the collection rate on the emissions showed that an increase in the collection rate also led to an increase in the emissions, except in Case 1, which differed from the others by having no energy recovery. With the 0% collection rate, the credits gained through energy recovery were at their maximum. Thus the increasing emissions reflected the decrease of the cred-its. Although material recycling increased together with the collection rate, all of its benefits did not show up in the inventory results. This is due to the fact that the credits for energy recovery can more easily be modelled as emissions than the credits for material recycling. Therefore the credits for energy recovery are emphasized in the inventory results.

6.2 The life cycle impact assessment results

Most of the LCI and LCIA results of this LCA study show that landfilling of newspaper in the un-treated mixed waste is environmentally worse than its energy recovery. The three LCIA methods used gave slightly inconsistent results when considering the performance of the various energy re-covery options. Incineration performed equally badly or worse than landfilling, when looking at the results from the Eco-indicator 99 and EPS 2000. But all the LCIA methods showed that co-combustion of newspaper performed better than material recycling or incineration if solid recovered fuel (SRF) can be used to replace coal as fuel. The better performance of an energy recovery option is in contrast with other LCA studies that have compared recycling and energy recovery of paper. In most of the previous LCA studies, however, the modelled energy recovery option has been based on incineration of paper in mixed waste and not on co-combustion of paper in SRF.

There are several aspects that must be taken into account when considering the results of this study. The alternatives including energy recovery are currently not in use in the studied area. Thus, there are uncertainties in their modelling. The performance of an energy recovery option is very much dependent on the possibilities of connecting the waste-to-energy facility into the existing energy production system. Drawing on the discussion in Chapter 2.4.4, an incineration facility in the HMA would probably not act as a form of energy recovery, unless the industry could use the heat load from incineration.

The biodiversity impacts of forestry are a fundamental question when considering the management of paper waste. The overall assessment of land use is under development in the LCA methodology. In the LCIA methods used in this study, the land use aspects were not included in a satisfactory manner. Nevertheless, the paper and pulp industry has a crucial role considering the biodiversity of the Finnish nature, since over 85% of the forest land is currently in commercial use. Acknowledg-ing that the impacts of land use have not yet sufficiently been included in our study, it should be realised that the comparison of material and energy recovery of newspaper cannot yet be performed on a solid basis. The question should, however, be studied in more detail in the future.

The overall comparison of the results given by the three life cycle impact assessment methods showed surprisingly small differences between them. All the methods ranked the same case (Case 2b) as the environmentally best alternative if avoided impacts obtained by energy recovery of waste were included. Slight differences were found, however, in the ranking of the other alternatives by the different methods. One could, however, have expected the variation to be larger, since there are some essential differences in the methods and approaches they use. Among these are the following:

- the DAIA evaluates a limited selection of impacts and interventions compared with the other two methods,
- the Eco-indicator 99 and EPS 2000 use the end-point approach for assessment whereas the DAIA uses the mid-point approach, and
- the bases of normalisation and weighting are different in the three methods.

The different LCIA methods are fairly easy to use. In this case study they also pointed in the same direction giving somewhat more confidence for the interpretation of the results. The applicability of each method in different LCA-studies needs, however, to be assessed on the basis of the environ-mental interventions included in the assessment.

6.3 The applicability of the LCA-WASTE approach to other studies of waste management

The main objective of the LCA-WASTE study was to develop a commonly applicable method for assessing the ecology and costs of alternative waste management solutions. The LCA-WASTE method is described in detail in the publication of Myllymaa et al. (2005), where the assessment of both the ecology and costs is described. This LCA report, however, only concentrates on modelling the system in order to assess the environmental impacts. From the point of view of the applicability of the method presented, the following conclusions can be made.

The general frame of life cycle methodology can directly be transferred to other case studies. The advantage of LCA is that it is widely known and both its strengths and weaknesses are commonly recognised. By including the production phases into the waste management systems, a realistic picture of the importance of the individual life cycle phases on the overall impacts can be obtained. By modelling the waste transportation in detail, useful data were generated on environmental impacts and costs connected to the types and emptying frequencies of waste containers. Although the impacts and costs are assessed for one waste fraction only, the waste management system must be studied as a whole in order to find feasible solutions. All in all, the project documented a wide variety of practical issues and problems that must be solved when considering waste management and energy related solutions and the possibilities for applying them in different areas.

The project addressed a collection of calculation elements that can be chained and used for calculations needed in the respective study. Hence, the developed method describes the process and shows important aspects that should be taken into account in different phases of an LCA on waste management. Especially, the project demonstrates how to model the waste management system taking into account inputs and outputs of each unit process and how to analyse the data from the point of view of environmental impacts in order to find the best option. In the project, the data on emissions and other environmental interventions were gathered from different sources and the data were arranged according to different unit processes. The data can be utilized in other waste management systems. With the help of the data and the methodological solutions presented in the work, experts working in the environmental administration, consultancies, enterprises etc. can conduct their LCA studies easier than without examples. When applying the method to other waste fractions, the chosen waste management system should be modelled according to its technical relationships. There is also a need for collecting data on emissions and costs related to the unit processes of the specific system. This so called inventory data can then be analysed by alternative impact assessment methods in order to ensure that the conclusions are the same on the basis of different impact assessment methods.

Some aspects can be identified concerning the possibilities of generalizing the process used in the LCA-WASTE study to other case studies. In the inventory phase the method concentrates on searching and producing data related to the specific waste fraction studied. On the other hand, it is known that the system as a whole has a decisive role and therefore the whole waste management system should be studied and not one waste fraction only. Part of the data on emissions and costs related to paper are not relevant for other waste fractions and for other regions and therefore a specific inventory has to be carried out for each waste fraction separately. Carrying out a life cycle inventory is, however, a heavy, long and partially subjective process, where comprehensive and good statistics or databases can crucially ease the work. The calculation sheets of the method developed include many variables and the use of the sheets requires good knowledge on terms, concepts and circumstances of waste management.

7 Summary

Background

This report is based on the life cycle assessment (LCA) carried out in a project called "Life Cycle Approach to Sustainability of Waste Management – A Case Study on Newspaper (LCA-WASTE)". In the LCA-WASTE project, a complete life cycle assessment was performed on newspaper with special attention to the waste management solutions. The objectives of the LCA-WASTE project were, firstly, to develop a generally applicable method for assessing the effects of alternative waste management solutions and, secondly, to provide information on the impacts of different waste man-agement targets for waste policy making.

The case study used the waste management system of the Helsinki Metropolitan Area (HMA) and looks into newspaper as the product under study. Newspaper was selected on the grounds of paper being one of the largest municipal solid waste components and a material/product originating in Finland's most important renewable natural resource, forest. The newsprint studied is manufactured by the UPM-Kymmene Group Kaipola Mill in Central Finland. The main raw materials used for newsprint are thermo-mechanical pulp (TMP, processed from spruce pulpwood and chips) and de-inked pulp (DIP, processed from separately collected newspapers and magazines). The Kaipola Mill uses over 50% (180 000 tons in the year 2000) of the total amount of separately collected paper (newspapers and magazines) in Finland.

The internationally standardised life cycle assessment (LCA) was applied in the study. LCA is an environmental management tool and it is used for predicting and comparing the potential environ-mental impacts of products or services. Life cycle assessment is a systematic framework for the identification, quantification, interpretation and evaluation of the environmental interventions (emissions, resource extractions and landuse), caused by a product, service or function, and it fol-lows a "cradle-to-grave" approach. LCA consists of four phases: goal and scope definition, inven-tory analysis, impact assessment and interpretation of results.

Scope of the study

The aim of the LCA-WASTE study was to compare different waste management systems for news-paper waste, thus the functional unit of the product system, against which the interventions were calculated, was defined as one ton of newspaper delivered to consumers. The product systems con-sisted of the whole life cycle of newspaper. The systems included the main life cycle phases and sub-processes within the life cycle of newspaper, namely forestry, paper mill, newspaper printing, waste recovery and treatment, transportations and by-products (i.e., avoided emissions from energy recovery of waste) (Fig. 1). Energy generation, fuel production and chemical manufacture were taken into account in each life cycle phase whenever information was available.

Five alternatives for the newspaper waste management were formulated and analysed in the study. The alternatives included various recovery and treatment methods applicable to the newspaper in the separately collected paper fraction and to the newspaper in the mixed waste. The methods con-sidered for the separately collected paper fraction were 1) material recycling, 2) gasification and co-combustion, and 3) incineration. The methods considered for newspaper in the mixed waste were 1) landfilling, 2) mechanical-biological pre-treatment followed by gasification and co-combustion, and 3) incineration.

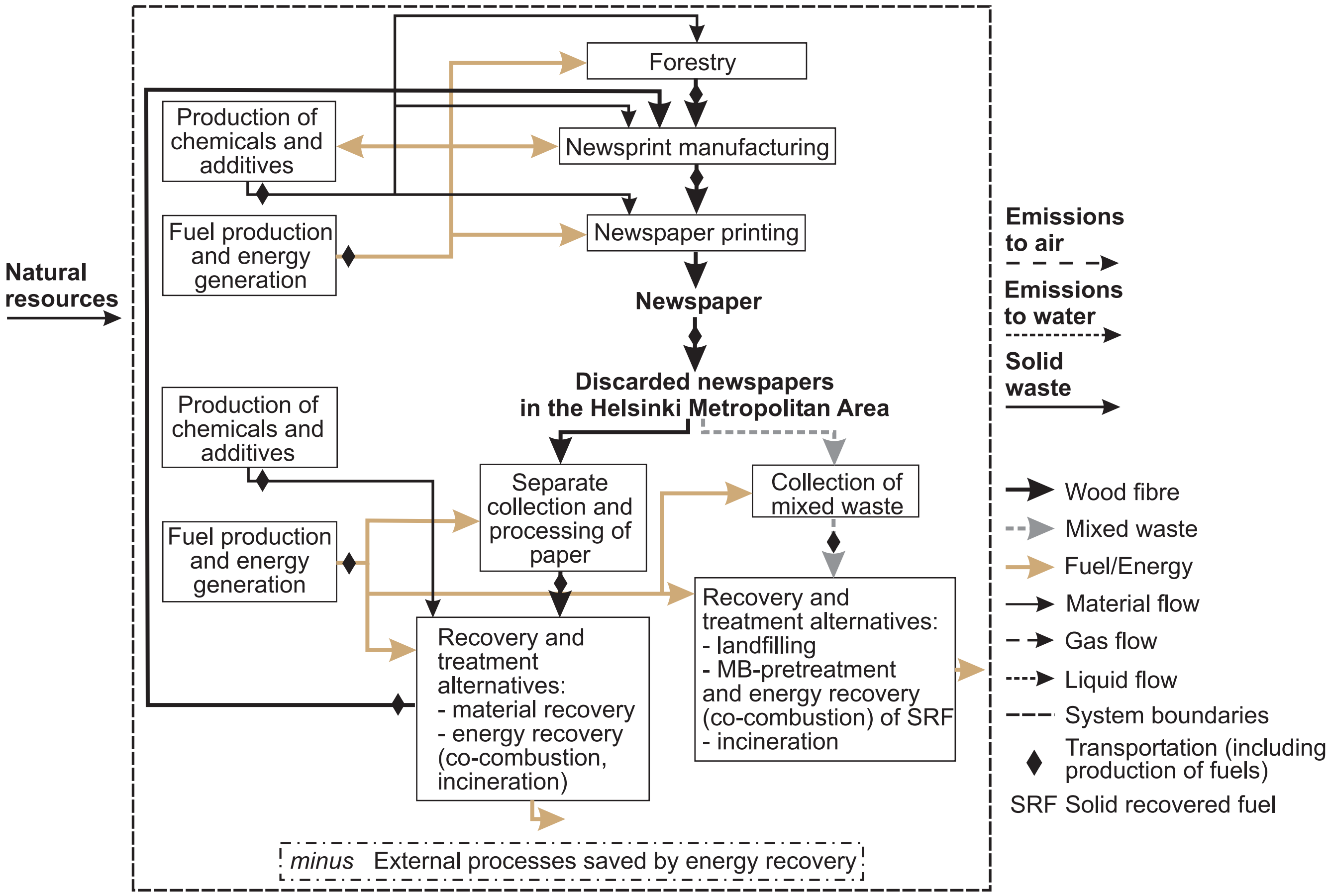

Figure 1. Boundaries of the product systems (i.e., waste recovery and treatment options) studied in the LCA-WASTE project. The functional unit of the system is one ton of newspapers delivered to consumers.

The five options for the waste management of newspaper (i.e., Cases 1, 2a, 2b, 3a and 3b) were as follows:

Case 1 describes the current system in the HMA:

Separately collected paper: material recycling into newsprint manufacturing.

Mixed waste: landfilling without pre-treatment.

Cases 2a and 2b are based on the plans to set up new treatment facilities in the HMA by 2010:

a) Separately collected paper: material recycling.
Mixed waste: gasification and co-combustion of SRF (solid recovered fuel, containing newspaper and various other materials) sorted from the mixed waste by mechanical-biological (MB) pre-treatment. The co-combustion concept here consists of gasification of SRF, purification of the product gas and co-combustion of the purified gas with pulverised coal and natural gas in a combined heat and power (CHP) plant.

b) Identical to Case 2a except that 50% of the separately collected newspapers are gasified and co-combusted.

Cases 3a and 3b are, for the present, theoretical in Finland:

a) Separately collected paper: material recycling.
Mixed waste: incineration with energy recovery. Incineration is considered as burning mixed waste in a plant built especially for waste treatment.

b) Identical to Case 3a except that 50% of the separately collected newspapers are incinerated.

The life cycle inventory phase

The data needed for the inventory were collected from companies and organisations, literature and different databases. The data on paper processing were obtained from Paperinkeräys Oy and the data on newsprint manufacture were provided by the UPM-Kymmene Group. The data on different waste management cases was gathered mainly from reports produced by or for the YTV Waste Management and the Vantaa Energy.

The following databases were used as data sources: KCL EcoData maintained by the Finnish Pulp and Paper Research Institute (KCL), Lipasto maintained by VTT (Technical Research Centre of Finland) and IISI database (International Iron and Steel Institute). In addition, the Hertta and Vahti Environmental Data Management Systems maintained by the Finnish Environment Institute were used.

The average Finnish electricity and heat generation (in the grid) were used as electricity and heat supply for the whole product systems. The paper mill makes an exception, since here the power plant of the mill produced a significant share of the energy needed. The additional energy needed and purchased was, however, assumed to be from the grid.

Several assumptions were made during the inventory phase regarding each life cycle phase. The most important assumptions were as follows:

The paper mill phase

- In cases 2b and 3b, 50% of the separately collected and processed newspapers were either co-combusted (Case 2b) or incinerated (Case 3b). This was assumed to decrease the use of de-inked pulp and increase the use of virgin fibre-based thermo-mechanical pulp in newsprint manufacturing.

The waste recovery and treatment phase

- Material recycling of newspaper was assumed to take place in a closed loop. In other words, all newspapers collected separately for material recycling in the HMA were returned to the Kaipola Mill for de-inking and recovery in the newsprint manufacturing.
- Of the newspapers delivered to consumers, 76% were assumed to enter separate collection in the current situation, and 21% to enter the mixed waste stream. The remaining 3% were assumed to end up in small-scale recycling (e.g., as kindlings, biowaste bags or wrappings), which was excluded from the product systems due to its minor relevance.
- An infinite time period was considered for newspaper landfilling, i.e., all the materials included in newspaper were assumed to leak into the environment as emissions into air or water. However, for emissions of nitrogen and for BOD and COD, the reduction rate of the purification process at the waste water treatment plant was taken into account. The treatment of sludge from leachate purification was not modelled.
- The efficiency of the MB pre-treatment plant in separating newspaper from mixed waste into the SRF fraction was assumed to be 100%.

The transportation phases

- The emissions from transportations also included the emissions arising from the fuel pro-duction. Data on the emissions from transportations were mainly calculated using the VTT database Lipasto.

The whole product system

- In modelling the environmental interventions of electricity production, the fuel mix used for the average Finnish electricity generation and for imported electricity during 2000-2002 was used. The emissions arising from the fuel production were included.
- For heat production, the fuel mix used for the average district heat production in Finland in 2000 was used. The emissions arising from the fuel production were included.

Gasification and co-combustion of SRF and incineration of mixed waste produced energy that substituted for other energy production. The fuel used for the substituted energy determines the avoided emissions derived by energy recovery of waste. In this study, two ways of assessing the emissions avoided by energy recovered from wastes were studied, namely using the fuel mixture 1) used for the average Finnish electricity and heat production, and 2) that used in a local pulverised coal power combined heat and power (CHP) plant. The saved processes were taken into account in the product systems as negative emissions.

The results of the inventory phase show that there are no major differences in emissions to air or into water between the cases if avoided emissions are not taken into account. Only methane emissions in Case 1 (originating from the landfill) are drastically higher than in the other cases. But including the avoided emissions in the assessment makes a great difference for the results.

When the emissions to air from the product systems with the avoided emissions based on the Finnish average energy production are examined, Cases 2b and 3b have the lowest net emissions (Fig. 2). The methane, fossil carbon dioxide and sulphur dioxide net emissions are lowest in Case 3b. The nitrogen oxide net emissions are lowest in Case 2b. However the differences are very small. Case 1 seems to be the worst option. When the avoided emissions are based on the coal powered CHP-plant, the lowest methane net emissions are in Cases 2a and 3a, due to the fact that the emission data for the CHP-plant do not include methane. Case 2b has the lowest net emissions of fossil carbon dioxide and nitrogen oxide and Case 3b the lowest net emissions of sulphur dioxide. Thus, Cases 2b and 3b cause the lowest net emissions to air. The energy recovery of the landfill gas does not change the situation because the avoided emissions of Case 1 do not exceed any other avoided emissions.

The amount of the avoided emissions in the different cases depends on the emission data used, but also on the ratio between heat and electricity generation in the considered treatment alternative. In Cases 2a and 2b, the co-combustion of the gasification gas was assumed to produce 30% electricity and 70% heat. In Cases 3a and 3b, the incineration was assumed to produce 3.5% electricity and 96.5% heat. The different heat and electricity production ratios increase the variation in the avoided emissions between the cases.

When the energy consumption of the cases is considered, Case 2b has the lowest net consumption. However, the difference between Cases 2b and 3b is quite small, when the avoided consumption is based on the Finnish average energy production. When the avoided consumption is based on the coal powered CHP-plant, Case 2b has clearly the lowest net consumption.

The majority of the wastes produced within the product systems are recovered in the systems, thus they were not recorded as wastes in the LCI. Over 50% of the wastes recorded in the LCI are recovered somewhere outside the product systems. These wastes are mostly unqualified newsprint from the printing facility. Their recycling processes were not included in the systems because their amounts are constant in all the cases.

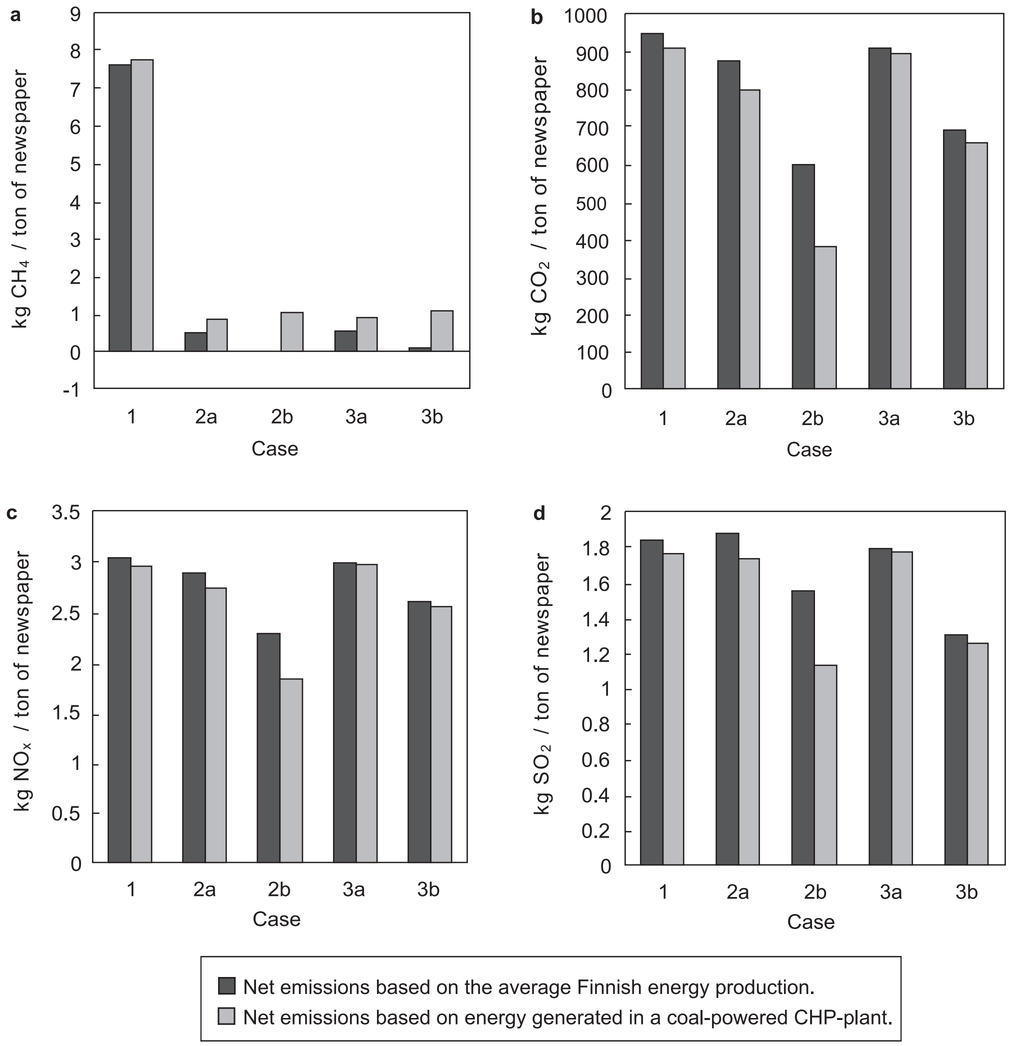

Figure 2. Net emissions of a) methane (CH_4), b) carbon dioxide (CO_2), c) nitrogen oxide (NO_x) and d) sulphur dioxide (SO_2) to air from the waste management options. The data for modelling the emissions avoided by energy recovery of waste has been varied.

The life cycle impact assessment

The life cycle inventory data of each waste recovery and treatment option were interpreted with three impact assessment methods, DAIA (Decision Analysis Impact Assessment), Eco-indicator 99 and EPS 2000 (A systematic approach to environmental priority strategies in product development). These methods differ from each other in several aspects. The basic difference between the methods is in the impact aspects taken into account. In this case study, the DAIA application was restricted to the impact categories that have scientific-based characterisation factors from the point of view of Finnish emissions (climate change, acidification, aquatic eutrophication, oxygen depletion and tropospheric ozone formation). In Eco-indicator 99 there are eleven impact categories and the aim is to cover all important cause-effect chains related to three damage categories (human health, ecosystem quality and resources) whereas in the EPS method there are 16 impact categories related to five safeguard subjects. Furthermore, the difference between impact categories leads to the different number of interventions included in the methods. In our application 12 interventions were included in DAIA whereas 33 were included in Eco-indicator 99 and 26 in EPS 2000.

Secondly, the methods differ from each other in the modelling of environmental impacts. In short, the characterisation of DAIA is based on the midpoint approach, meaning that the impacts are modelled at a midpoint level in the environmental mechanism between emissions and damages. In contrast, Eco-indicator 99 and EPS 2000 use the end-point approach aiming at modelling damages. Thirdly, the bases of normalisation in the methods are different. The reference system of normalisation in DAIA represents the impacts of Finnish emissions. In Eco-indicator 99 the reference systems are calculated by European environmental interventions. In EPS the normalisation has been avoided because of monetary weighting and the global spatial extension. And fourth, the weighting factors used in DAIA and Eco-indicator 99 have been produced by a panel method, whereas EPS 2000 uses monetary weighting.

The three LCIA methods all have their own terms for the final results of the LCIA, which represent the overall impacts on the environment. In DAIA the term impact score or value is used, whereas in EPS 2000 the results are given as environmental load units (ELUs) and in Eco-indicator 99 as ecoindicator value or ecopoints.

The impact scores given by the DAIA model show that for all the five impact categories included, the lowest environmental impact is given by Case 2b, when the avoided impacts are taken into consideration. In the overall results obtained by DAIA the dominating impact categories are climate change, acidification and aquatic eutrophication. Hence, due to energy recovered from SRF with high efficiency and the impacts avoided by compensating coal-powered energy production with this, the alternative with gasification of newspaper in SRF (Case 2b) performs better than the other alternatives.

The ecopoints given by Eco-indicator 99 for the nine impact categories included in the assessment show that in most of the categories the lowest impact is given by Case 2b, when the avoided impacts are included in the assessment. For the impact categories respiratory effects on humans caused by organic substances, damage to ecosystem quality caused by ecotoxic emissions and damage to ecosystem quality caused by land occupation and land conversion, the lowest ecopoints are given by Case 2a (and in the last mentioned also by Cases 1 and 3a). But the three categories where Case 2b did not get the lowest ecopoints, are of minor importance for the overall results. It must be noticed, however, that in the assessment of land use impacts, only land use for forestry was included, and there were uncertainties about the number of square metres actually affected by acquisition of fibre wood for newsprint manufacturing. The three dominating impact categories in the overall results are damage to resources caused by extraction of fossil fuels, respiratory effects on humans caused by inorganic substances and damages to human health caused by climate change. These all reflect the production and consumption of energy in the product system. Hence the result is the same as given by DAIA.

The ELUs given by EPS 2000 show more heterogeneity in ranking the cases than DAIA and Eco-indicator 99. Of the fourteen impact categories included in the assessment, Case 2b has the lowest ELUs from seven, when the avoided impacts are included in the assessment. Case 1 gets the lowest and Case 2b the highest ELUs in wood growth capacity and fish and meat production capacity. Case 2b gets the highest ELUs also in the depletion of natural gas reserves and second highest in depletion of elemental or mineral reserves. The ELUs for the impact category species extinction are also highest for Cases 2b and 3b, due to the impacts from landuse for forestry. The dominating impact categories in the overall results are life expectancy, severe morbidity, depletion of natural gas reserves and depletion of elemental or mineral reserves. The two first named include impacts from all the major air emission components, such as CO_2, SO_2, NO_x, CH_4, NH_3, N_2O and CO. Most of these emissions originate primarily from energy production, hence also the overall results of EPS 2000 are in favour of Case 2b if avoided impacts are included. The result is not as evident as from the other two methods. But if avoided impacts are not included the overall result is changed.

It can be summarised from the above that the results of this study indicate better environmental performance for energy recovery of newspaper with a co-combustion option compared with recycling of newspaper (Case 2b compared to Case 2a) or compared with incineration (Case 2a compared to 3a) in most of the impact categories included the LCIA methods used if energy from waste can compensate for energy generated with coal (Fig. 3). In most of the impact categories in the three models, the worst position is given to either landfilling (Case 1) or incineration (Case 3a or 3b). Hence, energy recovery by incineration is not a preferable option. If, however, the energy from waste does not substitute any other form of energy production or if it compensates energy from biofuels, the best alternative can not be assessed unambiguously.

The overall results given by the different LCIA methods are fairly similar when comparing the environmental performance of the five waste recovery and treatment alternatives with the assumption that energy from waste substitutes energy produced with coal. This finding is, however, restricted to our LCA application and may not be applicable to other types of applications for reasons discussed in the following.

The impact assessment reported above, had, however, some weaknesses. The modelling of biodiversity impacts in the Eco-indicator 99 and EPS 2000 models were not considered satisfactory. The ecological impacts of recycling are, however, strongly related to its impacts on forest biodiversity. Also, the impacts of the use of slimicides at the paper mill could not be included in the LCIA, because there were no data available on the decomposition products and their concentrations in the paper mill waste water.

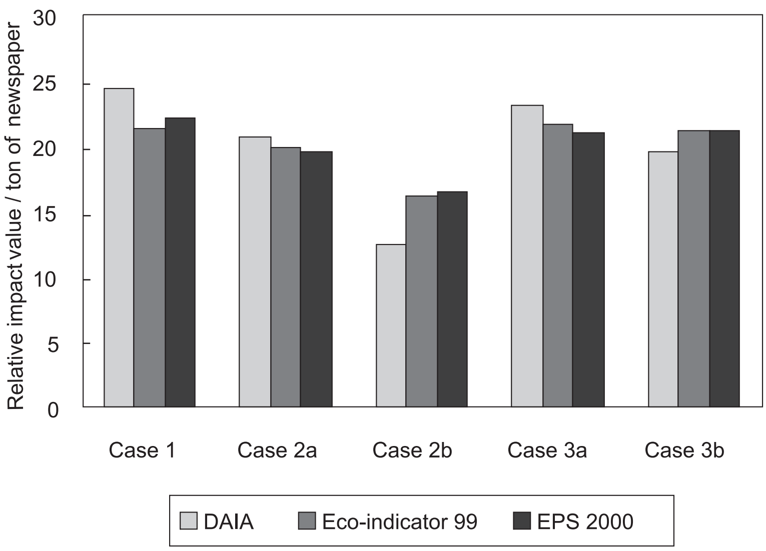

Figure 3. Comparison of the overall LCIA results given by the three impact assessment methods. Incineration facility modelled in Cases 3a and 3b as generating mainly electricity. Credits from the energy recovery of waste are assessed from a coal-powered CHP-plant. The total impact values of the alternatives calculated by each method is converted to 100 points in order to compare the results.

Main conclusions

As measured by the inventory analysis results, the material and energy recovery options (Cases 2a, 2b, 3a and 3b) were superior to landfilling (Case 1) when comparing the different waste recovery and treatment options. Although the co-combustion and incineration of newspaper produced emissions, they were compensated by the emissions avoided in other energy production facilities. The avoided emissions have a significant impact on the net emissions of the cases. Based on the emissions to air it can be stated that the energy recovery options (Cases 2b and 3b) were more favourable than the material recovery options (Cases 2a and 3a). Material and energy recovery were actually included in all the cases, but the energy recovery ratio was higher in Cases 2b and 3b than in Cases 2a and 3a respectively, and thus the avoided emissions to air were also higher. The differences between the cases applying gasification and incineration were small. Hence, which energy recovery method is to be preferred depends strongly on the fuel mixture used for the compensated energy production, on the ratio of electricity and heat production in the incineration and co-combustion processes and on the assumed total energy efficiency of the modelled plants.

The product systems were modelled as closed-loop systems, with virgin wood compensating for the decrease in the flow of discarded newspapers to the paper mill. This would probably not be the case in practice, as the decreasing flow of discarded newspapers from the Helsinki Metropolitan Area (HMA) would more probably be compensated by discarded paper from other areas rather than by virgin wood.

Most of the results of the LCIA study also showed that landfilling of newspaper in the untreated mixed waste is environmentally worse than their energy recovery. The three LCIA methods used gave slightly inconsistent results when considering the performance of the various energy recovery options. Incineration performed equally badly or worse than landfilling, when looking at the results from the Eco-indicator 99 and EPS 2000. But all the LCIA methods showed that co-combustion of newspaper performed better than material recycling or incineration if solid recovered fuel (SRF) can be used to replace coal as fuel. The better performance of an energy recovery option is in contrast with other LCA studies that have compared recycling and energy recovery of paper. In most of the previous LCA studies, however, the modelled energy recovery option has been based on incineration of paper in mixed waste and not on co-combustion of paper in SRF.

There are several aspects that must be taken into account when considering the results of this study. The alternatives including energy recovery are currently not in use in the studied area. Thus, there are uncertainties in their modelling. The performance of an energy recovery option is very much dependent on the possibilities of connecting the waste-to-energy facility into the existing energy production system.

The biodiversity impacts of forestry are a fundamental question when considering the management of paper waste. The overall assessment of land use is under development in the LCA methodology. In the LCIA methods used in this study, the land use aspects were not included in a satisfactory manner. Nevertheless, the paper and pulp industry has a crucial role considering the biodiversity of the Finnish nature, since over 85% of the forest land is currently in commercial use. Acknowledging that the impacts of land use have not yet sufficiently been included in our study, it should be realised that the comparison of material and energy recovery of newspaper cannot yet be performed on a solid basis. The question should, however, be studied in more detail in the future.

The different LCIA methods used in the study were fairly easy to use. In this case study they also pointed in the same direction giving somewhat more confidence for the interpretation of the results. The applicability of each method needs, however, to be assessed case by case on the basis of the environmental interventions included in the assessment.

The main objective of the LCA-WASTE project was to develop a commonly applicable method for assessing the ecology and costs of alternative waste management solutions. The general frame of life cycle methodology can be directly transferred to other case studies. The advantage of LCA is that the method is widely known and also its strengths and weaknesses are widely recognised. The project addressed a collection of calculation elements that can be chained and used for calculations needed in the respective study. Hence, the developed LCA-WASTE method describes the process and shows important aspects that should be taken into account in different phases of an LCA on waste management. With the help of the data and the methodological solutions presented in the work, experts working in the environmental administration, consultancies, enterprises etc. can con-duct their LCA studies easier than without examples.

In the inventory phase the method concentrates on searching and producing data related to the specific waste fraction studied. On the other hand, it is known that the system as a whole has a decisive role and therefore the whole waste management system should be studied and not one waste fraction only. Part of the data on emissions and costs related to paper are not relevant for other waste fractions or for other regions and therefore a specific inventory has to be carried out for each waste fraction separately. Carrying out a life cycle inventory is a heavy, long and partially subjective process, where comprehensive and good statistics or databases can crucially ease the work. All in all, the project documented a variety of practical issues and problems that must be solved when considering waste management and energy-related solutions and possibilities for applying them in different areas.

Abbreviations

BOD	Biological oxygen demand
COD	Chemical oxygen demand
DIP	De-inked pulp
HMA	Helsinki Metropolitan Area
IISI	International Iron and Steel Institute
ISO	International Organization for Standardization
IWM	Integrated waste management
KCL	Finnish Pulp and Paper Research Institute
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
MB	Mechanical-biological
MSWI	Municipal solid waste incineration
MSWM	Municipal solid waste management
SRF	Solid recovered fuel
TMP	Thermo-mechanical pulp
YTV	Helsinki Metropolitan Area Council

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Appendix 1. Small-scale recycling of paper

According to Vilenius (1999) households use discarded paper also for their own purposes such as kindlings and biowaste wrappings. Approximately 23 000 t are burned and 3 000 t used as wrappings.

The Finnish population was 5 159 653 (the year 1998) and the population of the YTV area was 912 528 (the year 2001) (Tilastokeskus 2003).

Burning:

23 000 t * (912 528 / 5 159 653) = 4 067.7 t

Biowaste wrappings:

3 000 t * (912 528 / 5 159 653) = 530.6 t

Total:

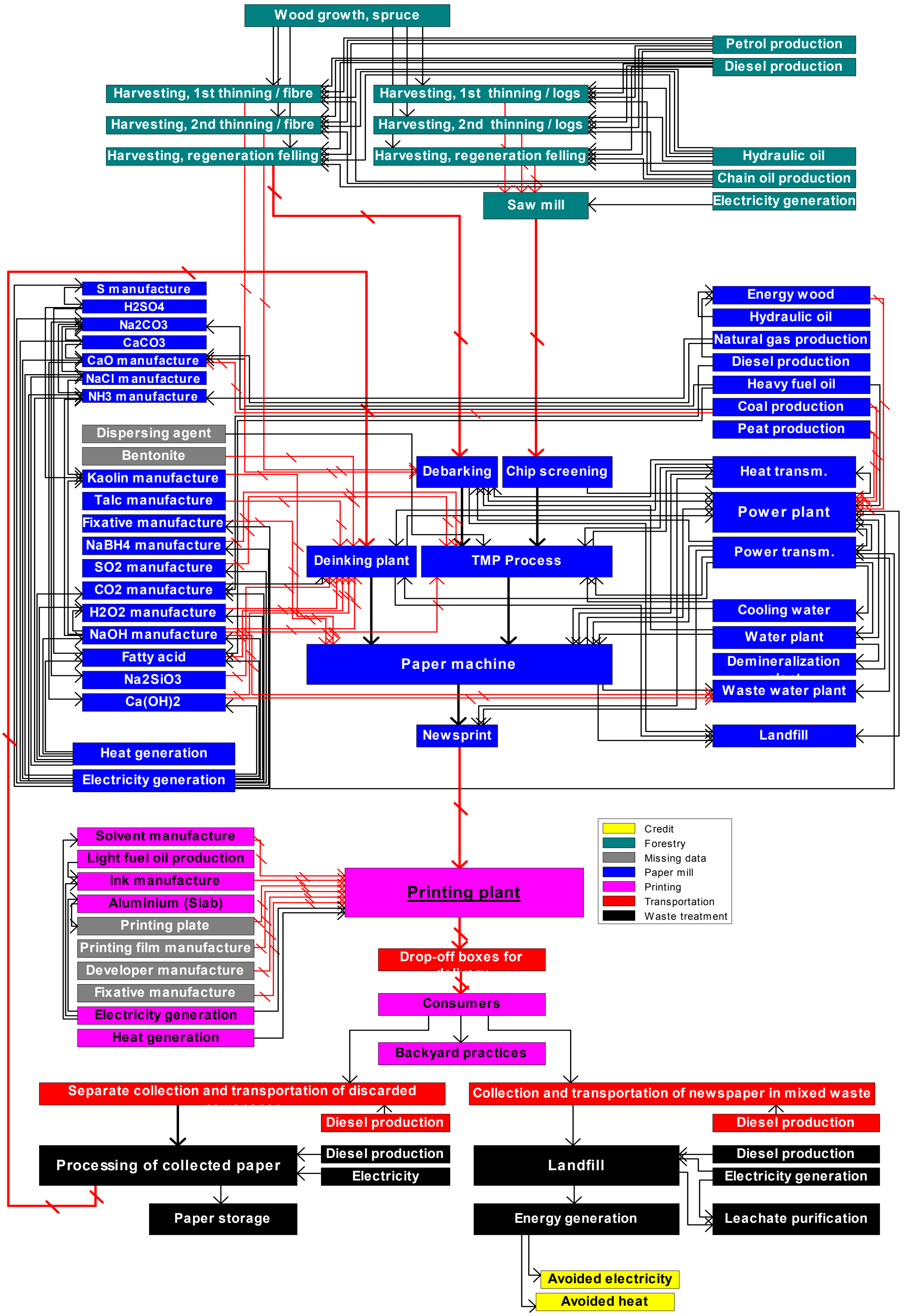
4 067.7 t + 530.6 t = 4598.3 t

The amount of discarded paper calculated by the method of Tanskanen (2000) in the YTV area:
143 136 t

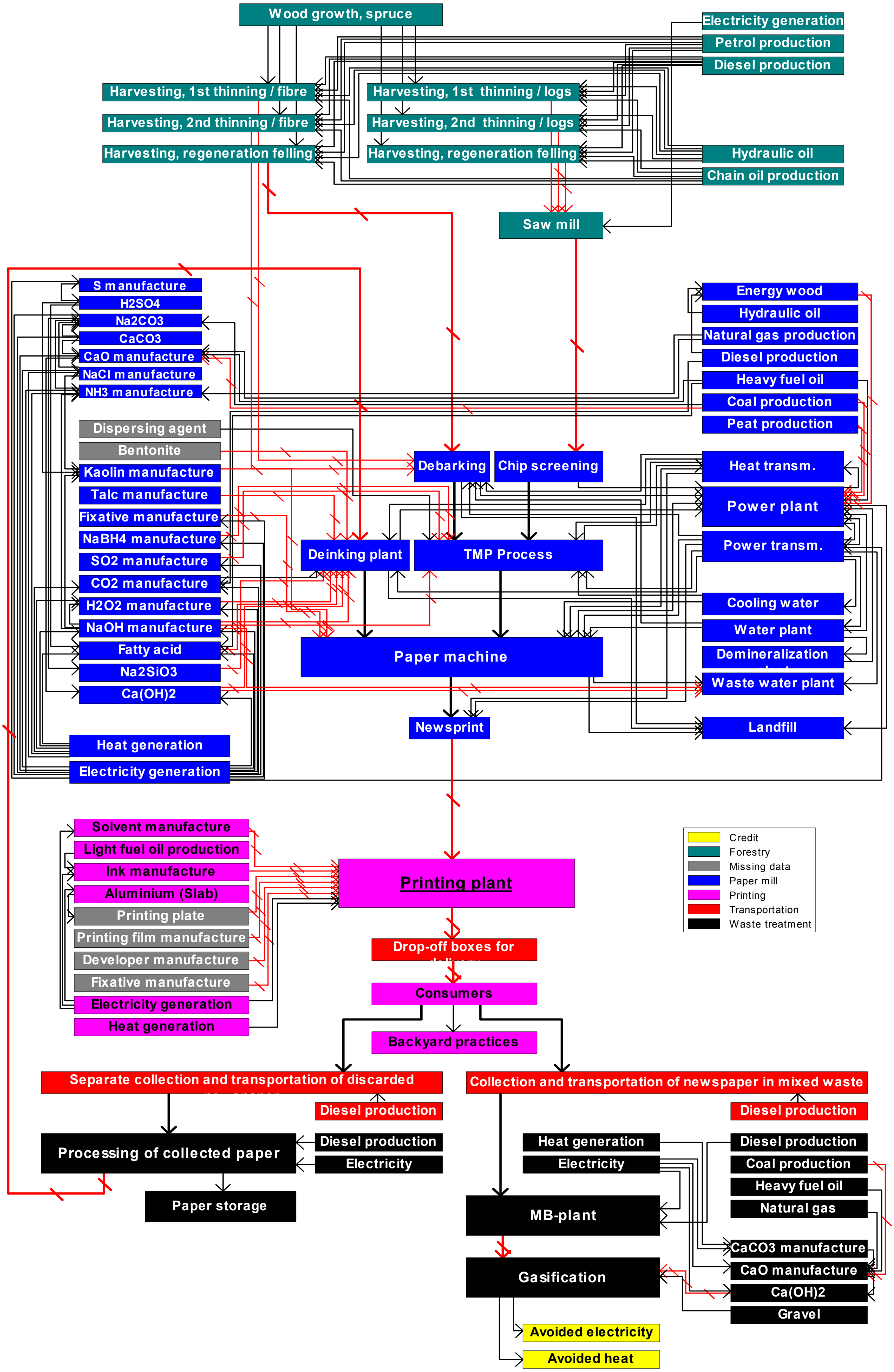
The proportion of small scale recycling in the YTV area is this:
(4 598 t / 143 136 t) * 100 % = **3.213 %**

Appendix 2. KCL-ECO flow charts for Cases 1, 2a, 2b, 3a and 3b

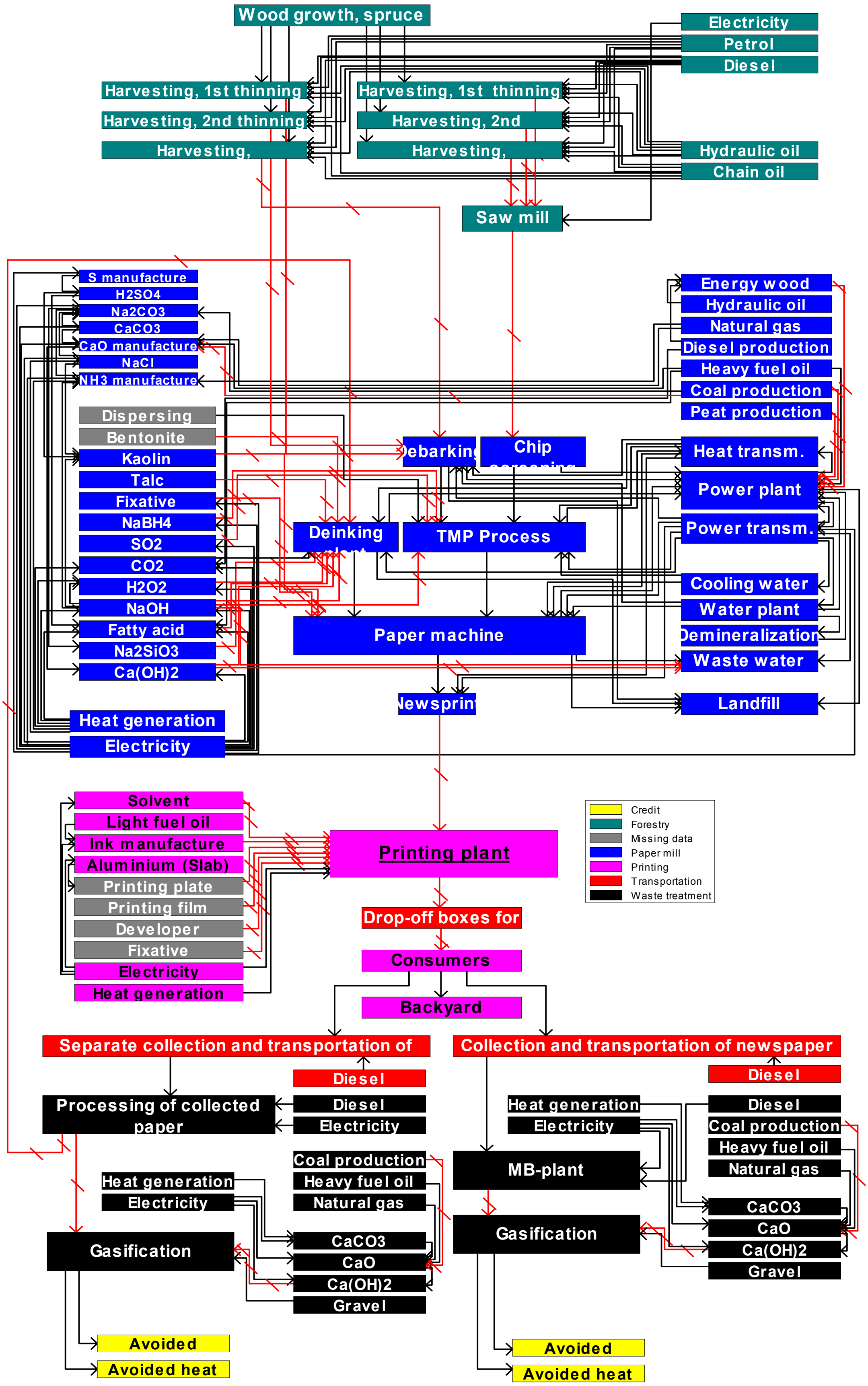
The product system of Case 1 in the KCL-ECO software. Landfill gas is utilised as energy. This energy substitutes the Finnish average energy production.



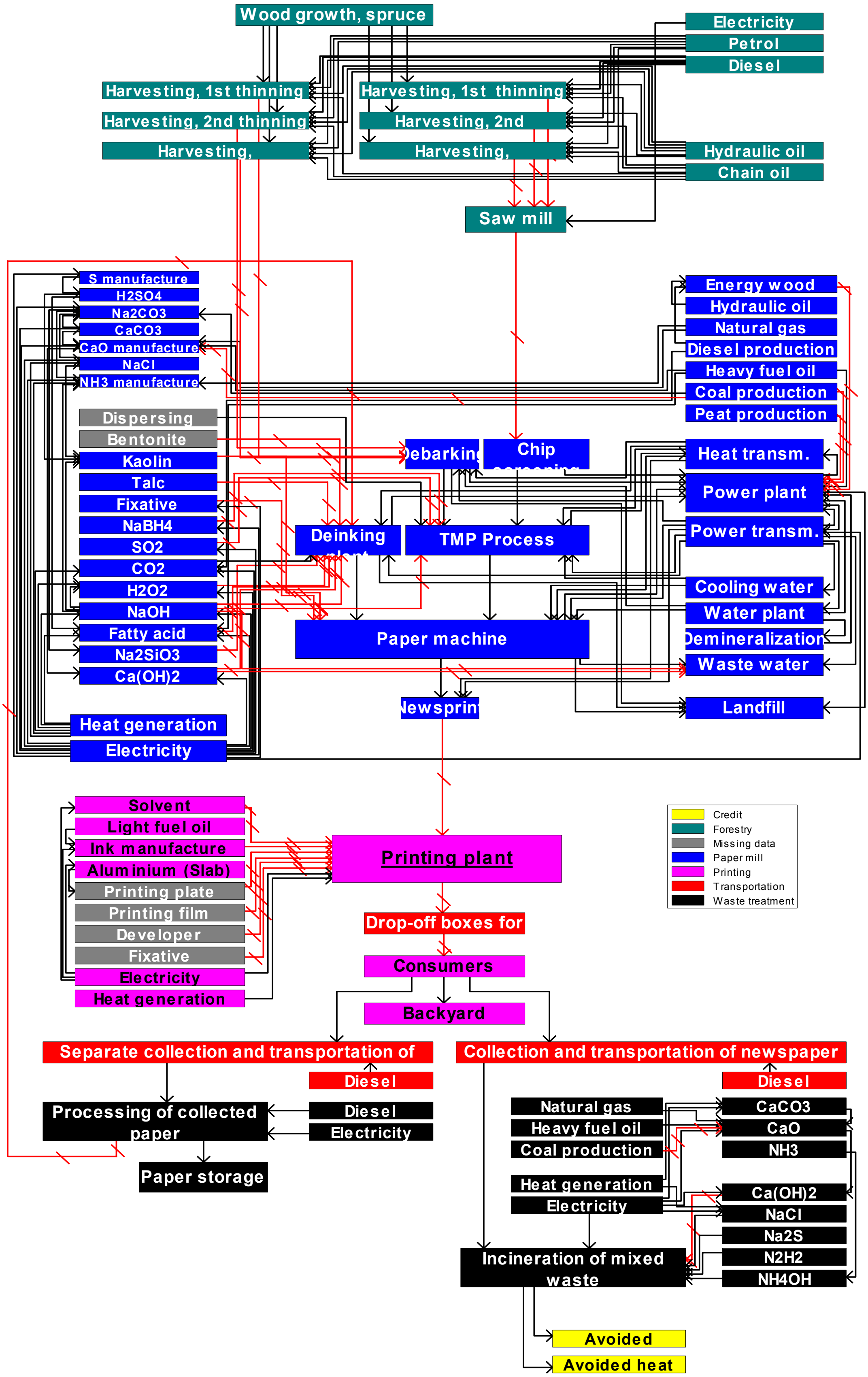
The product system of Case 2a in the KCL-ECO software.
The energy produced from waste substitutes the Finnish average energy production.



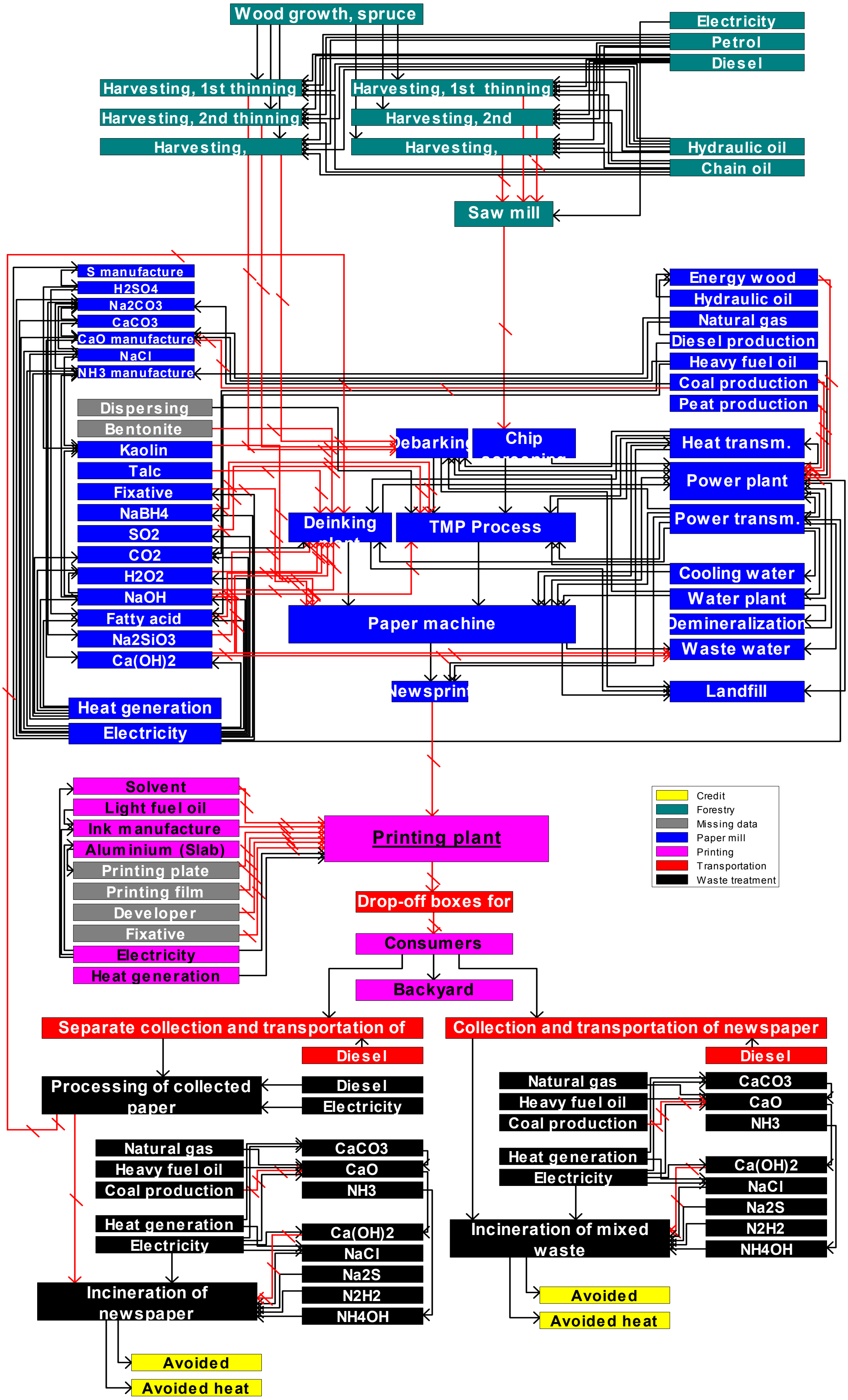
The product system of Case 2b in the KCL-ECO software.
The energy produced from waste substitutes the Finnish average energy production.



The product system of Case 3a in the KCL-ECO software.
The energy produced from waste substitutes the Finnish average energy production.

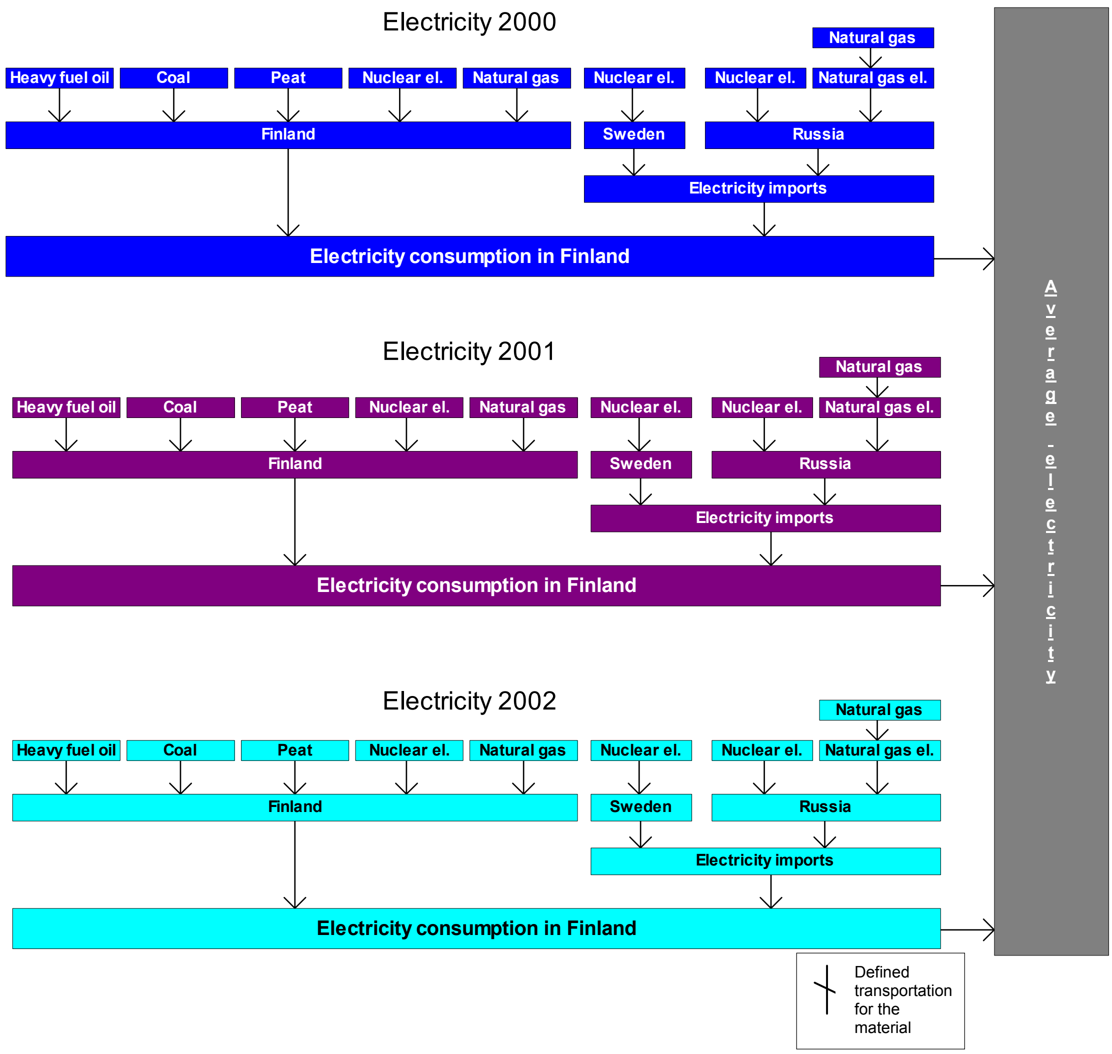


The product system of Case 3b in the KCL ECO software.
The energy produced from waste substitutes the Finnish average energy production.



Appendix 3. The electricity model in the KCL-ECO software

Only fossil CO_2 emissions are taken into consideration in the life cycle inventory, hence renewable fuels are not included in the electricity model.



Appendix 4. Inventory data on waste management

Data for modelling the landfilling of newspaper

Table 4.1. Inputs and outputs of the landfilling of newspaper in mixed waste (Pelkonen et al. 2000, Finnveden et al. 2000, Fliedner 1999, Kopalainen 2003, YTV 2002).

Landfill Values per 1 t newspaper					
Inputs:			Outputs:		
<Energy>			<Emissions to air>		
eletric power	0.00088	MWh	CH4	33.575	kg
<Fuels>			CO2, biogenic	710.73	kg
diesel oil	0.83	kg	CO2, fossil	2.8552	kg
<Materials/Products>		kg	NOx	0.0312288	kg
Newspaper	1	t	SO2	0.0017845	kg
			NMVOC	0.0085696	kg
			<Fuels> methane	118.5	kg
			<Water> leachate	2	m^3

Table 4.2. Inputs and outputs of energy recovery of the landfill gas (Finnveden et al. 2000).

Energy recovery of the landfill gas Values per 1 kg methane					
Inputs:			Outputs		
<Fuels>			<Emissions to air>		
methane	1	kg	CO2, biogenic	2.74342	kg
			<Energy>		
			electric power	0.004175	MWh
			heat energy	0.03006	GJ

Table 4.3. Inputs and outputs of leachate purification at the Suomenoja waste water treatment plant (Pelkonen et al. 2000, Alapoti 2002, Espoon vesi 2002, Valve 2003).

Leachate purification			
Inputs:		Outputs:	
<Energy>	[MWh]	<Emissions to air>	
electric power		N2	[kg]
<Water>		<Emissions to water>	
leachate	[m3]	BOD	[kg]
		Cd, water	[kg]
		Cl-, chlorides, water	[kg]
		COD	[kg]
		Cr, water	[kg]
		Cu, water	[kg]
		Hg, water	[kg]
		NO3-, nitrates, water	[kg]
		Pb, water	[kg]
		sulfide	[kg]
		waste water	[kg]
		Zn, water	[kg]
		<Solid wastes>	
		NH4, sludge	[kg]

Continues on the next page

Additional Equations:
<Emissions to air>
N2=0.75075*leachate
<Emissions to water>
BOD=0.348758*leachate
Cd, water=6.825E-005*leachate
Cl-, chlorides, water=1.365*leachate
COD=2.09173*leachate
Cr, water=0.002184*leachate
Cu, water=0.006825*leachate
Hg, water=1.365E-006*leachate
NO3-, nitrates, water=0.4095*leachate
Pb, water=0.0005005*leachate
sulfide=0.455*leachate
waste water=1000*leachate
Zn, water=0.01092*leachate
<Energy>
electric power=0.0004*leachate
<Solid wastes>
NH4, sludge=0.20475*leachate

Data for modelling the processing of the separately collected newspapers

Table 4.4. Inputs and outputs from the processing of separately collected newspapers at the processing plant of Paperinkeräys Oy (Tuunainen 2002, VTT Lipasto 2002).

Processing of collected paper Values per 1 t newspaper					
Inputs:			Outputs:		
<Energy>			<Emissions to air>		
electric power	0.004	MWh	CH4	9.54E-05	kg
<Fuels>			CO	0.00794365	kg
diesel oil	0.511737	kg	CO2, fossil	1.64677	kg
<Materials/Products>			HC	0.00314326	kg
Newspaper	1	t	N2O	0.0007	kg
			NOx	0.0214799	kg
			particles	0.0021112	kg
			SO2	0.00179108	kg
			<Materials/Products>		
			processed newspaper	1	t

Data for modelling the MB pre-treatment plant

Table 4.5. Inputs and outputs from the mechanical-biological pre-treatment of newspaper in mixed waste. Data is allocated for the mechanical treatment (Suunnittelukeskus Oy 2003, VTT Lipasto 2002).

MB-pre-treatment plant Values per 1 t newspaper					
Inputs:			Outputs:		
<Energy>			<Emissions to air>		
electric power	0.036	MWh	CH4	0.00016284	kg
heat energy	0.22284	GJ	CO	0.0135644	kg
<Fuels>			CO2, fossil	2.81198	kg
diesel oil	0.87383	kg	dust	0.01808	kg
<Materials/Products>			HC	0.00536734	kg
Newspaper	1	t	N2O	0.0011953	kg
			NOx	0.0366785	kg
			particles	0.00360503	kg
			SO2	0.0030584	kg
			<Fuels>		
			SRF	1.2	t

Table 4.6. Inputs and outputs of the gasification of SRF and co-combustion of the purified gas in the Martinlaakso CHP-plant boiler 2.

Martinlaakso CHP-plant Values per 1 GJ of produced energy					
Inputs:			Outputs:		
<Chemicals>			<Emissions to air>		
Ca(OH)2 (90%)	2.36	kg	As, air	1.27E-08	kg
<Fuels>			Cd, air	6.36E-09	kg
SRF	0.106	t	Co, air	1.59E-08	kg
<Materials/Products>			CO2, biogenic	143	kg
gravel	2.12	kg	Cr, air	3.07E-08	kg
			Cu, air	6.15E-08	kg
			Hg, air	3.50E-06	kg
			Mn, air	1.59033E-08	kg
			Ni, air	3.07E-08	kg
			Pb, air	6.15E-08	kg
			Sb, air	3.07E-07	kg
			Sn, air	3.07E-07	kg
			SO2	0.0742	kg
			V, air	1.59E-07	kg
			Zn, air	3.71E-06	kg
			<Energy>		
			electric power	0.0831	MWh
			heat energy	0.701	GJ
			<Solid wastes>		
			Al, filter ash	0.0417	kg
			bottom ash	0.358	kg
			C, filter ash	0.063	kg
			Cl, filter ash	0.104	kg
			filter ash	0.835	kg
			heavy metals, filter ash	0.017	kg

Data for modelling the incineration plant Högdalen, producing mainly heat

Table 4.7. Partitioning coefficients for the incineration plant (Björklund 1998).

Högdalen				
Substance	to slag (kg/kg in waste)	to raw gas (kg/kg in waste)	to clean gas (kg/kg in raw gas)	to fly ash (kg/kg in waste)
Ctot-b	0.0219	0.978	0.992	0.0074
DM	0.9	0.1 kg/kg ash	0.001	0.999
AOX	5.34E-08 kg/kg waste	5.34E-07 kg/kg waste	0.84	0.16
PAH	5.34E-08 kg/kg waste	1.00E-06 kg/kg Ctot-b in gas	0.01	0.99
dioxins	3.29E-13 kg/kg waste	3.29E-12 kg/kg waste	0.05	0.95
Otot	0.094	Ctot-b*32/12 kg/kg Ctot-b to CO2	0.99	0.01
H2O	0.144	0.856 kg/kg H2O in waste	0.9998	0.0002
Ntot	0.017	0.983	1 kg/kg N-NH3+N-NOx+N-N2O	0
N-NOX		1.217E-05 kg/MJ in waste	1	
N-NH3	0	7.93E-07 kg/MJ in waste	1	0
N-NO3	0.0183 kg/kg N in waste	0		0
N-N2O		3.23E-06 kg/MJ in waste	1	
Stot	0.205	0.795	0.25	0.75
Ptot	0.211	0.789	0	1
Cltot	0.107	0.893	2.10E-04 kgCl/kg CO2 in gas	1
K	0.536	0.464	0.529	0.471
Ca	0.583	0.417	0.001	0.999
Pb	0.82	0.18	0.0001	0.9999
Cd	0.133	0.867	0.0007	0.9993
Hg	0.035	0.965	0.05	0.95
Cu	0.935	0.065	0.001	0.999
Cr	0.715	0.285	0.0349	0.9651
Ni	0.975	0.025	0.0615	0.9385
Zn	0.45	0.55	0.0002	0.9998
CO2-b		Ctot-b*44/12 kg/kg Ctot-b to gas	1	
CO		3.50E-03 kg/kg Ctot-b in gas	1	
particles		0.1 kg TS/kg ash in waste	0.001	0
S-SOX		0.795 kg/kg S in waste	0.25	

Table 4.8. Coefficients for the additive consumption of the incineration plant (Björklund 1998).

Additives				
	kg/kg waste			
Ca(OH)2	0.78	kg/kg Cl in waste	1.42E-03	kg/kg waste
NH4OH	4.98E-04	kg/MJ in waste		
Na2S	30.6	kg/kg Hg in waste	8.35E-08	kg/kg waste
	1.60E-05			
N2H2	1.20E-05			
NaCl	4.01E-05			

Table 4.9. Electricity consumption of the incineration plant (Björklund 1998).

Electricity consumed	
electricity	0.25 MJ/kg waste

Table 4.10. Energy content of newspaper (Teittinen 2003).

Energy	
Total	13.3 MJ/kg waste

Table 4.11. Data on the incineration of newspaper in the incineration plant.

Emissions	**Values for Högdalen**			
	to slag kg/kg waste incinerated	to raw gas kg/kg waste incinerated	to clean gas kg/kg waste incinerated	to fly ash kg/kg waste incinerated
Amount	0.19			
Ctot-b	0.00856947	0.3826914	0.379629869	6.34141E-05
DM	0.819	0.000091	0.000000091	0.818181
AOX	5.34E-08	5.34E-07	4.49E-07	8.544E-09
PAH	5.34E-08	3.83E-07	3.83E-09	5.2866E-08
dioxins	3.29E-13	3.29E-12	1.65E-13	3.1255E-13
H2O	0.01296	0.07704	0.077024592	0.000002592
Ntot	0.00004641	0.00268359	2.15E-04	0
N-NOx	0	0.000161618	0.000161618	0
N-NH3	0	1.05E-05	1.0531E-05	0
N-NO3	0.000049959	0	0	0
N-N2O	0	4.29E-05	4.2921E-05	0
Stot	0.00018655	0.00072345	0.000180863	0.0006825
Cltot	0.00019474	0.00162526	2.95E-04	0.00182
Pb	8.2082E-07	1.8018E-07	1.8018E-11	1.0009E-06
Cd	1.2103E-09	7.8897E-09	5.52279E-12	9.09363E-09
Hg	9.555E-11	2.63445E-09	1.31723E-10	2.5935E-09
Cu	1.27628E-05	8.8725E-07	8.8725E-10	1.36364E-05
Cr	3.12312E-06	1.24488E-06	4.34463E-08	4.21556E-06
Zn	0.000009828	0.000012012	2.4024E-09	2.18356E-05
CO2-b	0	1.4032018	1.4032018	0
CO	0	1.34E-03	1.34E-03	0
particles	0	0.0091	0.0000091	0
S-SOx	0	0.00072345	0.000180863	0

Table 4.12. Additive consumption of the incineration of newspaper.

Additives	kg/kg waste incinerated
Ca(OH)2	0.0014196
NH4OH	6.61E-03
Na2S	8.3538E-08
N2H2	1.20E-05
NaCl	4.01E-05

Table 4.13. Electricity consumption of the incineration of newspaper.

Electricity	MJ/kg waste incinerated
El, consumed	0.25

Table 4.14. Composition of newspaper applied in the calculations of incineration (Högdalen plant) and landfilling.

Substance	**%**	**Source**
C-biogenic	39.13	Pelkonen et al. 2000, p. 8
DM	91.0	Hukkanen 2002
H2O	9.0	Hukkanen 2002
Ntot	0.273	Pelkonen et al. 2000, p. 8
Stot	0.091	Pelkonen et al. 2000, p. 8
Cltot	0.182	Pelkonen et al. 2000, p. 10
Pb	0.0001001	1.1 mg/kg DM; Hukkanen 2002
Cd	0.00000091	0.01 mg/kg DM; Hukkanen 2002
Hg	0.000000273	0.003 mg/kg DM; Hukkanen 2002
Cu	0.001365	15 mg/kg DM; Pelkonen et al. 2000, p. 10
Cr	0.0004368	4.8 mg/kg DM; Hukkanen 2002
Zn	0.002184	24 mg/kg DM; Pelkonen et al. 2000, p. 10
Otot	36.4	Pelkonen et al. 2000, p. 10
Htot	5.733	Pelkonen et al. 2000, p. 8

Table 4.15. Inputs and outputs of incineration of newspaper in a mixed waste incineration plant producing heat with 85% total efficiency (Orware data).

Incineration of newspaper (orware data) Values per 1 gj of produced energy					
Inputs:			Outputs:		
<Chemicals>			<Emissions to air>		
Ca(OH)2 (90%)	0.186	kg	AOX, air	9.24E-05	kg
N2H2	0.00142	kg	Cd, air	1.14E-09	kg
Na2S	0.00000987	kg	Cl, tot air	0.0607	kg
NaCl	0.00474	kg	CO	0.276	kg
NH4OH	0.781	kg	CO2, biogenic	289	kg
<Energy>			Cr, air	8.94E-06	kg
electric power	0.00820	MWh	Cu, air	1.83E-07	kg
<Materials/Products>			dioxins, air	3.40E-11	kg
Newspaper	0.118	t	DM, air	1.87E-05	kg
			H2O, air	15.9	kg
			Hg, air	2.71E-08	kg

		N2O, air	0.00884	kg
		NH3, air	0.00217	kg
		NOx	0.0333	kg
		PAH, air	7.88E-07	kg
		particles	0.00187	kg
		Pb, air	3.71E-09	kg
		Stot, air	0.0372	kg
		SO2	0.0372	kg
		Zn, air	4.95E-07	kg
		<Energy>		
		electric power	0.0169	MWh
		heat energy	1.68	GJ
		<Solid wastes>		
		AOX, flyash	1.76E-06	kg
		AOX, slag	1.10E-05	kg
		C tot biogenic, flyash	0.0131	kg
		C tot biogenic, slag	1.7642	kg
		Cd, flyash	1.87E-06	kg
		Cd, slag	2.49E-07	kg
		Cl tot, flyash	0.375	kg
		Cl tot, slag	0.0401	kg
		Cr, flyash	0.000868	kg
		Cr, slag	0.000643	kg
		Cu, flyash	0.00281	kg
		Cu, slag	0.00263	kg
		Dioxins, flyash	6.43E-11	kg
		Dioxins, slag	6.77E-11	kg
		DM, flyash	0.741	kg
		DM, slag	1.57	kg
		H2O, flyash	0.000534	kg
		H2O, slag	2.67	kg
		Hg, flyash	5.34E-07	kg
		Hg, slag	1.97E-08	kg
		N tot, slag	0.00955	kg
		NO3, slag	0.0103	kg
		PAH, flyash	1.09E-05	kg
		PAH, slag	1.10E-05	kg
		Pb, flyash	0.000206	kg
		Pb, slag	0.000169	kg
		S tot, flyash	0.141	kg
		S tot, slag	0.0384	kg
		Zn, flyash	0.00450	kg
		Zn, slag	0.00202	kg

Data on the incineration of newspaper for the plant producing mainly electricity (the Swiss plant)

For the sensitivity analysis, the incineration facility was modelled as producing electricity with 9.4% efficiency and heat with 19.6% efficiency (Ecoinvent data v1.1. 2004, Doka 2003). The ecoinvent data used for this concept, represent the average of 28 current municipal solid waste incineration (MSWI) plants in Switzerland.

Only the data on emissions to air from the Ecoinvent data were used. The data excluded infrastructure. The emission values are waste-specific emissions from incineration. The waste contains 100% newspaper. The lower heating value of the waste is 14.11 MJ/kg. Net energy produced in MSWI: 1.32 MJ/kg electric energy and 2.77 MJ/kg waste thermal energy (Ecoinvent data v.1.1 2004).

Table 4.16. Inputs and outputs of incineration of newspaper in a mixed waste incineration plant producing electricity and heat with 25% total efficiency (Ecoinvent data v.1.1 2004).

Incineration of newspaper (Ecoinvent data) Values per 1 GJ of energy produced			
Inputs:		Outputs:	
<Chemicals>		<Emissions to air>	
CrO	4.89E-06 kg	Ag, air	1.52E-09 kg
FeCl3	0.00276 kg	Al, air	0.00465 kg
HCl, chem	0.000883 kg	Ba, air	3.325E-06 kg
NaOH	0.467 kg	Cd, air	1.87E-09 kg
NH3, chem	0.00836 kg	CH4	0.00156 kg
TiO2	0.000240 kg	CN (cyanide), air	0.000149 kg
<Energy>		CO	0.0545 kg
electric power	0.0170 MWh	Co, air	7.09E-12 kg
<Materials/Products>		CO2, biogenic	362 kg
Newspaper	0.244 t	Cr, air	1.86E-10 kg
		Cu, air	5.40E-08 kg
		Fe, air	1.13E-06 kg
		HCl, air	3.64E-06 kg
		Hg, air	6.92E-13 kg
		K, air	0.00345 kg
		Mn, air	6.23E-11 kg
		N2O	0.0105 kg
		NH3, air	0.000132 kg
		Ni, air	2.44E-11 kg
		NOx	0.00528 kg
		Pb, air	8.19E-07 kg
		Si, air	0.0119 kg
		SO2	0.00170 kg
		Zn, air	2.22E-07 kg
		<Energy>	
		electric power	0.0896 MWh
		heat energy	0.677 GJ
		heat, waste	2.98 GJ
		<Solid wastes>	
		DM, slag	16.4 kg
		rejects	2.91 kg

Appendix 5. Inventory data for the Finnish average electricity and heat generation

Table 5.1. Fuel mixture and emissions to air from the Finnish average electricity production in the years 2000, 2001, 2002. The emissions given in this table exclude the production of fuels. (Heikkinen 2003)

Fuel	**unit/MWh**	**2000**	**2001**	**2002**
coal	kg	35	43	54
oil	kg	3	2	3
natural gas	kg	13	15	14
peat	GJ	0.32	0.58	0.62
wood based fuels	kg	57	57	60
blast furnace gas	GJ	0.15	0.12	0.11
nuclear energy	GJ	3.5	3.35	3.25
Emissions	**unit/MWh**	**2000**	**2001**	**2002**
SO_2	kg	0.231	0.321	0.379
NO_x	kg	0.301	0.41	0.47
CO_2	kg	159.528	206.191	236.976
particles	kg	0.045	0.051	0.056

Table 5.2. Net imports of electricity from Russia and Sweden in the years 2000, 2001 and 2002 (Adato Energia Oy 2003).

Net imports	**unit**	**2000**	**2001**	**2002**
Russia	GWh	4 519	7 683	7 937
Sweden*	GWh	7 361	2 276	3 988

* Net imports from Norway were negative so they were compensated with the net imports of Sweden.

Table 5.3. Energy source distribution applied for the imported electricity (IVO 1998).

Electricity	**Nuclear power**	**Natural gas**	**Hydro power**
Russia	50%	30%	20%
Sweden	50%		50%

Table 5.4. The Finnish average district heating in the year 2000. The emissions include the production of fuels and transmission losses. The CH/VOC emissions include the CH_4 emissions. The following heavy metals were included: arsenic, mercury, cadmium, chromium and lead. (Tattari 2003)

Consumption of energy resources		**Unit/kWh**
Renewable	0.7	MJ
Non-renewable	3.3	MJ
Total	4.0	MJ
Emissions to air		**Unit/kWh**
CO_2	234	g
CO	390	mg
NO_x	503	mg
N_2O	21	mg
SO_2	453	mg
CH/VOC	775	mg
CH_4	740	mg
particles	517	mg
heavy metals	0.093	mg

Table 5.5. Inputs and outputs of Finnish average electricity generation.

Finnish average electricity generation Values per 1 MWh of electric power					
Inputs:			Outputs:		
<Energy>			<Emissions to air>		
electric power (hydro)	0.0445207	MWh	aldehydes, air	0.00037931	kg
<Fuels>			As, air	1.25E-06	kg
blast furnace gas	0.10904	GJ	Cd, air	8.76E-07	kg
peat	21.8007	kg	CH4	0.182864	kg
wood based fuels	49.973	kg	CO	0.0130392	kg
<Materials/Products>			CO2, fossil	200.83	kg
oil	2.29267	kg	Cr, air	5.73E-06	kg
<Resources>			Cu, air	3.57E-06	kg
coal (in ground)	39.2125	kg	F, air	6.36E-06	kg
natural gas (in ground)	18.4089	kg	HC	0.000458533	kg
oil (in ground)	1.57441	kg	Hg, air	4.35E-06	kg
uranium ore	0.00810178	kg	N2O	0.00570031	kg
water used (total)	9.82643	l	Ni, air	1.84E-05	kg
water, unspecified origin	9.82643	l	NMHC	1.15119	kg
			NMVOC	0.00115245	kg
			NOx	0.379046	kg
			organic matter (unspecified)	0.00075862	kg
			particles	0.0487229	kg
			Pb, air	1.75E-05	kg
			SO2	0.315621	kg
			V, air	5.01E-05	kg
			Zn, air	7.84E-06	kg
			<Emissions to water>		
			Cl-, chlorides, water	1.54E-05	kg
			COD	0.0131998	kg
			dissolved matter (unspecified)	0.00259627	kg
			F-, fluorides, water	0.00121192	kg
			Fe++, Fe3+, iron, water	2.34E-06	kg
			N, tot	0.00103212	kg
			N, water as NH4	0.000879455	kg
			Na+, sodium, water	0.000198862	kg
			NH4+, NH3, as N, ammonia, water	0.000562438	kg
			NO3-, nitrates, water	0.000286575	kg
			oils (unspecified)	0.000619755	kg
			P, tot	3.72E-05	kg
			SO4-, sulphates, water	0.00025611	kg
			suspended matter (unspecified)	0.0109134	kg
			waste, oil	2.52E-05	kg
			water (unspecified)	9.03918	l
			<Energy>		
			electric power	1	MWh
			<Solid wastes>		
			waste, hazardous	0.000917067	kg
			waste, total	1.95889	kg
			waste, unspecified	1.96187	kg

Table 5.6. Inputs and outputs of Finnish average heat generation.

Finnish average heat generation Values per 0.0036 GJ of energy produced					
Inputs:			Outputs:		
<Energy>			<Emissions to air>		
non renewable energy	3.3	MJ	CH4	0.000740002	kg
renewable energy	0.699998	MJ	CO	0.000389999	kg
			CO2, fossil	0.234	kg
			heavy metals, air	9.30E-05	g
			NMHC	3.50E-05	kg
			NOx	0.000502999	kg
			particles	0.000517	kg
			SO2	0.000452999	kg
			<Energy>		
			heat energy	0.0036	GJ

Appendix 6. Inventory data on energy production at the coal-powered CHP plant

Modelling of the coal-powered energy production, which was used for calculating the credits gained by energy recovery of newspaper, was based on the data from Martinlaakso power plant, boiler 2.

Table 6.1. The data on the electricity production of boiler 2 in the Martinlaakso power plant. The data are negative because they were applied for the avoided emissions and consumption. (Vahti 2003)

Boiler 2 of the Martinlaakso power plant (electricity) Values per 1 MWh electric power [o]					
Inputs:			Outputs:		
<Chemicals>			<Emissions to air>		
CaO	-17.333	kg	As	-2.42E-06	kg
<Energy>			CO2, fossil	-516.016	kg
electric power	1	MWh	Cr, air	-1.33E-05	kg
<Fuels>			Ni, air	-6.05E-06	kg
hard coal	-215.033	kg	NOx	-0.924118	kg
natural gas	-0.0027111	kg	particles	-2.50E-02	kg
			Pb, air	-7.26E-06	kg
			SO2	-0.913231	kg
			V, air	-0.00020321	kg
			Zn, air	-0.00031207	kg
			<Energy>		
			electric power	1	MWh

Table 6.2. The data on the heat production of boiler 2 in the Martinlaakso power plant. The data are negative because they were applied for the avoided emissions and consumption. (Vahti 2003)

Boiler 2 of the Martinlaakso power plant (heat) Values per 1 GJ heat energy [o]					
Inputs:			Outputs:		
<Chemicals>			<Emissions to air>		
CaO	-0.214	kg	As	-3.00E-07	kg
<Energy>			CO2, fossil	-63.7512	kg
heat energy	1	GJ	Cr, air	-1.64E-06	kg
<Fuels>			Ni, air	-7.50E-07	kg
hard coal	-26.566	kg	NOx	-0.11417	kg
natural gas	-3.35E-05	kg	particles	-3.09E-03	kg
			Pb, air	-9.00E-07	kg
			SO2	-0.112825	kg
			V, air	-2.51E-05	kg
			Zn, air	-3.86E-05	kg
			<Energy>		
			heat energy	1	GJ

Appendix 7. Summaries of the consumption of energy and resources in the product systems

Consumption of energy

Table 7.1. Energy consumption in the product systems. Avoided consumption calculated based on the Finnish average energy production. Incineration modelled with the Orware data.

Form of energy	Consumption (MJ) per ton of newspaper				
	Case 1	**Case 2a**	**Case 2b**	**Case 3a**	**Case 3b**
Hydro power	365.52	352.07	444.32	381.37	530.06
Peat power	3190.7	3154	1882.8	3234	2116.9
Coal power	2599.3	2525.6	3081	2706.6	3611.6
Natural gas power	2015.6	1954.1	2427.3	2114.5	2896.3
Nuclear power	943.87	909.14	1147.3	984.81	1368.7
Energy from oils	3496.1	3478.7	2811.6	3516.2	2941.3
Energy from wood based fuels	6021.6	5946.1	5584.4	6110.6	6065.6
Other non-renewable	500.37	-323.29	-3123.8	-369.15	-3254.5
Other renewable	106.14	-68.578	-662.62	-78.305	-690.35
Total	**19239**	**17928**	**13592**	**18601**	**15586**

Table 7.2. Energy consumption in the product systems. Avoided consumption based on boiler 2 of the Martinlaakso power plant. Incineration modelled with the Orware data.

Form of energy	Consumption (MJ) per ton of newspaper				
	Case 1	**Case 2a**	**Case 2b**	**Case 3a**	**Case 3b**
Hydro power	381.80	383.02	532.54	384.07	537.75
Peat power	3235.3	3238.7	2124.4	3241.4	2138
Coal power	1535.5	324.24	-3194.8	1361.9	-221.66
Natural gas power	2062	2036.9	2663.4	2086.6	2816.8
Nuclear power	985.90	989.05	1375.2	991.78	1388.6
Energy from oils	3484.5	3451	2732.4	3476.3	2827.3
Energy from wood based fuels	6112.9	6119.8	6079.6	6125.7	6108.8
Other non-renewable	1172.1	1172.6	1140.56	1172.5	1140.2
Other renewable	248.63	248.73	241.93	248.71	241.87
Total	**19219**	**17964**	**13695**	**19089**	**16978**

Consumption of other resources

Table 7.3. Consumption of resources in the product systems, when avoided consumption is based on the average Finnish energy production. Incineration modelled with the Orware data.

Resource	Consumption (kg) per ton of newspaper				
	Case 1	Case 2a	Case 2b	Case 3a	Case 3b
Bentonite	7.3607	7.3607	3.6804	7.3607	3.6804
China clay	70.503	70.503	70.503	70.503	70.503
Iron ore	0.0003	0.0003	0.0003	0.0003	0.0003
Rock material	0	4.9409	14.085	0	0
Salt rock	13.237	13.237	8.1065	13.237	8.1238
Sand (in ground)	0.00007	0.00007	0.00007	0.00007	0.00007
Clay (in ground)	0.00001	0.00001	0.00001	0.00001	0.00001
Talc ore	13.219	13.219	6.6093	13.219	6.6093
Limestone	7.2800	15.226	26.439	7.7500	5.1277
Bauxite	7.9860	7.9860	7.9860	7.9860	7.9860
Total	**119.59**	**132.48**	**137.41**	**120.06**	**102.03**

Table 7.4. Consumption of resources in the product systems, when avoided consumption is based on the coal-powered energy production. Incineration modelled with the Orware data.

Resource	Consumption (kg) per ton of newspaper				
	Case 1	Case 2a	Case 2b	Case 3a	Case 3b
Bentonite	7.3607	7.3607	3.6804	7.3607	3.6804
China clay	70.503	70.503	70.503	70.503	70.503
Iron ore	0.0003	0.0003	0.0003	0.0003	0.0003
Rock material	0	4.9409	14.085	0	0
Salt rock	13.237	13.237	8.1065	13.237	8.1238
Sand (in ground)	0.00007	0.00007	0.00007	0.00007	0.00007
Clay (in ground)	0.00001	0.00001	0.00001	0.00001	0.00001
Talc ore	13.219	13.219	6.6093	13.219	6.6093
Limestone	3.1963	7.3517	3.9919	6.3615	1.1694
Bauxite	7.9860	7.9860	7.9860	7.9860	7.9860
Total	**115.50**	**124.60**	**114.96**	**118.67**	**98.07**

Appendix 8. Consumption of energy and resources in the life cycle phases of the product systems

Avoided emissions calculated with the average Finnish energy and heat production

Table 8.1. Consumption of energy and resources in Case 1.

Natural resource	Unit	Total	Avoided emissions based on the Finnish average energy	Forestry	Paper mill	Printing	Transportations	Waste recovery and treatment
wood	m3	1.47	0	1.47	0	0	0	0
<Energy>								
oil	kg	30.8	-0.234	2.27	21.5	1.84	4.84	0.562
<Fuels>								
coal (in ground)	kg	92.8	-3.99	1.09	89.2	6.46	0	0.0255
crude oil	kg	0.0391	0	0	0.0391	0	0	0
natural gas (in ground)	kg	43.3	-1.87	0.512	41.2	3.38	0	0.0120
uranium ore	kg	0.0185	-0.000825	0.000226	0.0178	0.00129	0	5.27E-06
<Resources>								
iron ore	kg	0.000266	0	0	0	0.000266	0	0
bauxite (Al2O3, ore)	kg	7.99	0	0	0	7.99	0	0

Table 8.2. Consumption of energy and resources in Case 2a.

Natural resource	Unit	Total	Avoided emissions based on the Finnish average energy	Forestry	Paper mill	Printing	Transportations	Waste recovery and treatment
wood	m3	1.47	0	1.47	0	0	0	0
<Energy>								
oil	kg	30.6	-0.444	2.27	21.5	1.84	4.84	0.631
<Fuels>								
coal (in ground)	kg	90.1	-7.59	1.09	89.2	6.46	0	0.936
crude oil	kg	0.0402	0	0	0.0391	0	0	0.00113
natural gas (in ground)	kg	41.9	-3.57	0.512	41.2	3.38	0	0.3655
uranium ore	kg	0.0178	-0.00157	0.000226	0.0178	0.00129	0	6.93E-05
<Resources>								
iron ore	kg	0.000266	0	0	0	0.000266	0	0
bauxite (Al2O3, ore)	kg	7.99	0	0	0	7.99	0	0

Table 8.3. Consumption of energy and resources in Case 2b.

Natural resource	Unit	Total	Avoided emissions based on the Finnish average energy	Forestry	Paper mill	Printing	Transportations	Waste recovery and treatment
wood	m3	2.43	0	2.43	0	0	0	0
<Energy>								
oil	kg	22.2	-1.266	3.74	12.3	1.84	4.84	0.710
<Fuels>								
coal (in ground)	kg	111.8	-21.65	1.80	123.1	6.46	0	2.109
crude oil	kg	0.0228	0	0	0.0195	0	0	0.00321
natural gas (in ground)	kg	52.5	-10.16	0.846	57.7	3.38	0	0.7789
uranium ore	kg	0.0225	-0.00447	0.000372	0.0252	0.00129	0	8.17E-05
<Resources>								
iron ore	kg	0.000266	0	0	0	0.000266	0	0
bauxite (Al2O3, ore)	kg	7.99	0	0	0	7.99	0	0

Table 8.4. Consumption of energy and resources in Case 3a. Incineration modelled with the Orware data.

Natural resource	Unit	Total	Avoided emissions based on the Finnish average energy	Forestry	Paper mill	Printing	Transportations	Waste recovery and treatment
wood	m3	1.47	0	1.47	0	0	0	0
<Energy>								
oil	kg	30.8	-0.039	2.27	21.5	1.84	4.84	0.426
<Fuels>								
coal (in ground)	kg	96.7	-0.66	1.09	89.2	6.46	0	0.610
crude oil	kg	0.0490	0	0	0.0391	0	0	0.00995
natural gas (in ground)	kg	45.1	-0.31	0.512	41.2	3.38	0	0.282
uranium ore	kg	0.0193	-0.00014	0.000226	0.0178	0.00129	0	1.19E-04
<Resources>								
iron ore	kg	0.000266	0	0	0	0.000266	0	0
bauxite (Al2O3, ore)	kg	7.99	0	0	0	7.99	0	0

Table 8.5. Consumption of energy and resources in Case 3b. Incineration modelled with the Orware data.

Natural resource	Unit	Total	Avoided emissions based on the Finnish average energy	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
wood	m3	2.43	0	2.43	0	0	0	0
<Energy>								
oil	kg	23.2	-0.111	3.76	12.3	1.84	4.84	0.491
<Fuels>								
coal (in ground)	kg	131.2	-1.89	1.80	123.1	6.46	0	1.717
crude oil	kg	0.0479	0	0	0.0195	0	0	0.0284
natural gas (in ground)	kg	61.8	-0.89	0.846	57.7	3.38	0	0.794
uranium ore	kg	0.0268	-0.00039	0.000372	0.0252	0.00129	0	3.34E-04
<Resources>								
iron ore	kg	0.000266	0	0	0	0.000266	0	0
bauxite (Al2O3, ore)	kg	7.99	0	0	0	7.99	0	0

Avoided emissions calculated with the with energy generated in a coal-powered CHP-plant

Table 8.6. Consumption of energy and resources in Case 1.

Natural resource	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
wood	m3	1.47	0	1.47	0	0	0	0
<Energy>								
oil	kg	31.0	-0.0218	2.27	21.5	1.84	4.84	0.562
<Fuels>								
coal (in ground)	kg	54.0	-42.8	1.09	89.2	6.46	0	0.0255
crude oil	kg	0.0385	-0.000578	0	0.0391	0	0	0
natural gas (in ground)	kg	44.3	-0.866	0.512	41.2	3.38	0	0.0120
uranium ore	kg	0.0193	-2.48E-06	0.000226	0.0178	0.00129	0	5.27E-06
<Resources>								
iron ore	kg	0.000266	0	0	0	0.000266	0	0
bauxite (Al2O3, ore)	kg	7.99	0	0	0	7.99	0	0

Table 8.7. Consumption of energy and resources in Case 2a.

Natural resource	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-portations	Waste recovery and treatment
wood	m3	1.47	0	1.47	0	0	0	0
<Energy>								
oil	kg	31.0	-0.0421	2.27	21.5	1.84	4.84	0.631
<Fuels>								
coal (in ground)	kg	9.8	-87.9	1.09	89.2	6.46	0	0.9362
crude oil	kg	0.0391	-0.001115	0	0.0391	0	0	0.00112505
natural gas (in ground)	kg	43.7	-1.765	0.512	41.2	3.38	0	0.3655
uranium ore	kg	0.0194	-4.78E-06	0.000226	0.0178	0.00129	0	6.93E-05
<Resources>								
iron ore	kg	0.000266	0	0	0	0.000266	0	0
bauxite (Al2O3, ore)	kg	7.99	0	0	0	7.99	0	0

Table 8.8. Consumption of energy and resources in Case 2b.

Natural resource	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-portations	Waste recovery and treatment
wood	m3	2.43	0	2.43	0	0	0	0
<Energy>								
oil	kg	23.4	-0.1201	3.74	12.3	1.84	4.84	0.710
<Fuels>								
coal (in ground)	kg	-117.2	-250.7	1.80	123.1	6.46	0	2.1087
crude oil	kg	0.0196	-0.003178	0	0.0195	0	0	0.00320718
natural gas (in ground)	kg	57.6	-5.032	0.846	57.7	3.38	0	0.7789
uranium ore	kg	0.0269	-1.36E-05	0.000372	0.0252	0.00129	0	8.17E-05
<Resources>								
iron ore	kg	0.000266	0	0	0	0.000266	0	0
bauxite (Al2O3, ore)	kg	7.99	0	0	0	7.99	0	0

Table 8.9. Consumption of energy and resources in Case 3a. Incineration modelled with the Orware data.

Natural resource	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-portations	Waste recovery and treatment
wood	m3	1.47	0	1.47	0	0	0	0
<Energy>								
oil	kg	30.8	-0.0074	2.27	21.5	1.84	4.84	0.426
<Fuels>								
coal (in ground)	kg	47.7	-49.7	1.09	89.2	6.46	0	0.6101
crude oil	kg	0.0488	-0.000197	0	0.0391	0	0	0.00994693
natural gas (in ground)	kg	44.5	-0.918	0.512	41.2	3.38	0	0.2820
uranium ore	kg	0.0194	-8.42E-07	0.000226	0.0178	0.00129	0	1.19E-04
<Resources>								
iron ore	kg	0.000266	0	0	0	0.000266	0	0
bauxite (Al2O3, ore)	kg	7.99	0	0	0	7.99	0	0

Table 8.10. Consumption of energy and resources in Case 3b. Incineration modelled with the Orware data.

Natural resource	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-portations	Waste recovery and treatment
wood	m3	2.43	0	2.43	0	0	0	0
<Energy>								
oil	kg	23.3	-0.0212	3.76	12.3	1.84	4.84	0.491
<Fuels>								
coal (in ground)	kg	-8.7	-141.8	1.80	123.1	6.46	0	1.7170
crude oil	kg	0.0473	-0.000560	0	0.0195	0	0	0.0283556
natural gas (in ground)	kg	60.1	-2.617	0.846	57.7	3.38	0	0.7936
uranium ore	kg	0.0272	-2.40E-06	0.000372	0.0252	0.00129	0	3.34E-04
<Resources>								
iron ore	kg	0.000266	0	0	0	0.000266	0	0
bauxite (Al2O3, ore)	kg	7.99	0	0	0	7.99	0	0

Table 8.11. Consumption of energy and resources in Case 3a. Incineration modelled with the Ecoinvent data.

Natural resource	**Unit**	**Total**	**Avoided emissions based on the coal power**	**Forestry**	**Paper mill**	**Printing**	**Trans-portations**	**Waste recovery and treatment**
wood	m3	1.47	0	1.47	0	0	0	0
<Energy>								
oil	kg	30.8	-0.0163	2.27	21.5	1.84	4.84	0.423
<Fuels>								
coal (in ground)	kg	64.9	-32.5	1.09	89.2	6.46	0	0.573
crude oil	kg	0.0388	-0.000430	0	0.0391	0	0	0.000105
natural gas (in ground)	kg	44.8	-0.655	0.512	41.2	3.38	0	0.269
uranium ore	kg	0.0194	-1.84E-06	0.000226	0.0178	0.00129	0	1.18E-04
<Resources>								
iron ore	kg	0.000266	0	0	0	0.000266	0	0
bauxite (Al2O3, ore)	kg	7.99	0	0	0	7.99	0	0

Table 8.12. Consumption of energy and resources in Case 3b. Incineration modelled with the Ecoinvent data.

Natural resource	**Unit**	**Total**	**Avoided emissions based on the coal power**	**Forestry**	**Paper mill**	**Printing**	**Trans-portations**	**Waste recovery and treatment**
wood	m3	2.43	0	2.43	0	0	0	0
<Energy>								
oil	kg	23.2	-0.0463	3.76	12.3	1.84	4.84	0.484
<Fuels>								
coal (in ground)	kg	42.1	-92.6	1.80	123.1	6.46	0	3.29
crude oil	kg	0.0371	-0.001227	0	0.0195	0	0	0.0188
natural gas (in ground)	kg	61.5	-1.868	0.846	57.7	3.38	0	1.54
uranium ore	kg	0.0275	-5.25E-06	0.000372	0.0252	0.00129	0	6.66E-04
<Resources>								
iron ore	kg	0.000266	0	0	0	0.000266	0	0
bauxite (Al2O3, ore)	kg	7.99	0	0	0	7.99	0	0

Appendix 9. Production of wastes in the product systems

Production of wastes

Production of wastes in the product systems. Incineration modelled with the Högdalen data. Avoided production calculated with the average Finnish energy production.

Waste type	Production of waste (kg) per ton of newspaper				
	Case 1	Case 2a	Case 2b	Case 3a	Case 3b
Ash	66.5	69.2	49.4	68.8	48.0
Hazardous wastes	3.28	3.28	3.30	3.28	3.30
Biodegradable waste	10.5	10.5	12.1	10.5	12.1
Wastes to be recovered	155	155	145	155	145
Miscellaneous	49.6	45.3	14.6	49.0	25.3
Total	**285**	**283**	**225**	**286**	**234**

Life cycle phase	Production of waste (kg) per ton of newspaper				
	Case 1	Case 2a	Case 2b	Case 3a	Case 3b
Forestry	2.9219	2.9219	4.8212	2.9219	4.8213
Paper mill	133.05	133.05	83.416	133.05	83.416
Printing	152.86	152.86	152.86	152.86	152.86
Waste recovery and treatment	0.0878	2.9482	8.3468	2.3832	6.7903
Transportations	0.0371	0.0372	0.0389	0.0371	0.0388

Appendix 10. Emissions to air and water from the product systems

Avoided emissions calculated with the average Finnish energy and heat production

Table 10.1. Emissions to air and water in Case 1.

Emissions to air	Unit	Total	Avoided emissions based on the Finnish average energy	Forestry	Paper mill	Printing	Trans-portations	Waste recovery and treatment
Al, air	kg	4.74E-05	0	0	4.74E-05	0	0	0
aldehydes, air	kg	0.000934	-3.86E-05	1.06E-05	0.000863	9.87E-05	0	2.47E-07
As, air	kg	3.08E-06	-1.27E-07	3.47E-08	2.97E-06	1.98E-07	0	8.10E-10
Cd, air	kg	2.00E-06	-8.93E-08	2.44E-08	1.92E-06	1.39E-07	0	5.70E-10
CH4	kg	7.59	-0.169	0.0774	0.491	0.276	0.00753	6.91
CO	kg	1.48	-0.0808	0.314	0.0967	0.153	0.989	0.00606
Co, air	kg	0	0	0	0	0	0	0
CO2, fossil	kg	947	-68.1	35.6	781	117	80.2	2.07
Cr, air	kg	1.58E-05	-5.83E-07	1.59E-07	1.53E-05	9.11E-07	0	3.73E-09
Cu, air	kg	9.79E-06	-3.64E-07	9.94E-08	9.48E-06	5.68E-07	0	2.32E-09
dust	kg	0.000174	0	0	0.000174	0	0	0
Fe, air	kg	4.74E-05	0	0	4.74E-05	0	0	0
H2S	kg	5.10E-06	0	0	0	5.10E-06	0	0
HCl, air	kg	0.000147	0	0	0	0.000147	0	0
heavy metals, air	g	0.0463	-0.0189	0.0322	0.00221	0.0309	0	0
HF, air	kg	0.000421	0	0	0	0.000421	0	0
Hg, air	kg	1.15E-05	-4.43E-07	1.21E-07	1.11E-05	6.92E-07	0	2.83E-09
metals (unspecified), air	kg	1.23E-06	0	0	0	1.23E-06	0	0
Mn, air	kg	0	0	0	0	0	0	0
N2O	kg	0.024190674	-0.000580586	0.000158691	0.0177011	0.0015537	0.00482066	0.000537109
NH3, air	kg	0.00847	0	0	0.00845	1.85E-05	0	0
Ni, air	kg	4.62E-05	-1.87E-06	5.11E-07	4.46E-05	2.92E-06	0	1.19E-08
VOC, summatut	kg	0.190386636	-0.000117379	0.102835083	0.0183946	0.067509362	0	0.00176497
NOx	kg	3.03	-0.141	0.178	2.06	0.253	0.658	0.0235
PAH, air	kg	0	0	0	0	0	0	0
particles	kg	0.577	-0.110	0.00611	0.419	0.240	0.0207865	0.00165
Pb, air	kg	4.27E-05	-1.78E-06	4.88E-07	4.12E-05	2.79E-06	0	1.14E-08
Sb, air	kg	0	0	0	0	0	0	0
Sn, air	kg	0	0	0	0	0	0	0
SO2	kg	1.84	-0.124	0.0540	1.59	0.247	0.0711	0.00212
V, air	kg	0.000117	-5.11E-06	1.40E-06	0.000113	7.97E-06	0	3.26E-08
Zn, air	kg	4.24E-05	-7.99E-07	2.18E-07	4.17E-05	0.00000125	0	5.10E-09

Emissions to water	Unit	Total	Avoided emissions based on the Finnish average energy	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
As, water	kg	3.72E-06	0	0	3.72E-06	0	0	0
BOD	kg	0.342	0	0.000704	0.198	4.21E-05	0	0.144
Cd, water	kg	2.81E-05	0	0	0	0	0	2.81E-05
COD	kg	5.627	-0.00134	0.00935	4.76	0.00224	0.000607	0.861
Cr, water	kg	0.000899	0	0	0	0	0	0.00089924
Cu, water	kg	0.00281	0	0	0	0	0	0.00281013
Hg, water	kg	5.62E-07	0	0	0	0	0	5.62E-07
N, water as NH4	kg	0.00641	-8.96E-05	2.45E-05	0.00634	0.000140	0	5.72E-07
NH4+, NH3, as N, ammonia, water	kg	0.00128	-5.73E-05	1.57E-05	0.00123	8.95E-05	0	3.66E-07
Ni, water	kg	0.00770	-0.000147	0.0000401	0.00757	0.000229	0	9.38E-07
N, tot	kg	0.147	-0.000259	0.0000818	0.109	0.000412	0.0000271	0.0381
P, tot	kg	0.00704	-3.79E-06	0.000135	0.00691	5.92E-06	0	2.42E-08
Pb, water	kg	0.000206	0	0	0	0	0	0.000206
Zn, water	kg	0.000206	0	0	0	0	0	0.000206

Table 10.2. Emissions to air and water in Case 2a.

Emissions to air	Unit	Total	Avoided emissions based on the Finnish average energy	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
Al, air	kg	4.74E-05	0	0	4.74E-05	0	0	0
aldehydes, air	kg	0.000908	-7.35E-05	1.06E-05	0.000863	9.87E-05	0	9.08E-06
As, air	kg	3.00E-06	-2.41E-07	3.47E-08	2.97E-06	1.98E-07	0	4.03E-08
Cd, air	kg	1.94E-06	-1.70E-07	2.44E-08	1.92E-06	1.39E-07	0	2.23E-08
CH4	kg	0.48	-0.371	0.0774	0.491	0.276	0.00753	0.00
CO	kg	1.38	-0.1794	0.314	0.0967	0.153	0.989	0.01033
Co, air	kg	3.71E-08	0	0	0	0	0	3.70566E-08
CO2, fossil	kg	875	-145.0	35.6	781	117	80.4	6.69
Cr, air	kg	1.54E-05	-1.11E-06	1.59E-07	1.53E-05	9.11E-07	0	1.21E-07
Cu, air	kg	9.63E-06	-6.92E-07	9.94E-08	9.48E-06	5.68E-07	0	1.74E-07
dust	kg	0.00466	0	0	0.000174	0	0	0.00449
Fe, air	kg	4.74E-05	0	0	4.74E-05	0	0	0
H2S	kg	5.10E-06	0	0	0	5.10E-06	0	0
HCl, air	kg	0.000147	0	0	0	0.000147	0	0
heavy metals, air	g	0.0231	-0.0422	0.0322	0.00221	0.0309	0	2.55702E-05
HF, air	kg	0.000421	0	0	0	0.000421	0	0
Hg, air	kg	1.93E-05	-8.43E-07	1.21E-07	1.11E-05	6.92E-07	0	8.19E-06
metals (unspecified), air	kg	1.23E-06	0	0	0	1.23E-06	0	0
Mn, air	kg	3.71E-08	0	0	0	0	0	3.71E-08
N2O	kg	0.024032316	-0.00110405	0.000158692	0.0177011	0.0015537	0.00482912	0.000893754
NH3, air	kg	0.00847	0	0	0.00845	1.85E-05	0	0
Ni, air	kg	4.47E-05	-3.56E-06	5.11E-07	4.46E-05	2.92E-06	0	2.29E-07
VOC, summatut	kg	0.188565556	-0.000223209	0.102835083	0.0183946	0.067509362	0	4.972E-05
NOx	kg	2.88	-0.302	0.178	2.06	0.253	0.660	0.0349
PAH, air	kg	0	0	0	0	0	0	0
particles	kg	0.643	-0.244	0.00611	0.419	0.240	0.0208098	0.20058
Pb, air	kg	4.14E-05	-3.39E-06	4.88E-07	4.12E-05	2.79E-06	0	2.93E-07
Sb, air	kg	7.16E-07	0	0	0	0	0	7.16E-07
Sn, air	kg	7.16E-07	0	0	0	0	0	7.16E-07
SO2	kg	1.88	-0.267	0.0540	1.59	0.247	0.0712	0.18186
V, air	kg	0.000113	-9.71E-06	1.40E-06	0.000113	7.97E-06	0	7.99E-07
Zn, air	kg	5.04E-05	-1.52E-06	2.18E-07	4.17E-05	0.00000125	0	8.71E-06

Emissions to water	Unit	Total	Avoided emissions based on the Finnish average energy	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
As, water	kg	3.72E-06	0	0	3.72E-06	0	0	0
BOD	kg	0.199	0	0.00070443	0.198	4.21E-05	0	0
Cd, water	kg	0	0	0	0	0	0	0
COD	kg	4.76	-0.00256	0.00935024	4.76	0.00224	0.000609	0.000130
Cr, water	kg	0	0	0	0	0	0	0
Cu, water	kg	0	0	0	0	0	0	0
Hg, water	kg	0	0	0	0	0	0	0
N, water as NH4	kg	0.00634	-0.000170	2.45E-05	0.00634	0.000140	0	7.52E-06
NH4+, NH3, as N, ammonia, water	kg	0.00124	-0.000109	1.57E-05	0.00123	8.95E-05	0	4.81E-06
Ni, water	kg	0.00758	-0.000279	0.0000401	0.00757	0.000229	0	1.23E-05
N, tot	kg	0.109	-0.000492	8.18E-05	0.109	0.000412	2.72E-05	2.25E-05
P, tot	kg	0.00704	-7.20E-06	0.000135	0.00691	5.92E-06	0	3.18E-07
Pb, water	kg	0	0	0	0	0	0	0
Zn, water	kg	0	0	0	0	0	0	0

Table 10.3. Emissions to air and water in Case 2b.

Emissions to air	Unit	Total	Avoided emissions based on the Finnish average energy	Forestry	Paper mill	Printing	Transportations	Waste recovery and treatment
Al, air	kg	2.60E-05	0	0	2.60E-05	0	0	0
aldehydes, air	kg	0.00112	-2.09E-04	1.74E-05	0.00119	9.87E-05	0	2.05E-05
As, air	kg	3.67E-06	-6.88E-07	5.72E-08	4.00E-06	1.98E-07	0	9.71E-08
Cd, air	kg	2.47E-06	-4.84E-07	4.03E-08	2.72E-06	1.39E-07	0	5.11E-08
CH4	kg	-0.0298	-1.058	0.1277	0.609	0.276	0.00752	0.01
CO	kg	1.24	-0.511	0.518	0.0721	0.153	0.992	0.0129
Co, air	kg	1.06E-07	0	0	0	0	0	1.06E-07
CO2, fossil	kg	597	-413.4	58.8	739	117	83.9	12.65
Cr, air	kg	1.76E-05	-3.16E-06	2.63E-07	1.93E-05	9.11E-07	0	2.62E-07
Cu, air	kg	1.12E-05	-1.97E-06	1.64E-07	1.20E-05	5.68E-07	0	4.44E-07
dust	kg	0.00599	0	0	0.0000871	0	0	0.00591
Fe, air	kg	2.60E-05	0	0	2.60E-05	0	0	0
H2S	kg	5.10E-06	0	0	0	5.10E-06	0	0
HCl, air	kg	0.000147	0	0	0	0.000147	0	0
heavy metals, air	g	-0.0349	-0.1202	0.0531	0.00130	0.0309	0	7.28927E-05
HF, air	kg	0.000421	0	0	0	0.000421	0	0
Hg, air	kg	3.62E-05	-2.40E-06	2.00E-07	1.44E-05	6.92E-07	0	2.33E-05
metals (unspecified), air	kg	1.23E-06	0	0	0	1.23E-06	0	0
Mn, air	kg	1.06E-07	0	0	0	0	0	1.05637E-07
N2O	kg	0.023842245	-0.0031473	0.000261845	0.019346	0.0015537	0.00480415	0.00102385
NH3, air	kg	0.00424	0	0	0.00422	1.85E-05	0	0
Ni, air	kg	5.35E-05	-1.01E-05	8.43E-07	5.95E-05	2.92E-06	0	3.89E-07
VOC, summatut	kg	0.249028189	-0.0006363	0.169680938	0.01234891	0.067509362	0	0.000125279
NOx	kg	2.28	-0.860	0.293	1.84	0.253	0.711	0.0490
PAH, air	kg	0	0	0	0	0	0	0
particles	kg	0.455	-0.695	0.0101	0.313	0.240	0.0211	0.567
Pb, air	kg	5.05E-05	-9.67E-06	8.05E-07	5.60E-05	2.79E-06	0	5.85E-07
Sb, air	kg	2.04E-06	0	0	0	0	0	2.04231E-06
Sn, air	kg	2.04E-06	0	0	0	0	0	2.04231E-06
SO2	kg	1.55	-0.760	0.0891	1.39	0.247	0.0702	0.510
V, air	kg	0.000142	-2.77E-05	2.30E-06	0.000157	7.97E-06	0	1.56E-06
Zn, air	kg	5.98E-05	-4.33E-06	3.60E-07	3.78E-05	0.00000125	0	2.47E-05

Emissions to water	Unit	Total	Avoided emissions based on the Finnish average energy	Forestry	Paper mill	Printing	Transportations	Waste recovery and treatment
As, water	kg	1.86E-06	0	0	1.86E-06	0	0	0
BOD	kg	0.193	0	0.00116233	0.192	4.21E-05	0	0
Cd, water	kg	0	0	0	0	0	0	0
COD	kg	4.73	-0.00729	0.0154281	4.72	0.00224	0.000636	0.000152
Cr, water	kg	0	0	0	0	0	0	0
Cu, water	kg	0	0	0	0	0	0	0
Hg, water	kg	0	0	0	0	0	0	0
N, water as NH4	kg	0.00378	-0.000486	4.04E-05	0.00408	0.000140	0	8.87E-06
NH4+, NH3, as N, ammonia, water	kg	0.00156	-0.000311	2.58E-05	0.00175	8.95E-05	0	5.67E-06
Ni, water	kg	0.00534	-0.000796	0.0000662	0.00583	0.000229	0	1.45E-05
N, tot	kg	0.104	-0.00140	0.000135	0.104	0.000412	2.84E-05	2.65E-05
P, tot	kg	0.00702	-2.05E-05	0.000223	0.00681	5.92E-06	0	3.75E-07
Pb, water	kg	0	0	0	0	0	0	0
Zn, water	kg	0	0	0	0	0	0	0

Table 10.4. Emissions to air and water in Case 3a. Incineration modelled with the Högdalen data.

Emissions to air	Unit	Total	Avoided emissions based on the Finnish average energy	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
Al, air	kg	4.74E-05	0	0	4.74E-05	0	0	0
aldehydes, air	kg	0.000972	-6.43E-06	1.06E-05	0.000863	9.87E-05	0	5.90E-06
As, air	kg	3.20E-06	-2.11E-08	3.47E-08	2.97E-06	1.98E-07	0	1.82E-08
Cd, air	kg	2.09E-06	-1.48E-08	2.44E-08	1.92E-06	1.39E-07	0	1.40E-08
CH4	kg	0.51	-0.349	0.0774	0.491	0.276	0.00753	0.01
CO	kg	1.65	-0.1824	0.314	0.0967	0.153	0.989	0.28477
Co, air	kg	0	0	0	0	0	0	0
CO2, fossil	kg	905	-112.7	35.6	781	117	80.2	5.25
Cr, air	kg	2.53E-05	-9.70E-08	1.59E-07	1.53E-05	9.11E-07	0	9.03E-06
Cu, air	kg	1.03E-05	-6.05E-08	9.94E-08	9.48E-06	5.68E-07	0	2.35E-07
dust	kg	0.000218	0	0	0.000174	0	0	0.0000442
Fe, air	kg	4.74E-05	0	0	4.74E-05	0	0	0
H2S	kg	5.10E-06	0	0	0	5.10E-06	0	0
HCl, air	kg	0.000147	0	0	0	0.000147	0	0
heavy metals, air	g	0.0218	-0.0435	0.0322	0.00221	0.0309	0	1.52344E-06
HF, air	kg	0.000421	0	0	0	0.000421	0	0
Hg, air	kg	1.19E-05	-7.37E-08	1.21E-07	1.11E-05	6.92E-07	0	9.09E-08
metals (unspecified), air	kg	1.23E-06	0	0	0	1.23E-06	0	0
Mn, air	kg	0	0	0	0	0	0	0
N2O	kg	0.033594531	-9.65809E-05	0.000158692	0.0177011	0.0015537	0.00482068	0.00945694
NH3, air	kg	0.0112	0	0	0.00845	1.85E-05	0	0.00270
Ni, air	kg	4.80E-05	-3.11E-07	5.11E-07	4.46E-05	2.92E-06	0	2.69E-07
VOC, summatut	kg	0.190456294	-1.95261E-05	0.102835083	0.0183946	0.067509362	0	0.001736775
NOx	kg	2.98	-0.241	0.178	2.06	0.253	0.658	0.0762
PAH, air	kg	7.88482E-07	0	0	0	0	0	7.88E-07
particles	kg	0.460	-0.242	0.00611	0.419	0.240	0.0208	0.0159
Pb, air	kg	4.44E-05	-2.97E-07	4.88E-07	4.12E-05	2.79E-06	0	2.60E-07
Sb, air	kg	0	0	0	0	0	0	0
Sn, air	kg	0	0	0	0	0	0	0
SO2	kg	1.79	-0.217	0.0540	1.59	0.247	0.0711	0.0446
V, air	kg	0.000122	-8.49E-07	1.40E-06	0.000113	7.97E-06	0	7.34E-07
Zn, air	kg	4.37E-05	-1.33E-07	2.18E-07	4.17E-05	0.00000125	0	6.10E-07

Emissions to water	Unit	Total	Avoided emissions based on the Finnish average energy	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
As, water	kg	3.72E-06	0	0	3.72E-06	0	0	0
BOD	kg	0.199	0	0.000704	0.198	4.21E-05	0	0
Cd, water	kg	0	0	0	0	0	0	0
COD	kg	4.77	-0.000224	0.00935	4.76	0.00224	0.000607	0.000204
Cr, water	kg	0	0	0	0	0	0	0
Cu, water	kg	0	0	0	0	0	0	0
Hg, water	kg	0	0	0	0	0	0	0
N, water as NH4	kg	0.00650	-1.49E-05	2.45E-05	0.00634	0.000140	0	1.29E-05
NH4+, NH3, as N, ammonia, water	kg	0.00134	-9.53E-06	1.57E-05	0.00123	8.95E-05	0	8.24E-06
Ni, water	kg	0.00784	-2.44E-05	0.0000401	0.00757241	0.000229	0	2.11E-05
N, tot	kg	0.109	-4.30E-05	8.18E-05	0.109	0.000412	2.71E-05	3.77E-05
P, tot	kg	0.00705	-6.30E-07	0.000135	0.00691	5.92E-06	0	5.45E-07
Pb, water	kg	0	0	0	0	0	0	0
Zn, water	kg	0	0	0	0	0	0	0

Table 10.5. Emissions to air and water in Case 3b. Incineration modelled with the Högdalen data.

Emissions to air	**Unit**	**Total**	**Avoided emissions based on the Finnish average energy**	**Forestry**	**Paper mill**	**Printing**	**Trans-porta-tions**	**Waste recovery and treatment**
Al, air	kg	2.60E-05	0	0	2.60E-05	0	0	0
aldehydes, air	kg	0.00131	-1.83E-05	1.74E-05	0.001191	9.87E-05	0	1.66E-05
As, air	kg	4.25E-06	-6.02E-08	5.72E-08	4.00E-06	1.98E-07	0	5.13E-08
Cd, air	kg	2.90E-06	-4.23E-08	4.03E-08	2.72E-06	1.39E-07	0	3.93E-08
CH4	kg	0.06	-0.994	0.128	0.609	0.276	0.00752	0.03
CO	kg	2.02	-0.520	0.519	0.0721	0.153	0.992	0.801
Co, air	kg	0	0	0	0	0	0	0
CO2, fossil	kg	689	-321.4	58.8	739	117	83.7	12.41
Cr, air	kg	4.59E-05	-2.77E-07	2.63E-07	1.93E-05	9.11E-07	0	2.57E-05
Cu, air	kg	1.32E-05	-1.72E-07	1.64E-07	1.20E-05	5.68E-07	0	6.68E-07
dust	kg	0.000213	0	0	0.000087	0	0	0.000126
Fe, air	kg	2.60E-05	0	0	2.60E-05	0	0	0
H2S	kg	5.10E-06	0	0	0	5.10E-06	0	0
HCl, air	kg	0.000147	0	0	0	0.000147	0	0
heavy metals, air	g	-0.0386	-0.1239	0.0531	0.00130	0.0309	0	4.34E-06
HF, air	kg	0.000421	0	0	0	0.000421	0	0
Hg, air	kg	1.53E-05	-2.10E-07	2.00E-07	1.44E-05	6.92E-07	0	2.57E-07
metals (unspecified), air	kg	1.23E-06	0	0	0	1.23E-06	0	0
Mn, air	kg	0	0	0	0	0	0	0
N2O	kg	0.05164936	-0.000275322	0.000261844	0.019346	0.00155371	0.00479471	0.025968418
NH3, air	kg	0.0119	0	0	0.00422	1.85E-05	0	0.00769
Ni, air	kg	6.31E-05	-8.87E-07	8.43E-07	5.95E-05	2.92E-06	0	7.56E-07
VOC, summatut	kg	0.254433902	-5.56627E-05	0.169680938	0.01234891	0.067509363	0	0.004950353
NOx	kg	2.59	-0.688	0.294	1.84	0.253	0.709	0.186
PAH, air	kg	2.24771E-06	0	0	0	0	0	2.25E-06
particles	kg	-0.065	-0.691	0.01016	0.313	0.240	0.0210898	0.0423
Pb, air	kg	5.94E-05	-8.46E-07	8.05E-07	5.60E-05	2.79E-06	0	7.32E-07
Sb, air	kg	0	0	0	0	0	0	0
Sn, air	kg	0	0	0	0	0	0	0
SO2	kg	1.30	-0.619	0.0891	1.39	0.247	0.0698	0.124
V, air	kg	0.000167	-2.42E-06	2.30E-06	0.000157	7.97E-06	0	2.07E-06
Zn, air	kg	4.08E-05	-3.79E-07	3.60E-07	3.78E-05	0.00000125	0	1.73E-06

Emissions to water	Unit	Total	Avoided emissions based on the Finnish average energy	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
As, water	kg	1.86E-06	0	0	1.86E-06	0	0	0
BOD	kg	0.193	0	0.001162	0.192	4.21E-05	0	0
Cd, water	kg	0	0	0	0	0	0	0
COD	kg	4.73	-0.000638	0.01543	4.72	0.00224	0.000635	0.000555
Cr, water	kg	0	0	0	0	0	0	0
Cu, water	kg	0	0	0	0	0	0	0
Hg, water	kg	0	0	0	0	0	0	0
N, water as NH4	kg	0.00425	-4.25E-05	4.04E-05	0.00408	0.000140	0	3.62E-05
NH4+, NH3, as N, ammonia, water	kg	0.00186	-2.72E-05	2.58E-05	0.00175	8.95E-05	0	2.32E-05
Ni, water	kg	0.00611	-6.96E-05	0.0000662	0.00582954	0.000229	0	5.94E-05
N, tot	kg	0.105	-0.000123	0.000135	0.104	0.000412	2.83E-05	0.000105
P, tot	kg	0.00704	-1.80E-06	0.000223	0.00681	5.92E-06	0	1.53E-06
Pb, water	kg	0	0	0	0	0	0	0
Zn, water	kg	0	0	0	0	0	0	0

Avoided emissions calculated with energy generated in a coal-powered CHP-plant

Table 10.6. Emissions to air and water in Case 1.

Emissions to air	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
Al, air	kg	4.74E-05	0	0	4.74E-05	0	0	0
aldehydes, air	kg	0.000556	-4.17E-04	1.06E-05	0.000863	9.87E-05	0	2.47E-07
As, air	kg	2.74E-06	-4.67E-07	3.47E-08	2.97E-06	1.98E-07	0	8.10E-10
Cd, air	kg	2.09E-06	-2.68E-10	2.44E-08	1.92E-06	1.39E-07	0	5.70E-10
CH4	kg	7.76	-0.001	0.0774	0.491	0.276	0.00753	6.91
CO	kg	1.55	-0.0028	0.314	0.0967	0.153	0.987	0.00606
Co, air	kg	0	0	0	0	0	0	0
CO2, fossil	kg	907	-107.1	35.6	781	117	79.0	2.07
Cr, air	kg	1.38E-05	-2.56E-06	1.59E-07	1.53E-05	9.11E-07	0	3.73E-09
Cu, air	kg	1.02E-05	-1.09E-09	9.94E-08	9.48E-06	5.68E-07	0	2.32E-09
dust	kg	-0.000210	-0.000384465	0	0.000174	0	0	0
Fe, air	kg	4.74E-05	0	0	4.74E-05	0	0	0
H2S	kg	5.10E-06	0	0	0	5.10E-06	0	0
HCl, air	kg	0.000147	0	0	0	0.000147	0	0
heavy metals, air	g	0.0653	0.0000	0.0322	0.00221	0.0309	0	0
HF, air	kg	0.000421	0	0	0	0.000421	0	0
Hg, air	kg	1.19E-05	-1.33E-09	1.21E-07	1.11E-05	6.92E-07	0	2.83E-09
metals (unspecified), air	kg	1.23E-06	0	0	0	1.23E-06	0	0
Mn, air	kg	0	0	0	0	0	0	0
N2O	kg	0.02076136	-0.00400823	0.000158691	0.0177011	0.0015537	0.00481899	0.000537109
NH3, air	kg	0.00847	0	0	0.00845	1.85E-05	0	0
Ni, air	kg	4.69E-05	-1.17E-06	5.11E-07	4.46E-05	2.92E-06	0	1.19E-08
VOC, summatut	kg	0.190500049	-3.96631E-06	0.102835083	0.0183946	0.067509362	0	0.00176497
NOx	kg	2.95	-0.192	0.178	2.06	0.253	0.626	0.0235
PAH, air	kg	0	0	0	0	0	0	0
particles	kg	0.575	-0.111	0.00611	0.419	0.240	0.0199161	0.00165
Pb, air	kg	4.31E-05	-1.40E-06	4.88E-07	4.12E-05	2.79E-06	0	1.14E-08
Sb, air	kg	0	0	0	0	0	0	0
Sn, air	kg	0	0	0	0	0	0	0
SO2	kg	1.76	-0.190	0.0540	1.59	0.247	0.0595	0.00212
V, air	kg	0.000083	-3.91E-05	1.40E-06	0.000113	7.97E-06	0	3.26E-08
Zn, air	kg	-1.68E-05	-6.01E-05	2.18E-07	4.17E-05	0.00000125	0	5.10E-09

Emissions to water	**Unit**	**Total**	**Avoided emissions based on the coal power**	**Forestry**	**Paper mill**	**Printing**	**Trans-porta-tions**	**Waste recovery and treatment**
As, water	kg	3.72E-06	0	0	3.72E-06	0	0	0
BOD	kg	0.342	0	0.000704	0.198	4.21E-05	0	0.144
Cd, water	kg	2.81E-05	0	0	0	0	0	2.81E-05
COD	kg	5.63	-4.63E-06	0.00935023	4.75522	0.00224	0.000607	0.861
Cr, water	kg	0.000899	0	0	0	0	0	0.000899
Cu, water	kg	0.00281	0	0	0	0	0	0.00281
Hg, water	kg	5.62E-07	0	0	0	0	0	5.62E-07
N, water as NH4	kg	0.00650	-2.69E-07	2.45E-05	0.00634	0.000140	0	5.72E-07
NH4＋, NH3, as N, ammonia, water	kg	0.00134	-1.72E-07	1.57E-05	0.00123	8.95E-05	0	3.66E-07
Ni, water	kg	0.00784	-4.41E-07	0.0000401	0.00757	0.000229	0	9.38E-07
N, tot	kg	0.147	8.18E-05	0.109	0.000412	0.0381	2.71E-05	-8.12E-07
P, tot	kg	0.00705	-1.14E-08	0.000135	0.00691	5.92E-06	0	2.42E-08
Pb, water	kg	0.000206	0	0	0	0	0	0.000206
Zn, water	kg	0.000206	0	0	0	0	0	0.000206

Table 10.7. Emissions to air and water in Case 2a.

Emissions to air	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
Al, air	kg	4.74E-05	0	0	4.74E-05	0	0	0
aldehydes, air	kg	0.000125	-8.56E-04	1.06E-05	0.000863	9.87E-05	0	9.08E-06
As, air	kg	2.28E-06	-9.59E-07	3.47E-08	2.97E-06	1.98E-07	0	4.03E-08
Cd, air	kg	2.11E-06	-5.17E-10	2.44E-08	1.92E-06	1.39E-07	0	2.23E-08
CH4	kg	0.85	-0.003	0.0774	0.491	0.276	0.00753	0.00
CO	kg	1.55	-0.00563	0.314	0.0967	0.153	0.986	0.01033
Co, air	kg	3.71E-08	0	0	0	0	0	3.71E-08
CO2, fossil	kg	798	-219.8	35.6	781	117	77.9	6.69
Cr, air	kg	1.12E-05	-5.26E-06	1.59E-07	1.53E-05	9.11E-07	0	1.21E-07
Cu, air	kg	1.03E-05	-2.10E-09	9.94E-08	9.48E-06	5.68E-07	0	1.74E-07
dust	kg	0.00392	-0.000741	0	0.000174	0	0	0.00449
Fe, air	kg	4.74E-05	0	0	4.74E-05	0	0	0
H2S	kg	5.10E-06	0	0	0	5.10E-06	0	0
HCl, air	kg	0.000147	0	0	0	0.000147	0	0
heavy metals, air	g	0.0653	0.0000	0.0322	0.00221	0.0309	0	2.56E-05
HF, air	kg	0.000421	0	0	0	0.000421	0	0
Hg, air	kg	2.01E-05	-2.56E-09	1.21E-07	1.11E-05	6.92E-07	0	8.19E-06
metals (unspecified), air	kg	1.23E-06	0	0	0	1.23E-06	0	0
Mn, air	kg	3.71E-08	0	0	0	0	0	3.71E-08
N2O	kg	0.016902036	-0.00823092	0.000158692	0.0177011	0.0015537	0.00482571	0.000893754
NH3, air	kg	0.00847	0	0	0.00845	1.85E-05	0	0
Ni, air	kg	4.59E-05	-2.41E-06	5.11E-07	4.46E-05	2.92E-06	0	2.29E-07
VOC, summatut	kg	0.188781118	-7.64763E-06	0.102835083	0.0183946	0.067509362	0	4.972E-05
NOx	kg	2.72	-0.394	0.178	2.06	0.253	0.593	0.0349
PAH, air	kg	0	0	0	0	0	0	0
particles	kg	0.669	-0.216	0.00611	0.419	0.240	0.0190	0.20058
Pb, air	kg	4.19E-05	-2.89E-06	4.88E-07	4.12E-05	2.79E-06	0	2.93E-07
Sb, air	kg	7.16E-07	0	0	0	0	0	7.16E-07
Sn, air	kg	7.16E-07	0	0	0	0	0	7.16E-07
SO2	kg	1.73	-0.390	0.0540	1.59	0.247	0.0475	0.182
V, air	kg	0.000043	-8.04E-05	1.40E-06	0.000113	7.97E-06	0	7.99E-07
Zn, air	kg	-7.15E-05	-1.23E-04	2.18E-07	4.17E-05	0.00000125	0	8.71E-06

Emissions to water	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
As, water	kg	3.72E-06	0	0	3.72E-06	0	0	0
BOD	kg	0.199	0	0.000704	0.198	4.21E-05	0	0
Cd, water	kg	0.00E+00	0	0	0	0	0	0
COD	kg	4.77	-8.92E-06	0.00935024	4.76	0.00224	0.000608	0.000130
Cr, water	kg	0.000000	0	0	0	0	0	0
Cu, water	kg	0.00000	0	0	0	0	0	0
Hg, water	kg	0.00E+00	0	0	0	0	0	0
N, water as NH4	kg	0.00651	-5.18E-07	2.45E-05	0.00634	0.000140	0	7.52E-06
NH4+, NH3, as N, ammonia, water	kg	0.00134	-3.32E-07	1.57E-05	0.00123	8.95E-05	0	4.81E-06
Ni, water	kg	0.00785	-8.50E-07	0.0000401	0.00757	0.000229	0	1.23E-05
N, tot	kg	0.109	8.18E-05	0.109	0.000412	2.25E-05	2.71E-05	-1.57E-06
P, tot	kg	0.00705	-2.19E-08	0.000135	0.00691	5.92E-06	0	3.18E-07
Pb, water	kg	0	0	0	0	0	0	0
Zn, water	kg	0	0	0	0	0	0	0

Table 10.8. Emissions to air and water in Case 2b.

Emissions to air	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
Al, air	kg	2.60E-05	0	0	2.60E-05	0	0	0
aldehydes, air	kg	-0.00111	-2.44E-03	1.74E-05	0.001191	9.87E-05	0	2.05E-05
As, air	kg	1.62E-06	-2.73E-06	5.72E-08	4.00E-06	1.98E-07	0	9.71E-08
Cd, air	kg	2.95E-06	-1.47E-09	4.03E-08	2.72E-06	1.39E-07	0	5.11E-08
CH4	kg	1.02	-0.00800	0.128	0.609	0.276	0.00752	0.01
CO	kg	1.72	-0.0160	0.518	0.0721	0.153	0.984	0.01288
Co, air	kg	1.06E-07	0	0	0	0	0	1.06E-07
CO2, fossil	kg	377	-626	58.8	739	117	76.7	12.65
Cr, air	kg	5.75E-06	-1.50E-05	2.63E-07	1.93E-05	9.11E-07	0	2.62E-07
Cu, air	kg	1.32E-05	-6.00E-09	1.64E-07	1.20E-05	5.68E-07	0	4.44E-07
dust	kg	0.00388	-0.00211	0	0.0000871	0	0	0.00591
Fe, air	kg	2.60E-05	0	0	2.60E-05	0	0	0
H2S	kg	5.10E-06	0	0	0	5.10E-06	0	0
HCl, air	kg	0.000147	0	0	0	0.000147	0	0
heavy metals, air	g	0.0853	-0.0001	0.0531	0.00130	0.0309	0	7.29E-05
HF, air	kg	0.000421	0	0	0	0.000421	0	0
Hg, air	kg	3.86E-05	-7.31E-09	2.00E-07	1.44E-05	6.92E-07	0	2.33E-05
metals (unspecified), air	kg	1.23E-06	0	0	0	1.23E-06	0	0
Mn, air	kg	1.06E-07	0	0	0	0	0	1.06E-07
N2O	kg	0.003516025	-0.0234638	0.000261845	0.019346	0.0015537	0.00479443	0.00102385
NH3, air	kg	0.00424	0	0	0.00422	1.85E-05	0	0
Ni, air	kg	5.68E-05	-6.86E-06	8.43E-07	5.95E-05	2.92E-06	0	3.89E-07
VOC, summatut	kg	0.249642688	-2.1801E-05	0.169680938		0.067509362	0	0.000125279
NOx	kg	1.83	-1.123	0.293	1.84	0.253	0.519	0.0490
PAH, air	kg	0	0	0	0	0	0	0
particles	kg	0.530	-0.616	0.0101	0.313	0.240	0.0160	0.56673
Pb, air	kg	5.19E-05	-8.23E-06	8.05E-07	5.60E-05	2.79E-06	0	5.85E-07
Sb, air	kg	2.042E-06	0	0	0	0	0	2.04E-06
Sn, air	kg	2.042E-06	0	0	0	0	0	2.04E-06
SO2	kg	1.13	-1.113	0.0891	1.39	0.247	0.0025	0.510
V, air	kg	-0.000060	-2.29E-04	2.30E-06	0.000157	7.97E-06	0	1.56E-06
Zn, air	kg	-2.88E-04	-3.52E-04	3.60E-07	3.78E-05	0.00000125	0	2.47E-05

Emissions to water	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
As, water	kg	1.86E-06	0	0	1.86E-06	0	0	0
BOD	kg	0.193	0	0.001162	0.192	4.21E-05	0	0
Cd, water	kg	0.00E+00	0	0	0	0	0	0
COD	kg	4.73	-2.54E-05	0.0154281	4.72	0.00224	0.000633	0.000152
Cr, water	kg	0.000000	0	0	0	0	0	0
Cu, water	kg	0.00000	0	0	0	0	0	0
Hg, water	kg	0.00E+00	0	0	0	0	0	0
N, water as NH4	kg	0.00427	-1.48E-06	4.04E-05	0.00408	0.000140	0	8.87E-06
NH4+, NH3, as N, ammonia, water	kg	0.00187	-9.45E-07	2.58E-05	0.00175	8.95E-05	0	5.67E-06
Ni, water	kg	0.00614	-2.42E-06	0.0000662	0.00583	0.000229	0	1.45E-05
N, tot	kg	0.105	0.000135	0.104	0.000412	2.65E-05	2.82E-05	-4.46E-06
P, tot	kg	0.00704	-6.25E-08	0.000223	0.00681	5.92E-06	0	3.75E-07
Pb, water	kg	0	0	0	0	0	0	0
Zn, water	kg	0	0	0	0	0	0	0

Table 10.9. Emissions to air and water in Case 3a. Incineration modelled with the Orware data.

Emissions to air	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
Al, air	kg	4.74E-05	0	0	4.74E-05	0	0	0
aldehydes, air	kg	0.000494	-4.84E-04	1.06E-05	0.000863	9.87E-05	0	5.90E-06
As, air	kg	2.67E-06	-5.46E-07	3.47E-08	2.97E-06	1.98E-07	0	1.82E-08
Cd, air	kg	2.10E-06	-9.11E-11	2.44E-08	1.92E-06	1.39E-07	0	1.40E-08
CH4	kg	0.86	-0.000707	0.0774	0.491	0.276	0.00753	0.0109
CO	kg	1.83	-0.00269	0.314	0.0967	0.153	0.987	0.285
Co, air	kg	0	0	0	0	0	0	0
CO2, fossil	kg	893	-123.7	35.6	781	117	78.8	5.25
Cr, air	kg	2.24E-05	-2.98E-06	1.59E-07	1.53E-05	9.11E-07	0	9.03E-06
Cu, air	kg	1.04E-05	-3.71E-10	9.94E-08	9.48E-06	5.68E-07	0	2.35E-07
dust	kg	0.0000876	-0.000131	0	0.000174	0	0	0.0000442
Fe, air	kg	4.74E-05	0	0	4.74E-05	0	0	0
H2S	kg	5.10E-06	0	0	0	5.10E-06	0	0
HCl, air	kg	0.000147	0	0	0	0.000147	0	0
heavy metals, air	g	0.0653	-0.00000444	0.0322	0.00221	0.0309	0	1.52E-06
HF, air	kg	0.000421	0	0	0	0.000421	0	0
Hg, air	kg	1.20E-05	-4.52E-10	1.21E-07	1.11E-05	6.92E-07	0	9.09E-08
metals (unspecified), air	kg	1.23E-06	0	0	0	1.23E-06	0	0
Mn, air	kg	0	0	0	0	0	0	0
N2O	kg	0.029037952	-0.00465137	0.000158692	0.0177011	0.0015537	0.00481889	0.00945694
NH3, air	kg	0.0112	0	0	0.00845	1.85E-05	0	0.00270
Ni, air	kg	4.70E-05	-1.37E-06	5.11E-07	4.46E-05	2.92E-06	0	2.69E-07
VOC, summatut	kg	0.190474472	-1.34859E-06	0.102835083	0.0183946	0.067509362	0	0.001736775
NOx	kg	2.97	-0.221	0.178	2.06	0.253	0.620	0.0762
PAH, air	kg	7.88482E-07	0	0	0	0	0	7.88E-07
particles	kg	0.655	-0.046	0.00611	0.419	0.240	0.0198	0.0159
Pb, air	kg	4.31E-05	-1.64E-06	4.88E-07	4.12E-05	2.79E-06	0	2.60E-07
Sb, air	kg	0	0	0	0	0	0	0
Sn, air	kg	0	0	0	0	0	0	0
SO2	kg	1.77	-0.220	0.0540	1.59	0.247	0.0576	0.0446
V, air	kg	0.0000772	-4.57E-05	1.40E-06	0.000113	7.97E-06	0	7.34E-07
Zn, air	kg	-2.63E-05	-7.01E-05	2.18E-07	4.17E-05	0.00000125	0	6.10E-07

Emissions to water	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
As, water	kg	3.72E-06	0	0	3.72E-06	0	0	0
BOD	kg	0.199	0	0.000704	0.198	4.21E-05	0	0
Cd, water	kg	0.00E+00	0	0	0	0	0	0
COD	kg	4.77	-1.57E-06	0.00935024	4.76	0.00224	0.000607	0.000204
Cr, water	kg	0.000000	0	0	0	0	0	0
Cu, water	kg	0.00000	0	0	0	0	0	0
Hg, water	kg	0.00E+00	0	0	0	0	0	0
N, water as NH4	kg	0.00652	-9.14E-08	2.45E-05	0.00634	0.000140	0	1.29E-05
NH4+, NH3, as N, ammonia, water	kg	0.00135	-5.85E-08	1.57E-05	0.00123	8.95E-05	0	8.24E-06
Ni, water	kg	0.00786	-1.50E-07	0.0000401	0.00757	0.000229	0	2.11E-05
N, tot	kg	0.109	8.18E-05	0.109	0.000412	3.77E-05	2.71E-05	-2.76E-07
P, tot	kg	0.00705	-3.87E-09	0.000135	0.00691	5.92E-06	0	5.45E-07
Pb, water	kg	0	0	0	0	0	0	0
Zn, water	kg	0	0	0	0	0	0	0

Table 10.10. Emissions to air and water in Case 3b. Incineration modelled with the Orware data

Emissions to air	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
Al, air	kg	2.60E-05	0	0	2.60E-05	0	0	0
aldehydes, air	kg	-0.0000571	-1.38E-03	1.74E-05	0.00119	9.87E-05	0	1.66E-05
As, air	kg	2.75E-06	-1.56E-06	5.72E-08	4.00E-06	1.98E-07	0	5.13E-08
Cd, air	kg	2.94E-06	-2.60E-10	4.03E-08	2.72E-06	1.39E-07	0	3.93E-08
CH4	kg	1.05	-0.002	0.1277	0.609	0.276	0.00752	0.03
CO	kg	2.52	-0.0077	0.519	0.0721	0.153	0.988	0.80057
Co, air	kg	0	0	0	0	0	0	0
CO2, fossil	kg	653	-352.6	58.8	739	117	79.6	12.41
Cr, air	kg	3.77E-05	-8.51E-06	2.63E-07	1.93E-05	9.11E-07	0	2.57E-05
Cu, air	kg	1.34E-05	-1.06E-09	1.64E-07	1.20E-05	5.68E-07	0	6.68E-07
dust	kg	-0.000159	-0.000373	0	0.0000871	0	0	0.000126
Fe, air	kg	2.60E-05	0	0	2.60E-05	0	0	0
H2S	kg	5.10E-06	0	0	0	5.10E-06	0	0
HCl, air	kg	0.000147	0	0	0	0.000147	0	0
heavy metals, air	g	0.0853	0.0000	0.0531	0.00130	0.0309	0	4.34E-06
HF, air	kg	0.000421	0	0	0	0.000421	0	0
Hg, air	kg	1.55E-05	-1.29E-09	2.00E-07	1.44E-05	6.92E-07	0	2.57E-07
metals (unspecified), air	kg	1.23E-06	0	0	0	1.23E-06	0	0
Mn, air	kg	0	0	0	0	0	0	0
N2O	kg	0.038660002	-0.0132596	0.000261844	0.019346	0.00155371	0.00478963	0.025968418
NH3, air	kg	0.0119	0	0	0.00422	1.85E-05	0	0.00769
Ni, air	kg	6.01E-05	-3.89E-06	8.43E-07	5.95E-05	2.92E-06	0	7.56E-07
VOC, summatut	kg	0.25448572	-3.84441E-06	0.169680938	0	0.01234891	0.067509363	0
NOx	kg	2.54	-0.630	0.294	1.84	0.253	0.600	0.1862
PAH, air	kg	2.25E-06	0	0	0	0	0	2.25E-06
particles	kg	0.492	-0.131	0.01016	0.313	0.240	0.0182067	0.04232
Pb, air	kg	5.56E-05	-4.67E-06	8.05E-07	5.60E-05	2.79E-06	0	7.32E-07
Sb, air	kg	0	0	0	0	0	0	0
Sn, air	kg	0	0	0	0	0	0	0
SO2	kg	1.25	-0.628	0.0891	1.39	0.247	0.0315	0.12434
V, air	kg	0.0000395	-1.30E-04	2.30E-06	0.000157	7.97E-06	0	2.07E-06
Zn, air	kg	-1.59E-04	-2.00E-04	3.60E-07	3.78E-05	0.00000125	0	1.73E-06

Emissions to water	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
As, water	kg	1.86E-06	0	0	1.86E-06	0	0	0
BOD	kg	0.193	0	0.001162	0.192	4.21E-05	0	0
Cd, water	kg	0.00E+00	0	0	0	0	0	0
COD	kg	4.73	-4.49E-06	0.0154287	4.72	0.00224	0.000633	0.000555
Cr, water	kg	0.000000	0	0	0	0	0	0
Cu, water	kg	0.00000	0	0	0	0	0	0
Hg, water	kg	0.00E+00	0	0	0	0	0	0
N, water as NH4	kg	0.00430	-2.61E-07	4.04E-05	0.00408	0.000140	0	3.62E-05
NH4+, NH3, as N, ammonia, water	kg	0.00189	-1.67E-07	2.58E-05	0.00175	8.95E-05	0	2.32E-05
Ni, water	kg	0.00618	-4.27E-07	0.0000662	0.00583	0.000229	0	5.94E-05
N, tot	kg	0.105	0.000135	0.104	0.000412	0.000105	2.82E-05	-7.87E-07
P, tot	kg	0.00704	-1.10E-08	0.000223	0.00681	5.92E-06	0	1.53E-06
Pb, water	kg	0	0	0	0	0	0	0
Zn, water	kg	0	0	0	0	0	0	0

Table 10.11. Emissions to air and water in Case 3a. Incineration modelled with the Ecoinvent data.

Emissions to air	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
Al, air	kg	3.96E-03	0	0	4.74E-05	0	0	0.00391
aldehydes, air	kg	0.000662	-3.16E-04	1.06E-05	0.000863	9.87E-05	0	5.54E-06
As, air	kg	2.87E-06	-3.54E-07	3.47E-08	2.97E-06	1.98E-07	0	1.82E-08
Cd, air	kg	2.10E-06	-1.99E-10	2.44E-08	1.92E-06	1.39E-07	0	1.44E-08
CH4	kg	0.85	-0.001074	0.0774	0.491	0.276	0.00753	0.0041
CO	kg	1.60	-0.00210	0.314	0.0967	0.153	0.988	0.052
Co, air	kg	5.97E-12	0	0	0	0	0	5.97E-12
CO2, fossil	kg	935	-81.2	35.6	781	117	79.3	4.26
Cr, air	kg	1.45E-05	-1.94E-06	1.59E-07	1.53E-05	9.11E-07	0	8.38E-08
Cu, air	kg	1.02E-05	-8.12E-10	9.94E-08	9.48E-06	5.68E-07	0	9.76E-08
dust	kg	-0.0001120	-0.000286	0	0.000174	0	0	0.0000000
Fe, air	kg	4.74E-05	0	0	4.74E-05	0	0	0
H2S	kg	5.10E-06	0	0	0	5.10E-06	0	0
HCl, air	kg	0.000150	0	0	0	0.000147	0	3.06746E-06
heavy metals, air	g	0.0653	-0.00000973	0.0322	0.00221	0.0309	0	0.00E+00
HF, air	kg	0.000421	0	0	0	0.000421	0	0
Hg, air	kg	1.20E-05	-9.90E-10	1.21E-07	1.11E-05	6.92E-07	0	6.35E-08
metals (unspecified), air	kg	1.23E-06	0	0	0	1.23E-06	0	0
Mn, air	kg	0	0	0	0	0	0	0
N2O	kg	0.030646672	-0.00303899	0.000158692	0.0177011	0.0015537	0.00481939	0.00945278
NH3, air	kg	0.0086	0	0	0.00845	1.85E-05	0	0.00012
Ni, air	kg	4.75E-05	-8.89E-07	5.11E-07	4.46E-05	2.92E-06	0	2.68E-07
VOC, summatut	kg	0.188771227	-2.95138E-06	0.102835083	0.0183946	0.067509362	0	3.51333E-05
NOx	kg	3.01	-0.146	0.178	2.06	0.253	0.634	0.0269
PAH, air	kg	0	0	0	0	0	0	0.00E+00
particles	kg	0.605	-0.083	0.00611	0.419	0.240	0.0201	0.0023
Pb, air	kg	4.43E-05	-1.07E-06	4.88E-07	4.12E-05	2.79E-06	0	9.45E-07
Sb, air	kg	0	0	0	0	0	0	0
Sn, air	kg	0	0	0	0	0	0	0
SO2	kg	1.81	-0.144	0.0540	1.59	0.247	0.0623	0.0075
V, air	kg	0.0000932	-2.97E-05	1.40E-06	0.000113	7.97E-06	0	7.32E-07
Zn, air	kg	-2.03E-06	-4.55E-05	2.18E-07	4.17E-05	0.00000125	0	3.01E-07

Emissions to water	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-porta-tion	Waste recovery and treatment
As, water	kg	3.72E-06	0	0	3.72E-06	0	0	0
BOD	kg	0.199	0	0.000704	0.198	4.21E-05	0	0
Cd, water	kg	0.00E+00	0	0	0	0	0	0
COD	kg	4.77	-3.44E-06	0.00935	4.76	0.00224	0.000607	0.000203
Cr, water	kg	0.000000	0	0	0	0	0	0
Cu, water	kg	0.00000	0	0	0	0	0	0
Hg, water	kg	0.00E+00	0	0	0	0	0	0
N, water as NH4	kg	0.00651	-2.00E-07	2.45E-05	0.00634	0.000140	0	1.28E-05
NH4+, NH3, as N, ammonia, water	kg	0.00135	-1.28E-07	1.57E-05	0.00123	8.95E-05	0	8.21E-06
Ni, water	kg	0.00786	-3.28E-07	0.0000401	0.00757	0.000229	0	2.11E-05
N, tot	kg	0.109	8.18E-05	0.109	0.000412	3.77E-05	2.71E-05	-2.76E-07
P, tot	kg	0.00705	-8.46E-09	0.000135	0.00691	5.92E-06	0	5.43E-07
Pb, water	kg	0	0	0	0	0	0	0
Zn, water	kg	0	0	0	0	0	0	0

Table 10.12. Emissions to air and water in Case 3b. Incineration modelled with the Ecoinvent data.

Emissions to air	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-porta-tions	Waste recovery and treatment
Al, air	kg	1.12E-02	0	0	2.60E-05	0	0	0.0111505
aldehydes, air	kg	0.000421	-9.01E-04	1.74E-05	0.001191	9.87E-05	0	1.56E-05
As, air	kg	3.30E-06	-1.01E-06	5.72E-08	4.00E-06	1.98E-07	0	5.11E-08
Cd, air	kg	2.94E-06	-5.68E-10	4.03E-08	2.72E-06	1.39E-07	0	4.05E-08
CH4	kg	1.03	-0.003061	0.1277	0.609	0.276	0.00752	0.0116
CO	kg	1.86	-0.00599	0.519	0.0721	0.153	0.989	0.138
Co, air	kg	1.70E-11	0	0	0	0	0	1.70E-11
CO2, fossil	kg	773	-231.4	58.8	739	117	81.0	9.59
Cr, air	kg	1.52E-05	-5.53E-06	2.63E-07	1.93E-05	9.11E-07	0	2.36E-07
Cu, air	kg	1.30E-05	-2.32E-09	1.64E-07	1.20E-05	5.68E-07	0	2.76E-07
dust	kg	-0.0007284	-0.000816	0	0.000087	0	0	0.0000000
Fe, air	kg	2.60E-05	0	0	2.60E-05	0	0	0
H2S	kg	5.10E-06	0	0	0	5.10E-06	0	0
HCl, air	kg	0.000155	0	0	0	0.000147	0	8.74E-06
heavy metals, air	g	0.0853	-0.00002773	0.0531	0.00130	0.0309	0	0.00E+00
HF, air	kg	0.000421	0	0	0	0.000421	0	0
Hg, air	kg	1.55E-05	-2.82E-09	2.00E-07	1.44E-05	6.92E-07	0	1.79E-07
metals (unspecified), air	kg	1.23E-06	0	0	0	1.23E-06	0	0
Mn, air	kg	0	0	0	0	0	0	0
N2O	kg	0.043245884	-0.00866321	0.000261844	0.019346	0.00155371	0.00479104	0.0259565
NH3, air	kg	0.0046	0	0	0.00422	1.85E-05	0	0.00033
Ni, air	kg	6.14E-05	-2.53E-06	8.43E-07	5.95E-05	2.92E-06	0	7.54E-07
VOC, summatut	kg	0.249630301	-8.41345E-06	0.169680938	0.01234891	0.067509363	0	9.95037E-05
NOx	kg	2.65	-0.415	0.294	1.84	0.253	0.638	0.0455
PAH, air	kg	0	0	0	0	0	0	0.00E+00
particles	kg	0.349	-0.237	0.01016	0.313	0.240	0.0192	0.0036
Pb, air	kg	5.92E-05	-3.04E-06	8.05E-07	5.60E-05	2.79E-06	0	2.69E-06
Sb, air	kg	0	0	0	0	0	0	0
Sn, air	kg	0	0	0	0	0	0	0
SO2	kg	1.38	-0.411	0.0891	1.39	0.247	0.0448	0.0186
V, air	kg	0.0000851	-8.46E-05	2.30E-06	0.000157	7.97E-06	0	2.06E-06
Zn, air	kg	-8.95E-05	-1.30E-04	3.60E-07	3.78E-05	0.00000125	0	8.55E-07

Emissions to water	Unit	Total	Avoided emissions based on the coal power	Forestry	Paper mill	Printing	Trans-porta-tion	Waste recovery and treatment
As, water	kg	1.86E-06	0	0	1.86E-06	0	0	0
BOD	kg	0.193	0	0.001162	0.192	4.21E-05	0	0
Cd, water	kg	0.00E+00	0	0	0	0	0	0
COD	kg	4.73	-9.82E-06	0.0154287	4.72	0.00224	0.000633	0.000553
Cr, water	kg	0.000000	0	0	0	0	0	0
Cu, water	kg	0.00000	0	0	0	0	0	0
Hg, water	kg	0.00E+00	0	0	0	0	0	0
N, water as NH4	kg	0.00430	-5.70E-07	4.04E-05	0.00408	0.000140	0	3.61E-05
NH4+, NH3, as N, ammonia, water	kg	0.00189	-3.65E-07	2.58E-05	0.00175	8.95E-05	0	2.31E-05
Ni, water	kg	0.00618	-9.35E-07	0.0000662	0.00583	0.000229	0	5.92E-05
N, tot	kg	0.105	0.000135	0.104	0.000412	0.000105	2.82E-05	-7.87E-07
P, tot	kg	0.00704	-2.41E-08	0.000223	0.00681	5.92E-06	0	1.53E-06
Pb, water	kg	0	0	0	0	0	0	0
Zn, water	kg	0	0	0	0	0	0	0

Appendix 11. The characterisation, normalisation and weighting factors of the LCIA models used in the LCA-WASTE study

Table 11.1. The environmental interventions included in the LCIA application of the LCA-WASTE study and the impact category specific factors for the interventions.

DAIA			**Eco-indicator 99**			**EPS 2000**		
Impact category	**Inter-vention**	**Characteri-sation factor**	**Impact category**	**Inter-vention**	**Damage factor**	**Impact category**	**Inter-vention**	**Characteri-sation factor**
Climate change	CO_2 (fossil)	1	Carcinogenic effects on humans	As (a)	0.0246	Life expectancy	CO_2 (fossil)	0.000000793
	CH_4	23		Cd (a)	0.135		CO	0.00000238
	N_2O	296		Ni (a)	0.0235		NO_x	0.0000245
Acidification	SO_2	0.01635		metals (unspec.)	0.0052		N_2O	0.000244
	NO_x	0.00327		As (w)	0.0657		SO_2	0.0000376
	NH_3	0.01472		Cd (w)	0.0712		H_2S	0.000056
Aquatic eutrophication	NO_x	0.07		Ni (w)	0.0311		HCl	0.0000242
	NH_3	0.07	Respiratory effects caused by organic substances	aldehydes	0.0000014		NH_3	0.0000264
	P(w)	3.06		CH_4	1.28E-08		CH_4	0.0000195
	N(w)	0.42		NMVOC	0.00000128		TSP	0.000424
Oxygen depletion	BOD(w)	1	Respiratory effects caused by inorganic substances	NH_3	0.000085		As (a)	0.000975
	NH_4(w)	4.57		TSP	0.00011		Cd (a)	0.0000944
Tropospheric ozone formation	NMVOC	0.273		NO_x	0.0000887		Cr (a)	0.000205
	NO_x	0.727		SO_2	0.0000546	Severe morbidity	CO_2 (fossil)	0.000000353
	CO	0.064	Damage caused by climate change	CO_2 (fossil)	0.00000021		CO	0.00000106
	CH_4	0.003		CH_4	0.0000044		NO_x	-0.00000206
				N_2O	0.000069		N_2O	0.00011
			Damage caused by ecotoxic effects	As (a)	592		SO_2	-0.00000658
				Cd (a)	9650		H_2S	-0.0000098
				Cr (a)	4130		HCl	-0.00000429
				Cu (a)	1460		NH_3	-0.00000466
				Ni (a)	7100		CH_4	0.00000865
				Hg (a)	829		TSP	-0.00000233
				Pb (a)	2540		As (a)	0.000124
				Zn (a)	2890		Cd (a)	0.00000223
				metals (unspec.)	260		Cr (a)	0.0000262
				heavy metals (a)	260	Morbidity	CO_2 (fossil)	0.000000655
				As (w)	11.4		CO	0.00000196
				Cd (w)	480		NO_x	0.00000361
				Cr (w)	68.7		N_2O	0.000214
				Cu (w)	147		SO_2	0.0000102
				Ni (w)	143		H_2S	0.00000152
				Hg (w)	197		HCl	0.00000664
				Pb (w)	7.39		NH_3	0.00000722
				Zn (w)	16.3		CH_4	0.000016

			Damage caused by the combined effect of acidification and eutrophication	NH_3	15.57		TSP	0.0000092
				NO_x	5.713		Cd (a)	0.0000512
				SO_2	1.041		Hg (a)	0.0048
			Damage caused by land occupation and land conversion	Occupation as forest land	0.11		Hg (w)	0.0048
			Damage caused by extraction of minerals	bauxite	0.5	Severe nuisance	Pb (a)	0.291
				iron ore	0.029	Nuisance	CO	0.00000025
			Damage caused by extraction of fossil fuels	coal	0.252		NO_x	0.00241
				natural gas	4.55		N_2O	0.00325
				crude oil	5.9		SO_2	0.00645
				oil	6.05		H_2S	0.001
							HCl	0.0042
							NH_3	0.00456
							TSP	0.00228
						Crop growth capacity	CO_2 (fossil)	0.000756
							CO	0.00227
							NO_x	0.7
							N_2O	1.19
							SO_2	-0.0183
							H_2S	-0.0273
							HCl	-0.0119
							NH_3	-0.0129
							CH_4	0.0525
							TSP	-0.00646
						Wood growth capacity	CO_2 (fossil)	-0.0405
							CO	-0.0428
							NO_x	-2.73
							N_2O	-4.06
							SO_2	0.0281
							H_2S	0.0418
							HCl	0.0182
							NH_3	-7.4
							CH_4	-0.113
							TSP	0.00991

						Fish and meat production capacity	NO_x	-0.0339
							N_2O	-0.0485
							SO_2	0.00118
							H_2S	0.00176
							HCl	0.00105
							NH_3	-0.0908
							Hg (a)	0.224
							N tot (w)	-0.401
							Hg (w)	0.224
						Soil acidification	NO_x	1.09
							N_2O	1.47
							SO_2	1.56
							H_2S	2.32
							HCl	1.39
							NH_3	1.47
						Depletion of oil reserves	oil	-
						Depletion of coal reserves	coal	-
						Depletion of natural gas reserves	natural gas	-
						Depletion of elemental or mineral reserves	bauxite	-
							iron ore	-
							uranium	-
						Species extinction	CO_2 (fossil)	1.26E-14
							CO	3.78E-14
							NO_x	7.5E-14
							N_2O	4.13E-12
							SO_2	-2.94E-13
							H_2S	-4.38E-13
							HCl	-1.88E-13
							NH_3	4.96E-13
							CH_4	3.09E-13
							TSP	-1.08E-13
							Hg (a)	1.2E-10
							COD	9.18E-15
							N tot (w)	1.8E-13
							P tot (w)	5E-13
							Hg (w)	1.2E-10

Table 11.2. Normalisation and weighting factors used in the LCIA application of the LCA-WASTE study.

Impact assessment method	Impact categories	Damage categories / safeguard subjects	Normalisation factor	Weighting factor
DAIA	Climate change		66 901 590 t/a CO_2 ekv	0.31
(Seppälä 1999,	Acidification		4 153.73 t/a H+ ekv	0.26
Seppälä 2003)	Aquatic eutrophication		27 610 t/a NP	0.25
	Oxygen depletion		145 720 t/a BOD_7	0.06
	Tropospheric ozone formation		254 246 t/a POCP	0.12
Eco-indicator 99	Carcinogenic effects on humans	Human health	0.0154 DALYs	400
(Goedkoop and	Respiratory effects caused by organic substances			
Spriensma 2001)	Respiratory effects caused by inorganic substances			
	Damage caused by climate change			
	Damage caused by ecotoxic effects	Ecosystem quality	5130 PDF*m^2y	400
	Damage caused by the combined effect of acidification and eutrophication			
	Damage caused by land occupation and land conversion			
	Damage caused by extraction of minerals	Resources	8410 MJ surplus energy	200
	Damage caused by extraction of fossil fuels			
EPS 2000	Life expectancy	Human health		85 000
(Steen 1999a,	Severe morbidity			100 000
Steen 1999b)	Morbidity			10 000
	Severe nuisance			10 000
	Nuisance			100
	Crop growth capacity	Ecosystem production capacity		0.15
	Wood growth capacity			0.04
	Fish and meat production capacity			1
	Soil acidification			0.01
	Depletion of oil reserves	Abiotic stock resource		0.506
	Depletion of coal reserves			0.0498
	Depletion of natural gas reserves			1.1
	Depletion of elemental or mineral reserves			0.439 (bauxite)
				0.961 (iron ore)
				1190 (uranium)
	Species extinction	Biodiversity		1.1E+11

Appendix 12. Assessment of the forest area affected by the newspaper product systems

Table 12.1. Shares of wood originating from different forestry operations.

Forestry operation	Share (%) of fibre wood (spruce) from the operation			
	Ref. 1		Ref. 2	
	Fibre wood	Logs	Fibre wood	Logs
1. thinning	7	1	11	1
2. thinning	24	12	22	9
Final felling	69	87	67	90

Ref. 1. Metsäteho 2003

Ref. 2. Salonen 2004

Table 12.2. The yield of spruce from different forestry operations.

Forestry operation	Yield (m^3/ha) of spruce from the operation	
	Ref. 1	Ref. 2
1. thinning	45	69
2. thinning	45	48
Final felling	60	69

Ref. 1. Salonen 2004

Ref. 2. Mielikäinen and Riikkilä 1997

Table 12.3. The use of spruce (m^3/ton of newspaper) in the studied waste management options (Cases 1, 2a, 2b, 3a and 3b).

	Case 1	Case 2 a	Case 2 b	Case 3 a	Case 3b
Collection rate 0%					
Sum (m^3)	3.383	3.383	3.383	3.383	3.383
Fibre wood (m^3)	0.971	0.971	0.971	0.971	0.971
Logs (m^3)	2.411	2.411	2.411	2.411	2.411
Collection rate 45%					
Sum (m^3)	2.250	2.250	2.250	2.250	2.250
Fibre wood (m^3)	0.647	0.647	0.647	0.647	0.647
Logs (m^3)	1.603	1.603	1.603	1.603	1.603
Collection rate 76%					
Sum (m^3)	1.469	1.469	1.469	1.469	1.469
Fibre wood (m^3)	0.422	0.422	0.422	0.422	0.422
Logs (m^3)	1.047	1.047	1.047	1.047	1.047
Collection rate 82%					
Sum (m^3)	1.325	1.325	1.325	1.325	1.325
Fibre wood (m^3)	0.380	0.380	0.380	0.380	0.380
Logs (m^3)	0.944	0.944	0.944	0.944	0.944
Collection rate 97%					
Sum (m^3)	0.962	0.962	0.962	0.962	0.962
Fibre wood (m^3)	0.276	0.276	0.276	0.276	0.276
Logs (m^3)	0.686	0.686	0.686	0.686	0.686

Documentation page

Publisher	Finnish Environment Institute (SYKE)	Date May 2005
Author(s)	Helena Dahlbo, Jari Laukka, Tuuli Myllymaa, Sirkka Koskela, Jyrki Tenhunen, Jyri Seppälä, Timo Jouttijärvi and Matti Melanen	
Title of publication	Waste management options for discarded newspaper in the Helsinki Metropolitan Area - Life cycle assessment report	
Parts of publication/ other project publications	This publication is also availble in the Internet www.environment.fi/publications	
Abstract	Consumption and the amount of wastes are constantly increasing and therefore the waste management solutions have an increasing impact on the ecology and costs of the life cycle of a product. In an optimal situation the environmental impacts of a waste management solution are as few as possible and this is achieved with as low costs as possible. Searching and comparing the most appropriate waste management solutions demands systematic and case-specific studies. The Finnish Environment Institute (SYKE) and the University of Helsinki carried out in 2002 - 2004 a joint project called ”Life cycle approach to sustainability of waste management - a case study on newspaper (LCA-WASTE)”, financed by the National Technology Agency of Finland (Tekes). In the project, the ecology and costs of different waste management alternatives for newspaper were studied. This report describes the process and results of the life cycle assessment performed in the study. Five waste management alternatives for discarded newspaper in the Helsinki Metropolitan Area (HMA) were formulated and assessed. The whole life cycle of newspaper, comprising forestry, manufacturing of newsprint, printing, waste recovery and treatment, transportations and by-products (in this study energy from waste), was included in the product system. Process-specific data from the facilities in operation, data from pilot studies and also databases were used in the life cycle inventory (LCI) phase. In order to assess the potential environmental impacts of the waste management alternatives, the inventory data were interpreted with three LCIA models, namely DAIA, Eco-indicator 99 and EPS 2000, in the life cycle impact assessment (LCIA) phase. The results of the economic assessment are not reported here. The combined assessment of the ecology and costs is reported in the publication: Myllymaa et al. 2005. A method for implementing life cycle surveys of waste management alternatives' environmental and cost effects. Finnish Environment 750.	
Keywords	life cycle, LCA, environmental impact, newspaper, waste management	
Publication series and number	The Finnish Environment 752	
Theme of publication	Environmental protection	
Project name and number, if any	LCA-WASTE project, SA06061	
Financier/ commissioner	National Technology Agency of Finland (Tekes)	
Project organization	Finnish Environment Institute (SYKE), University of Helsinki	

	ISSN 1238-7312	ISBN 952-11-1956-X	ISBN 952-11-1957-8 (PDF)
	No. of pages 151	Language English	
	Restrictions Public	Price 18 e	
For sale at/ distributor	Edita Publishing Ltd., P.O.Box 800, 00043 Edita Finland, Phone +358 20 450 00 Mail orders: Phone +358 20 450 05, telefax +358 20 450 2380 Internet: www.edita.fi/netmarket		
Financier of publication	Finnish Environment Institute, P.O.Box 140, FIN-00251 Helsinki, Finland		
Printing place and year	Edita Prima Ltd., Helsinki 2005		

Kuvailulehti

Julkaisija	Suomen ympäristökeskus (SYKE)	Julkaisuaika Toukokuu 2005
Tekijä(t)	Helena Dahlbo, Jari Laukka, Tuuli Myllymaa, Sirkka Koskela, Jyrki Tenhunen, Jyri Seppälä, Timo Jouttijärvi ja Matti Melanen	
Julkaisun nimi	Käytetyn sanomalehden jätehuoltovaihtoehdot pääkaupunkiseudulla – Elinkaariarviointiraportti	
Julkaisun osat/ muut saman projektin tuottamat julkaisut	Julkaisu on saatavana myös Internetistä www.environment.fi/publications	
Tiivistelmä	Kulutuksen ja jätemäärien jatkuvasti lisääntyessä jätehuoltoratkaisuilla on yhä suurempi vaikutus tuotteiden elinkaaren ekologisuuteen ja kustannuksiin. Optimitilanteessa jätehuoltoratkaisujen ympäristövaikutukset ovat mahdollisimman pieniä ja tilanne on saavutettu mahdollisimman vähin kustannuksin. Sopivimpien jätehuoltoratkaisujen etsiminen ja vertailu edellyttää systemaattista, tapauskohtaista tarkastelua. Suomen ympäristökeskus (SYKE) ja Helsingin yliopisto toteuttivat 2002 - 2004 Tekes-rahoitteisen hankkeen "Elinkaarinäkökulma jätehuollon kestävyyteen - tapaustarkasteluna sanomalehti (LCA-WASTE)". Hankkeessa tutkittiin sanomalehden erilaisten jätehuoltovaihtoehtojen ekologisuutta ja kustannuksia. Tässä raportissa kuvataan projektissa tehdyn elinkaariarvioinnin prosessi ja tulokset. Projektissa muotoiltiin ja analysoitiin viisi vaihtoehtoa käytettyjen sanomalehden jätehuollolle pääkaupunkiseudulla. Tuotejärjestelmään sisältyi sanomalehden koko elinkaari käsittäen metsätalouden, sanomalehtipaperin valmistuksen, painamisen, jätteiden hyödyntämisen ja käsittelyn, kuljetukset sekä sivutuotteet (tässä tutkimuksessa jätteestä tuotettu energia). Prosessispesifistä dataa käytössä olevista laitoksista, pilotmittakaavan tutkimuksiin pohjautuvaa dataa sekä tietokantojen dataa käytettiin elinkaari-inventaariovaiheessa. Jätehuoltovaihtoehtojen potentiaalisten ympäristövaikutusten arvioimiseksi elinkaari-inventaariossa koottu data tulkittiin elinkaariarvioinnin mukaisessa vaikutusarviointivaiheessa (LCIA) kolmella LCIA-mallilla, jotka olivat DAIA, Eco-indicator 99 ja EPS 2000. Taloudellisen arvioinnin tulokset eivät sisälly tähän raporttiin. Ympäristövaikutusten ja kustannusten yhteistarkastelu raportoidaan julkaisussa Myllymaa ym. 2005. Menettely jätehuoltovaihtoehtojen ympäristö- ja kustannusvaikutusten elinkaaritarkasteluun. Suomen ympäristö 750.	
Asiasanat	elinkaari, elinkaarianalyysi, LCA, ympäristövaikutukset, sanomalehtipaperi, jätehuolto, jätteet	
Julkaisusarjan nimi ja numero	Suomen ympäristö 752	
Julkaisun teema	Ympäristönsuojelu	
Projektihankkeen nimi ja projektinumero	LCA-WASTE, SA06061	
Rahoittaja/ toimeksiantaja	Teknologian kehittämiskeskus (Tekes)	
Projektiryhmään kuuluvat organisaatiot	Suomen ympäristökeskus (SYKE), Helsingin yliopisto (HY)	

	ISSN 1238-7312	ISBN 952-11-1956-X	ISBN 952-11-1957-8 (PDF)
	Sivuja 151	Kieli Englanti	
	Luottamuksellisuus Julkinen	Hinta 18 e	
Julkaisun myynti/ jakaja	Edita Publishing Oy, PL 800, 00043 Edita, vaihde 020 450 00 Asiakaspalvelu: puh. 020 450 05, telefax 020 450 2380 Sähköposti: asiakaspalvelu@edita.fi, www.edita.fi/netmarket		
Julkaisun kustantaja	Suomen ympäristökeskus, PL 140, 00251 Helsinki		
Painopaikka ja -aika	Edita Prima Oy, Helsinki 2005		

Presentationsblad

Utgivare	Finlands miljöcentral (SYKE)	Datum Maj 2005
Författare	Helena Dahlbo, Jari Laukka, Tuuli Myllymaa, Sirkka Koskela, Jyrki Tenhunen, Jyri Seppälä, Timo Jouttijärvi och Matti Melanen	
Publikationens titel	Alternativ för handling av använda dagstidningar i huvudstadsregionen – Rapport av livscykelanalys	
Publikationens delar/ andra publikationer inom samma projekt	Publikationen finns tillgänglig också på internet www.environment.fi/publications	
Sammandrag	Då konsumtionen och avfallsmängderna hela tiden ökar har avfallshanteringsmetoderna allt större effekt på hur ekologiska produkterna är och på kostnaderna under deras livscykler. Optimalt är avfallshanteringsmetodernas miljöeffekter möjligast små och skapar lägsta möjliga kostnader. Att söka och jämföra de lämpligaste lösningarna för avfallshantering kräver systematiska fallstudier. Finlands miljöcentral (SYKE) och Helsingfors universitet genomförde under 2002-2004 ett projekt finansierat av Tekes kallat ”Avfallshanteringens hållbarhet ur livscykelperspektiv – dagstidningar som fallstudie (LCA-WASTE)”. I projektet studerade vi ekologin och kostnaderna hos olika hanteringsmetoder för tidningspappersavfall. I denna rapport beskrivs processen och resultaten från livscykelanalysen som utfördes i projektet. Fem alternativ för behandling av använda dagstidningar i huvudstadsregionen utformades och analyserades. Hela livscykeln för dagstidningen: skogsbruket, producering av tidningspapper, tryckning, utvinning och hantering av avfallet, transport och biprodukter (i denna studie energi ur avfallet), inkluderades i produktsystemet. Process-specifikt data från operativa faciliteter, data från pilot-projekt samt databaser användes i inventariefasen (LCI) för livscykelanalysen. För att bedöma potentiella miljöpåverkningar från de fem alternativa avfallshanteringssystemen, har tre LCIA modeller används för att tolka inventariedata. Modellerna var DAIA, Eco-indicator 99 och EPS 2000. Resultaten från den ekonomiska analysen rapporteras inte här. Den kombinerade analysen av ekologin och kostnaderna rapporteras i publikationen: Myllymaa et al. 2005. Metoder för livscykelanalys av miljö- och ekonomiska effekter hos olika avfallshanteringsalternativ. Miljön i Finland 750 (på finska).	
Nyckelord	avfall, avfallshantering, livscykel, livslängd, livscykelanalys, LCA, miljöeffekter, tidningspapper	
Publikationsserie och nummer	Miljön i Finland 752	
Publikationens tema	Miljövård	
Projektets namn och nummer	LCA-WASTE-projektet, SA06061	
Finansiär/ uppdragsgivare	Teknologiska utvecklingscentralen Tekes	
Organisationer i projektgruppen	Finlands miljöcentral (SYKE), Helsingfors Universitet	

	ISSN 1238-7312	ISBN 952-11-1956-X	ISBN 952-11-1957-8 (PDF)
	Sidantal 151	Språk Engelska	
	Offentlighet Offentlig	Pris 18 e	
Beställningar/ distribution	Edita Publishing Ab, PB 800, FIN-00043 Edita, Finland, växel 020 450 00 Postförsäljningen: Telefon +358 20 450 05, telefax +358 20 450 2380 Internet: www.edita.fi/netmarket		
Förläggare	Finlands miljöcentral, PB 140, 00251 Helsingfors, Finland		
Tryckeri/ tryckningsort och -år	Edita Prima Ab, Helsingfors		

The Finnish Environment

ENVIRONMENTAL PROTECTION

Waste management options for discarded newspaper in the Helsinki Metropolitan Area
Life cycle assessment report

Paper is one of the largest fractions of municipal solid waste. Thus, the waste management solutions for discarded paper have impacts on the whole waste management system. In the LCA-WASTE study five waste recovery and treatment alternatives applicable to newspaper were assessed for their ecology and costs. The study area was the Helsinki Metropolitan Area.

This publication reports the process, data and results of assessing the environmental impacts with the life cycle assessment (LCA) methodology.

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This publication is also available in the Internet:
www.environment.fi/publications

ISBN 952-11-1956-X
ISBN 952-11-1957-8 (PDF)
ISSN 1238-7312

Edita Publishing Ltd.
P.O.Box 800, FIN-00043 EDITA, Finland
Phone + 358 20 450 00
Mail orders:
Phone + 358 20 450 05, fax + 358 20 450 2380
Edita-bookshop in Helsinki:
Annankatu 44, phone + 358 20 450 2566

FINNISH ENVIRONMENT INSTITUTE P.O.Box 140, FIN-00251 HELSINKI