DELIVERABLE FRONTPAGE

Project number:	243827 FP7-ENV-2009-1
Project acronym:	LC-IMPACT
Project title:	Development and application of environmental Life Cycle Impact assessment Methods for imProved sustAinability Characterisation of Technologies.
Deliverable number:	D4.10
Deliverable name:	Final evaluation of the newly developed characterisation and normalisation factors in an LCA case study - Paper production and printing
Version:	Final
WP number:	4
Lead beneficiary:	DTU
Nature:	R + O [1]
Dissemination level:	RE [2]
Delivery date Annex I:	Month 41
Actual delivery date:	01/05/2013
Authors:	Cosme N, Larsen HF, Hauschild MZ
Comments:	**Several parts of this deliverable will be published in scientific journalsand need to be treated confidentially until the publishing date (for internal EU review only).**

[1] Please indicate the nature of the deliverable using one of the following codes: **R** = Report, **P** = Prototype, **D** = Demonstrator, **O** = Other

[2] Please indicate the dissemination level using one of the following codes: **PU** = Public, **PP** = Restricted to other programme participants (incl. the Commission Services), **RE** = Restricted to a group specified by the consortium (incl. the Commission Services), **CO** = Confidential, only for members of the consortium (incl. the Commission Services)

Table of Contents

Final evaluation of the newly developed characterisation and normalisation factors in an LCA case study – Paper production and printing

Nuno Cosme, Henrik Fred Larsen, Michael Zwicky Hauschild*
Division for Quantitative Sustainability Assessment (QSA), Department of Management Engineering (DTU-MAN), Technical University of Denmark (DTU), Building 426, 2800 Kgs. Lyngby, Denmark

*Corresponding author:
Nuno Cosme; Tel: +45 45 25 47 29; Fax: +45 45 93 34 35; e-mail: nmdc@dtu.dk

Executive summary

The Life Cycle Assessment (LCA) methodology analyses the potential environmental impacts of product systems within a defined goal and scope. It can generally assess the relevant environmental processes and aspects and evaluate the environmental exchanges (inputs and outputs from the technosphere) and the potential environmental impacts of a product or service from 'cradle to grave', i.e. across the entire life cycle stages.

The goal of the present case study is to identify and comparatively quantify the potential environmental impact and consumption of resources arising from the life cycle of paper and printing matter production on a model sheet fed offset printing company in Denmark (that can also represent the average company in Europe), introducing some of the newly developed impact assessment categories within the framework of the European research project LC-IMPACT (land use, water use, whole effluent toxicity, indoor exposure to solvents, photochemical ozone formation, indoor exposure to fine particles, and noise) and to test their applicability.

The Functional Unit (FU) is defined here as 1 (one) ton of sheet fed offset printed matter produced at a model sheet fed offset printing company. The printed matter is to be considered as a non-laminated average piece of printed communication, e.g. books, pamphlets, brochures, posters, magazines, or similar, typically produced by a sheet fed offset method in a printing house.

The total paper-related potential impact (comprising forestry, pulp and paper production, and disposal of waste paper and product), the avoided potential impact from incineration of fossil fuel due to incineration of paper and the avoided potential impacts from production of virgin fibres due to production based on recycled fibres are allocated to the paper.

The characterisation results of the product system for sheet fed offset material at midpoint (following the assessment by ReCiPe methodology) are presented per impact category and divided into the main life cycle stages: Paper production, printing, and end-of-life (EOL). 'Offset product' refers to the total impact of the product system, and EOL includes recycling (with avoided production of virgin fibres and combustion of fossil fuels), and incineration (with recovered energy).

Both the land use impacts and emissions related impacts are dominated by the paper production stage. The chemicals related impacts are also dominated by the paper production

stage but the printing share is increased. This might be related to the fact that the paper production stage has an aggregated process in the assessment, which includes transport and average energy mix, while the printing stage is directly obtained from industry data, lacking transport related emissions and relying on Danish energy mix data, together with a higher use (and emission) of chemicals that are applied in the various stages that compose the printing stage.

Both the characterised and normalised impact scores at midpoint are dominated by the contribution of the paper production stage on several impact categories, including the land use related categories (very high contributions, and the energy and associated emissions related categories. Only some of the chemicals related categories (namely the ecotoxicity indicators) reveal a more balanced contribution between the materials and production stages.

Although not evident, EOL scores are mainly related to avoided energy production by the incinerated fraction and some avoided use of chemicals by the recycled fraction of the disposal stage. Nevertheless, there is a strong dominance by the energy-related ionizing radiation impact category throughout all life cycle stages.

The endpoint characterisation is still dominated by the paper production contribution to the impact scores and is reflected in the damage score to the area of protection (AoP) Ecosystems, which might be due to the impacts from transportation (that is missing in the printing stage) and the land use impacts. Some contribution from the printing stage to this damage category might be expected from the use of chemicals in the various auxiliary processes in the production stage, but the scores still reveal domination by the ionising radiation category. The damage to resources is mostly affected by the fossil fuels depletion category with effect on the avoided energy production (mostly thermal generation from coal) by the incinerated paper fraction in EOL and the transport in the paper production stage (because an aggregated process is used here contrary to the printing stage).

EOL contributions are related to avoided production of virgin fibres through the recycled fraction, hence less land use impacts, fuel and energy consumption, and the avoided production of energy through the incinerated fraction in the damage to human health category. Nevertheless the ionising radiation indicator still scores about 5-7 orders of magnitude higher than the remaining.

The overall high share of the ionising radiation indicator originated in the electricity production stage may also result from a normalisation imbalance from using normalisation factors from countries with higher share of nuclear power generation than the ones referring to the inventory flow used. Most of the energy consuming processes are assigned to the printing stage, which takes place in Denmark, where the electricity mix includes imported electricity from nuclear generation (10% of the total consumption) while producing none internally. EOL also shows a high share of damage to AoP Human Health as it includes avoided energy production by incineration of printed matter.

The analysis of the results of the midpoint characterisation with the new impact indicators (3) is limited, as forestry is only assessed for the paper production stage and photochemical ozone formation is only assessed for the printing stage. In the estimation of the photochemical ozone formation indicator, EOL refers to incineration, i.e. avoided energy production, and it exceeds the characterised impact score of the original production. It means that incineration in EOL has a lower impact than energy production for this midpoint category. EOL in the noise indicator is simply a fixed fraction of the original impact (53% avoided). Normalisation at midpoint does not change this interpretation.

Endpoint impact scores are clearly marked by the lack of consistency in the units presented for the various impact indicators. This fact is due to several not fully developed methods in the perspective that further unit conversion is needed: non-compatible units for the endpoint indicators hinder readily further aggregation from endpoint to damage estimation, which is an option for the results analysis at this modelling level. These units include PDF.yr, PDF.m^2.yr, PDF.m^3.yr, PAF.m^2.yr, MJse.m^2.yr, and NPPD.m^2.yr) and they cannot be (readily) aggregated and eventually normalised (with damage NFs) as suitable conversions are still required.

Nevertheless, normalisation references were provided, by calculations based on annual emissions (or consumptions) per capita. However, consistency is poor and the reference situation varies significantly between the various categories, either considering the reference region (country, Europe, or World) and the reference year (1995, 2000, 2010, or 2011).

Although not entirely relevant, the impact scores at endpoint were normalised with the NRs available. This normalisation does not lead to any further aggregation and it is simply performed to obtain a common unit for internal comparison (i.e. within the new impact categories results), for illustration, and error-checking purposes.

The combined assessment, i.e. endpoint ReCiPe indicators plus some of the new endpoint LC-IMPACT indicators, show similar contributions as to those previously obtained for the ReCiPe damage assessment alone, and simply reveal an expected small increase in damage to AoPs Ecosystems and Human Health, based on the relevance criteria used for the assessment of the main life cycle stages, but does not significantly changes the percentual contribution results. No changes in damage score to AoP Resources are verified as no LC-IMPACT new indicator contributed to this AoP.

Overall, the applicability test is conditioned by inconsistency and incompleteness aspects. On the one hand there is no consistency in the life cycle stages covered by the assessment (which is applicable for both the midpoint and endpoint characterisation), and on the other hand the indicators' scores obtained are not suitable for further aggregation into damage AoPs due to the incompleteness of several assessment methods by delivering not harmonised endpoint indicators – highly relevant for the interpretation phase. These two aspects ultimately hinder the analysis of applicability of the newly developed indicators in a LCIA perspective, the interpretation of the results, and the interest of the results as decision support information.

Scientifically, the methods developed in the LC-IMPACT framework described in the available deliverables reports and published elsewhere in scientific journals, seem appropriate and robust, covering the necessary and adequate cause-effect chain elements and are sufficiently environmental relevant to be included in the set of indicators/categories in LCIA. While appearing scientifically and technically sound, generally the methods do not deliver the best unit to the indicator (with the exception of water use, forestry and photochemical ozone formation indicators) and show that a final phase of harmonisation in terms of modelled endpoint is still needed before a further round of applicability testing and validation is conducted.

Ultimately, the questions reside in whether (1) it is worth investing in data acquisition to feed the new categories considering their (possible) contribution to the global impact assessment of the product system or there is no added value, and (2) how the overall results with these new indicators improve the relevance (environmental, geographical, or other) of the conclusions of the study to make it useful as a decision supporting tool (LCA).

Due to the limited number of new fully developed (harmonised) endpoint indicators added to the combined assessment there are no significant changes to the impact assessment of the paper production and printing product system. The development of the new assessment methods, although relevant for the individual indicators, shows little expression and contribution to the final results. The number of midpoint indicators is scarce due to the decision of which life cycle stages to include, thus revealing little application, while for the endpoint a significant number of indicators were not successfully delivered for damage to AoP assessment: from the possible 15 indicators developed, 2 did not conclude the characterisation phase, and 9 still need further unit conversion. Only 4 new indicators integrate the combined assessment method, for which no noticeable changes are found.

In addition, an effort should be invested in consistency of normalisation references, mainly harmonisation of resolution scale, reference year, and type of data.

Finally, transparency on the application of the newly developed assessment methods would benefit from an adequate detachment from method development and application, meaning that clear and concise information should be made available for practitioners and stakeholders in general. This was attempted in the LC-IMPACT project, and not entirely achieved, by the compilation of guidance documents or cookbooks – either by not covering the whole set of new methods or by lacking practical and clear information in the shared documentation. Improvements can be implemented by solving inconsistencies between the deliverables documents, the guidance documents, and the available/provided auxiliary spreadsheets, especially in what regards to units. The lack of follow-through calculations (when applicable) should also be avoided, and explanation of applicable values and necessary supplementary calculations for characterisation, normalisation, or estimation of intermediate parameters, included.

The main conclusions of this study should have provided useful information to assess: a) whether the methods are sufficiently developed and applicable, and b) if it is worth considering their contribution to the global impact assessment of the product system, i.e. if the results with these new indicators enhance the overall assessment of the product system, either by improving the relevance (environmental, geographical, or other) of the selected categories or the improvement of information provided with such tool (LCA) to the decision making process.

An overall analysis of the new methodologies introduced in the impact assessment phase, although scientific valid, is not clear about their applicability and relevance as it has not been clearly demonstrated. Due to a limited number of new midpoint indicators (assessed in this case study) and a significant number of fully usable new endpoint indicators, it is not possible to conclude on the value added to the impact assessment brought by these. It is however acknowledge that with a small extra effort in converting and standardising units for the considered endpoint indicators this analysis can conclude with more confidence.

Final evaluation of the newly developed characterisation and normalisation factors in an LCA case study – Paper production and printing

Nuno Cosme, Henrik Fred Larsen, Michael Zwicky Hauschild*
Division for Quantitative Sustainability Assessment (QSA), Department of Management Engineering (DTU-MAN), Technical University of Denmark (DTU), Building 426, 2800 Kgs. Lyngby, Denmark

*Corresponding author:
Nuno Cosme; Tel: +45 45 25 47 29; Fax: +45 45 93 34 35; e-mail: nmdc@dtu.dk

1. Introduction

The Life Cycle Assessment (LCA) methodology analyses the potential environmental impacts of product systems within the defined goal and scope. It can generally assess the relevant environmental processes and aspects and evaluate the environmental exchanges (inputs and outputs from the technosphere) and the potential environmental impacts of a product or service from 'cradle to grave', i.e. across the entire life cycle stages including resource extraction and processing, production, manufacturing and assembly, transportation and packaging, use, reuse, recycling, treatment, and disposal stages (Bare 2010; Hauschild 2005; Lautier et al. 2010).

Application of LCA methodology to printer matter production is relatively new and reports scarce. Available LCA reports on offset printed matter include those produced by Dalheilm & Axelsson 1995; Axelsson et al 1997, Johansson 2002, and by the Danish EPA (Drivsholm et al. 1996; Drivsholm et al. 1997; Larsen et al. 2006). Additionally, INFRAS (1998) although focusing on graphic paper also includes print products (e.g. newpapers) in the functional unit (Larsen et al. 2006).

In a general overview, all these studies point to the paper production stage (with forestry and pulp production delivering the paper product) as the dominating contributor to the estimated potential environmental impacts from the life cycle of offset printed matter. Additionally, there is a strong focus on the energy-related impact categories and emissions (Larsen et al. 2006). The chemicals-related impact categories (including ecotoxicity and human toxicity) are assessed by various methods (EPS, CML, EI95, EDIP) and overall seem to lack transparency and limited application (Larsen et al. 2006). The Danish EPA study has added focus on chemicals-related processes to the LCA framework and found a lesser contribution from the paper production stage in the aggregated weighted potential environmental impacts (Larsen et al. 2006).

The present study is based on an equal focus on energy- and chemicals-related emissions and processes for both toxic and non-toxic categories. The report describes an LCA study of a model (i.e. average) sheet fed printing company. The product system is built on the technical background documents by Larsen et al. (2005) and the Ecolabelling of printed matter – life cycle of model sheet fed offset printed matter, by Larsen et al. (2006) to the Danish EPA.

Furthermore the study is mainly intended to compare the application of ‘traditional’ impact categories with the new impact categories, based on newly developed methodologies within the EU FP7 research project LC-IMPACT (development and application of environmental **L**ife **C**ycle **I**mpact assessment **M**ethods for im**P**roved sust**A**inability **C**haracterisation of **T**echnologies - 243827 FP7-ENV-2009-1).

This study was done in accordance with the ISO 14040-series.

2. Goal and scope definition

2.1. Goal

2.1.1. Introduction and overview

The goal of the present case study is to identify and comparatively quantify the potential environmental impact and consumption of resources arising from the life cycle of generic paper and printing matter production on a model sheet fed offset printing company in Denmark (that can also represent the average company in Europe), introducing the newly developed impact assessment categories within the framework of the European research project LC-IMPACT (land use, water use, whole effluent toxicity, indoor exposure to solvents, photochemical ozone formation, indoor exposure to fine particles, and noise) and to test their applicability.

2.1.2. Intended application

The present case study is primarily intended to apply and evaluate the new impact assessment methods developed within the LC-IMPACT project.

2.1.3. Method, assumptions and impact limitations

The case study is specific and the results may not be directly transferred to other products within the same product category.

2.1.4. Reasons for carrying out the study

The main reason for carrying out the study is to test the applicability of the new impact assessment methodologies developed in the LC-IMPACT project, and align their applicability in a case study context.

2.1.5. Target audience

The target audience is technical and external, since it is a research project. The scientific community as a future user may be interested in the applicability of the new LCIA methods developed in the LC-IMPACT project, and finally the public in general as potential users of the results and inventoried data.

2.1.6. Comparisons intended to be disclosed to the public

Some elements of comparison may arise from the assessment and analysis, but no assertions on superiority are done, hence the study is not classified as "comparative".

2.1.7. Commissioner of the study and other influential actors

The studies are commissioned by the European Commission. Besides the general influence from other project partners, the JRC has a stake and might have influence on the studies.

2.1.8. Classifying the decision context

According to the ILCD Handbook the studies needs to be defined as either A, B or C types. These types reflect differences in scope and purpose (see Figure 2.1).

The present case study belongs to type C1. The rationale is that there will be no direct decision-making based on the studies (type C), and there are interactions with other systems (type C1) due to e.g. avoided burdens by incineration and recycling.

<table>
<tr><td rowspan="3">Decision support?</td><td rowspan="3">Yes</td><td colspan="2">Kind of process-changes in background system / other systems</td></tr>
<tr><td>None or small-scale</td><td>Large-scale</td></tr>
<tr><td>Situation A
"Micro-level decision support"</td><td>Situation B
"Meso/macro-level decision support"</td></tr>
<tr><td></td><td>No</td><td colspan="2">Situation C
"Accounting"
(with C1: including interactions with other systems, C2: excluding interactions with other systems)</td></tr>
</table>

Figure 2.1: The different types of studies and how to distinguish their decision context (from EC et al. 2010).

2.2. Scope

2.2.1. Overview

All stages of the life cycle are covered as regards to the use of raw materials/energy (from material extraction to disposal when possible). For the potential environmental impacts the main focus is on the production stage. The composition of mixed raw materials (e.g. printing ink, fixers, or film developers) is generic and simplified.

Average typical data have been used instead of data from a specific printing company with a detailed functional unit.

2.2.2. Functional unit

The Functional Unit (FU) is here defined as 1 (one) ton of sheet fed offset printed matter produced at a model sheet fed offset printing company.

The printed matter is to be considered as a non-laminated average piece of printed communication e.g. books, pamphlets, brochures, posters, magazines, or similar, typically produced by a sheet fed offset method in a printing house.

The life time of the various printed matter formats may vary from a few weeks (e.g. pamphlets and other advertisement materials) to several years (e.g. posters and books). For practical reasons and the sake of normalisation of the LCA results the final product life time was set to 1 year.

2.2.3. Product system

The product system is identified as shown in Figure 2.2.

As the scope of this study is to test the applicability of the new impact assessment categories originated from the LC-IMPACT project, transport is only included when it is an integrated part of any considered unit process (e.g. production of paper from cradle to gate). Therefore, transport of raw materials from producer to the printing company and the transport in the production, use, and disposal stages are not included. However, transport for recycling of paper as described in Frees et al. (2004) is included because it is an integrated part of the unit process used here.

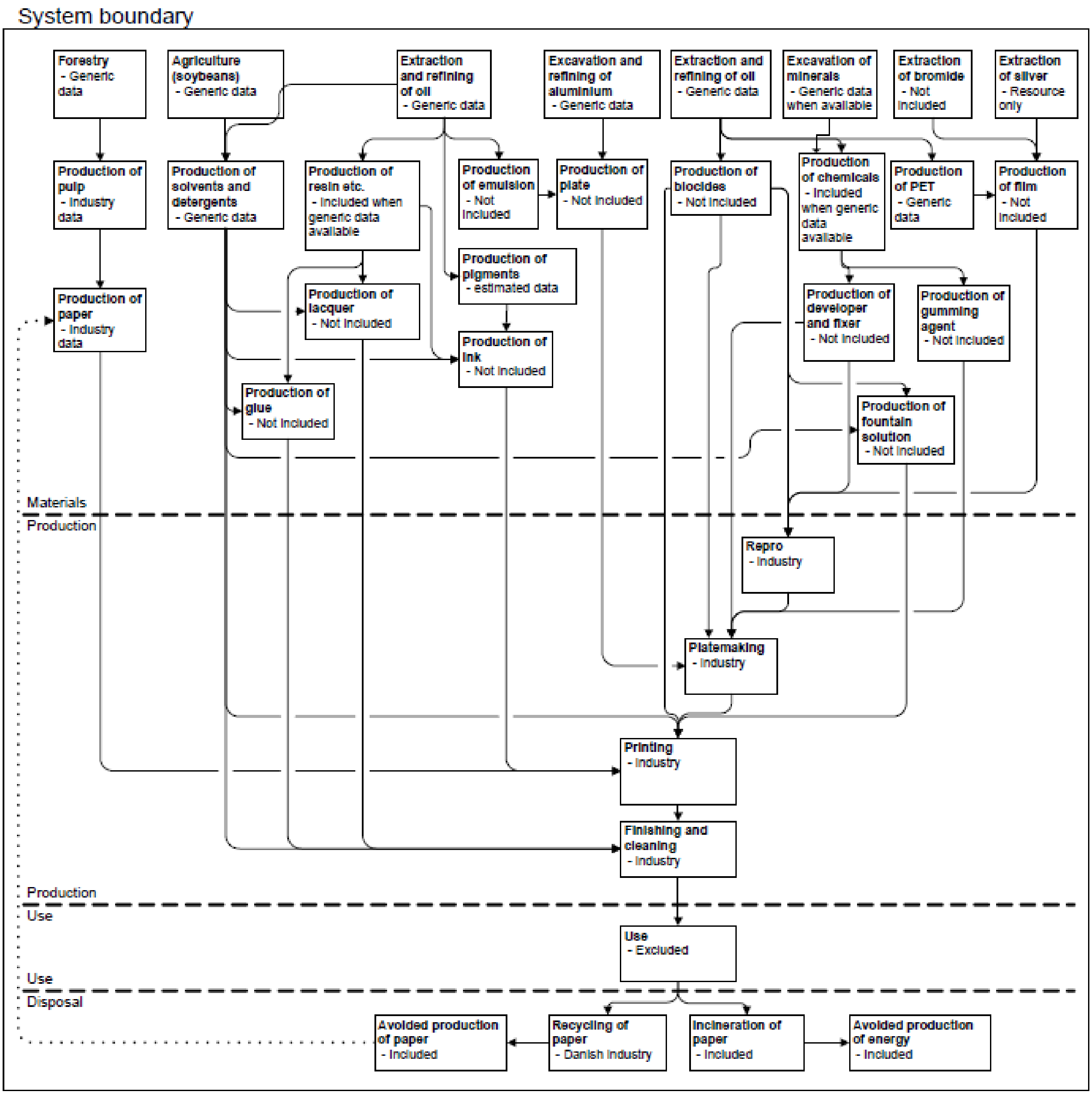

Figure 2.2: The product system for paper and printed matter production (sheet fed offset printed matter) (taken from Larsen et al. 2006).

As defined by Larsen et al. (2006) for the finishing stage only lacquering and gluing processes are included. Lamination is typically not done at the sheet fed offset printing company (Brodin & Korostenski 1995) and inventory data is not readily available, hence lamination is excluded for the present study. Packaging processes occurring at the printing company such as the use of wooden pallets, paper and/or "shrink plastic" are also excluded due to lack of data. Additionally, packaging processes are assessed to be of very low significance as compared to the remaining activities. For disposal of printed matter it is assumed that 53% of the paper consumption (including both spillage and product) is recycled and the rest (i.e. 47%) is incinerated for heat recovery. This assumption is based on the Danish situation in 2000 (Tønning 2002). Differences in recyclability of the printed matter (e.g. deinking or repulping problems due to content of Hot Melt glue or water based inks) are not included due to lack of readily available quantitative data and the scoping of this study. Direct and indirect overhead operations such as production of printing machines and office supplies are expected to contribute insignificantly to the overall impacts and are generally not included. However total energy consumption covering, for example, heating and lighting at the model printing company (indirect overhead operations) is included (Larsen et al. 2006).

2.2.4. Representativeness and appropriateness of LCI data

2.2.4.1. Time scope

As defined by Larsen et al. (2006) the time to produce one functional unit is assumed to be a few days and the production takes place in the period 1990-2002. The use stage and disposal stage will for most of the printed matter take a few weeks and cover the same time period. Given that the lifetime is assumed to be one year in the functional unit, the disposal will take place in the period 1991-2003. For long-lived items like books and posters the use stage may cover several years and this would delay the disposal stage by several decades. The material stage is assumed to cover at least 1980-2002.

2.2.4.2. Technological scope

The technologies used for the material stage are to some extent dependent on the unit process data that have been readily available for this study. The aggregated process (from Ecoinvent) chosen to cover the paper production (*RER: paper, woodfree, coated, at integrated mill*) that later feeds the printing stage refers to the European production of coated woodfree paper in an integrated paper mill - including transports to paper mill, wood handling, chemical pulping and bleaching, paper production, energy production on-site, recovery cycles of chemicals and internal waste water treatment. For the present example of pulp and paper production, the technologies covered are modern and used in the Swedish pulp and paper industry in 2001 (Frees et al. 2004) for producing white paper based on ECF (Elemental Chlorine Free) sulphate pulp (virgin fibres) for use in the printing industry.

For the production stage, the technologies included in this study generally cover the technologies used at sheet feed offset printing companies during 1990-2000 especially in the Nordic countries but also in Northern Europe. It is evaluated that these technologies still dominate. However, the chosen scoping excludes “new” state-of-the-art technologies. These technologies include, for example, Computer-To-Plate (CTP) and waterless offset (Silfverberg et al. 1998) which have been used to a limited degree for some years (Larsen et al. 1995) and for which the market share is increasing. On the other hand, technologies and techniques which are no longer used (or only used to a limited degree under controlled conditions) in Northern Europe for say 20-30 years are most probably still used especially in Eastern European countries. Examples of such “old” technologies and techniques could be the extended use of dampening form rollers with cloth (Heber dampening system) needing at least daily cleaning using hazardous solvent-based cleaning agents which are emitted directly to the water recipient after use - no Waste Water Treatment Plant (WWTP) or simply a mechanical one. Another example could be the extended use of aromatic very volatile solvents for manual cleaning of the printing machine leading to extensive exposure of workers and large air emissions. The use of cleaning agents containing more than 0.1% aromatic solvents is not considered in this study, and only limited use of dampening form rollers with cloth (Heber dampening system) is included, i.e. 10-20% of the dampening systems. Emission of solvent-based cleaning agents to water is therefore very limited (0.1-1%) in the reference scenario, and only water emission of detergents used for cleaning is relatively high (50%).

For the disposal stage the technologies used for incineration and recycling of paper are modern Northern European types.

The sources for the inventory data used can be found in Appendix I.

2.2.4.3. Geographical scope

For the material stage, the production of paper is assumed to take place in Sweden and printing inks are assumed to be produced in Europe.

The production of printed matter is assumed to take place in Denmark with generic similarities with companies in Europe.

Disposal and recycling are based on a scenario for Denmark.

2.2.5. Allocation

The total paper-related potential impact (comprising forestry, pulp and paper production, and disposal of waste paper and product), the avoided potential impacts from incineration of fossil fuel due to incineration of paper and the avoided potential impact from production of virgin fibres due to production based on recycled fibres are allocated to the paper. For consumption of aluminium (offset plates) it is assumed that recycled aluminium is used and the extra energy used to produce virgin aluminium to replace the loss of 8% during the recycling process is allocated to the functional unit.

2.2.6. Planning reporting

This LCA study is intended to be presented in a written report format.

3. Inventory analysis

3.1. Introduction and overview

The starting point for the inventory is the production stage of generic printed matter produced at a model sheet fed offset printing company. The raw materials included are described in the next section. Each raw material is divided into its components and the resource consumption/emissions of the production of the raw material and its components (i.e. material stage) are mapped and included whenever readily available and relevant. For many of the composite raw materials no data exists on production (i.e. typically a mixing process), but for their components generic data on resource consumption and emissions are available and used in many cases. In any case, data on emission of specific substances at the material stage is typically not available and this kind of data is almost exclusively used in the production stage for which they have been available and focused upon in this study.

An overview of inventory references is given in Appendix I, data for the activities at the model printing company is shown together with data provided by offset printing companies and in Appendix II, and a full aggregated inventory is shown in Appendix III (from Table 8.2 to Table 8.7).

3.2. Composition of raw materials

The raw materials for the production stage included in this generic study are the dominant types typically used in 'traditional' sheet feed offset, i.e. film, film developer, fixer, biocides, plates, plate developer, gumming solution, paper, alcohol (isopropyl alcohol, IPA), printing ink, fountain solution, lacquer (varnishes), glue and cleaning agents (Larsen et al. 2006). The composition of these raw materials is as far as possible based on known typically recipes as described in Larsen et al. (1995) in Danish and published in a short English version (Larsen et al. 1996). Other reports, articles and updated MSDSs from suppliers/producers on relevant raw materials have also been consulted. However, due to lack of data (e.g. toxicity data) assumptions about the components have had to be made as shown below (Larsen et al. 2006).

3.2.1. Film

The thickness of the film is assumed to be 0.1 mm (KODAK 2001a), the silver content 10 g/m^2 and the content of halides (assumed to be bromide) 7 g/m^2 (Baumann & Gräfen 1999a). The 0.1 mm thick base layer consists of polyethylene, PET (i.e. polyethylene terephthalate) (KODAK 2001a; Lapp et al. 2000). Other components such as gelatine and components with minor occurrence (i.e. well below 1% w/w) like filter dyes, fungicides, and wetting agents, are excluded. As the density of PET is 1,370 kg/m^3 (APR 2003) the generic film is assumed to consist of 89% w/w polyethylene, 6% w/w silver and 5% w/w bromine (Larsen et al. 2006).

3.2.2. Film developer

The composition of the film developer is based on KODAK RA 2000 Developer (KODAK 2001b, 2003) and shown in Table 3.1. This developer is known to be used within the repro process at Danish sheet feed offset printing companies and its composition is in accordance with the general description of developers in Seedorff et al. (1993) (Larsen et al. 2006).

Table 3.1: Composition of the working solution for generic film developer.

Component	% w/w
Water	91.0
Potassium sulphite	3.5
Diethylene glycol*	2.0
Hydroquinone	1.8
Sodium sulphite	0.76
Sodium carbonate	0.76
4-hydroxymethyl-4-methyl-1-phenyl-3-pyrazolidinone	0.25

* For upstream production data substituted by ethylene glycol

3.2.3. Fixer

The composition of the fixer is based on KODAK 3000 Automix Fixer (KODAK 2000, 2003) and shown in Table 3.2. This fixer is known to be used within the repro process at Danish sheet feed offset printing companies and its composition is in accordance with the general description of fixers in Seedorff et al. (1993) (Larsen et al. 2006).

Table 3.2: Composition of the working solution for generic fixer.

Component	% w/w
Water	81
Ammonium thiosulphate	14
Sodium acetate	2.6
Boric acid	0.66
Ammonium sulphite	0.66
Acetic acid	0.66
Sodium bisulphite	0.33

3.2.4. Biocides

When rinsing water for film developing and plate making are recycled, biocides (algicides, fungicides, bactericides) are typically used (Kjærgaard 1997). One of the dominant types of biocides used within the printing industry is the group of isothiazolines, which in many cases is represented by Kathon® consisting of three parts 5-chloro-2-methyl-isothiazolin-3-one (CMI) and one part 2-methyl-2-isothiazolin-3-one (MI) (Larsen et al. 1995, 2002; Andersen et al. 1999; Gruvmark 2004). The product Nautalgin C1 (Deltagraph 1997) which is used as a biocide agent when recycling rinsing water contains about 1-2% CMI, 0.1-1% MI and water. The generic biocide agent used here for conservation of recycled rinsing water in film developing and plate making is therefore assumed to be water-based and containing 2% w/w CMI and 0.67% w/w MI. Biocides occurring as part of raw materials (e.g. fountain solutions) are dealt with below (Larsen et al. 2006).

3.2.5. Plates

The generic plate considered in this study is a mono-metal-positive-plate (aluminium), which is known to be used within sheet, fed offset plate making (Larsen et al. 1995). According to information from Hoechst (1994) on Ozasol® plates, the thickness of offset plates is in the range of 0.12-0.5 mm. Here we use the average 0.3 mm. As the density of aluminium is 2,700 kg/m^3 (IAI 2003) the mass of aluminium per square meter plate is 0.81 kg. The emulsion layer on top of the plate has a thickness of 3 µm according to Baumann and Gräfen (1999b). The density of the emulsion is estimated to be 1,230 kg/m^3 on the basis of a weighted average (2:1) of the density (1,200 kg/m^3) of low molecular phenol formaldehyde resin (Muskopf 2000) and the density (1,300 kg/m^3) of polyvinyl alcohol (Baumann & Rothardt 1999). The mass of the emulsion per square meter therefore lies close to 4 g/m^2 (3.7 g/m^2). According to Ludwiszewska (1992) the range is 1.5 g/m^2-4 g/m^2 plate, but for positive plates in most cases near the highest value (Larsen et al. 2006).

Based on the figures estimated above, the generic offset plate is assumed to be composed of 99.5 % aluminium and 0.5% emulsion. The generic emulsion is assumed to have the composition shown in Table 3.3 (Larsen et al. 1995; KODAK 2002a).

Table 3.3: Composition of generic offset plate emulsion.

Component	% w/w
Phenol formaldehyde resin*	64
Polyvinyl alcohol	34
2-diazo-1(2H)-naphthalinone derivate	1
Other additives**	1

* For upstream production, data substituted by alkyd resin
** For example pigments

3.2.6. Plate developer

The composition of the generic developer is shown in Table 3.4 and based on Larsen et al. (1995).

Table 3.4: Composition of generic positive offset plate developer.

Component	% w/w
Water	90
Disodium metasilicate	8
Sodium hydroxide	2

3.2.7. Gumming agent

The composition of the generic gumming agent used in this study (see Table 3.5) is based on UNIFIN (Agfa 2002) which is known to be used within sheet fed offset and Larsen et al. (1995).

Table 3.5: Composition of generic gumming agent.

Component	% w/w
Water	85
Carboxymethyl cellulose (CMC)	5
Sodium-dodecyl-diphenyloxide-disulphonate	5
Citric acid	5
5-chloro-2-methyl-isothiazolin-3-one	0.1
2-methyl-2-isothiazolin-3-one	0.033

3.2.8. Paper

The generic paper used in the reference scenario in this study is a white uncoated fine type paper produced from sulphate pulp based on virgin fibres as defined in the Danish draft report on recycling of paper and card board (Frees et al. 2004).

Even though coated paper like MultiArt Silk and MultiArt Gloss from PAPYRUS has a widespread use within sheet fed offset printing, the coating process is excluded here. This is due to lack of readily available data, and the assessment that the coating process most probably is insignificant for the environmental impact as compared to the other processes included in the production of paper (Larsen et al. 2006).

3.2.9. Alcohol (IPA)

The alcohol added to the fountain solution is typically 2-propanol (isopropyl alcohol, IPA) or a mixture of IPA (10%) and ethanol (90%) called IPA-spirit (Miljønet 2004). In this generic LCA, pure IPA is chosen (Larsen et al. 2006).

3.2.10. Printing ink

Several different pigments, some different binders and solvents, and several types of additives are used in sheet feed offset printing ink. The generic composition shown in Table 3.6 has been chosen, mainly based on Larsen et al. (1995).

Table 3.6: Composition of generic sheet fed offset printing ink.

'Typical' composition		Upstream inventory substitute		Downstream inventory substitute	
Component	**% (w/w)**	**Component**	**% (w/w)**	**Component**	**% (w/w)**
Pigment Yellow 12 and 13 (P.Y. 12 and 13)	6	P.Y. 14	6	P.Y. 12	6
Pigment Blue 15:3 (P.B. 15:3)	5	P.B. 15	5	P.B. 15	5
Pigment Red 57:1 (P.R. 57:1)	5	P.Y. 14 and P.B. 15	5	P.R. 57:1	5
Pigment Black 7 (P.B 7, Carbon Black)	3	P.B. 7	3	P.B. 7	3
Modif. phenol resin	20	Alkyd resin	20	Alkyd resin	20
Soya oil alkyd	12	Alkyd resin	12	Alkyd resin	12
Soya oil	12	Soya oil	12	Soya oil	12
n-paraffin (heavy)	29	n-paraffin (heavy)	29	Tetradecane	29
Polyethylene wax	3	Polyethylene wax	3	Polyethylene wax	3
Additives (incl. siccatives)	5	excluded	excluded	excluded	excluded

Besides the composition of the ink, the upstream and downstream inventory substitutes are also shown in Table 3.6. "Upstream inventory substitute" means the chemical on which the inventory upstream from the production stage (not including the production stage) is based. "Downstream inventory substitute" similarly means the chemical on which the inventory from production stage (included) and downstream is based. The reason for this division is that in many cases, upstream data are only available for certain substances or mixtures (e.g. modified phenol resin) within a functional group (e.g. binders) and furthermore, these data typically only include resource and energy consumption, and emissions given as "sum parameters" (e.g. COD, BOD) and not emissions of single substances. However, for the production stage we typically have a better knowledge of the composition of the raw materials, and individual substances can therefore be used when assessing emission from this stage and downstream if data on potential impact is available for these substances (Larsen et al. 2006).

The pigments included in Table 3.6 ("typical" composition) are the most frequently used according to Larsen et al. (1995). The relative distribution within the group of pigments is based on an example from Baumann & Rothardt (1999) concerning a leaflet with 50 % area printed in four colour (half-tone; 20% black, 70% yellow, 50% blue, 50% red) and 20% area of text (15% black). The relative distribution of each pigment type is corrected for the different content of pigments in the different coloured printing inks according to Larsen et al. (1995).

The mix of pigments shown in Table 3.6 does not exist in any printing ink but should be seen as an attempt to reflect an approximation of the average relative consumption of pigments for producing generic printed matter by sheet fed offset (Larsen et al. 2006). It may be relevant to look at a significantly higher relative consumption of carbon black (dominating in production of books) but this is not included in this study.

Pigment Yellow 12 (P.Y. 12), P.Y. 13 and P.Y 14 are all diaryl (diazo) pigments based on dichloro benzidine. The only difference in structure is the number of methyl groups, i.e. P.Y. 12 (no group), P.Y. 13 (four groups) and P.Y 14 (two groups) (Baumann & Rothardt 1999). It seems unlikely that these differences would give rise to major significant differences in inventory data and environmental properties. Furthermore, P.Y. 14 (for which inventory data is available) is actually used in offset printing inks but to a much lesser extent than P.Y. 12 and P.Y 13 (Baumann & Rothardt 1999).

Pigment Blue 15:3 (P.B. 15:3) is substituted by P.B. 15. Both of them are copper phthalocyanine pigments with only minor differences in structure, e.g. different crystal modification (Herbst & Hunger 1993) and they share the same CAS number.

Pigment Red 57:1 (P.R. 57:1) belongs to the group of BONA (beta-oxynaphtoic acid) pigment lakes, which are monoazo pigments (Herbst & Hunger 1993). This structure is quite different from the structure of the two substitutes (i.e. P.Y. 14 and P.B. 15) so this substitution is only justified by lack of data.

Carbon Black is not substituted.

Binders included comprise the dominant hard resin: Modified phenol resin, the alkyd resin: Soya oil alkyd, and the drying oil: Soya oil (actually semi-drying). No data is available on the modified phenol resin or the soya oil alkyd, and both of them are substituted by general alkyd resin.

The solvent n-paraffin (heavy) is substituted by one of its components tetradecane (Hansen & Gregersen 1986) for the inventory/impact assessment downstream.

Additives, e.g. siccatives and antioxidants, are excluded due to lack of data (Larsen et al. 2006).

3.2.11. Fountain solution

The composition of the generic fountain solution concentrate is shown in Table 3.7. This composition is based on MSDS of two products from Akzo Nobel (2003a, 2004) and Larsen et al. (1995). The full recipe for a fountain solution is very complex (Larsen et al. 1995), and only the known main components and very toxic components are included in Table 3.7. Other constituents like acids, surface active substances, corrosion inhibitors and more are excluded due to lack of data and these substances probably do not contribute significantly because they occur in very low quantities and/or are not very toxic.

Table 3.7: Composition of generic fountain solution concentrate.

Component	% w/w
Water	94
IPA	3
Diethylene glycol*	3
2-brom-2-nitropropan-1,3-diol (Bronopol)	0.25

Component	% w/w
5-chloro-2-methyl-isothiazolin-3-one**	0.045
2-methyl-2-isothiazolin-3-one**	0.015

* For upstream production data substituted by ethylene glycol
** Part of Kathon

Fountain solution concentrates registered at the Danish Ecolabelling Agency all contain Kathon at the same concentration level, i.e. 0.0475%, 0.055% and 0.06%, and one type also contains 0.1% Bronopol (Gruvmark 2004) (Larsen et al. 2006).

3.2.12. Lacquer

Three main types of lacquer are used within finishing of sheet fed offset printed matter, i.e. water based lacquer, "offset lacquer" and UV lacquer. Consumption of water based lacquer (dispersion lacquer) is dominant, accounting for at least 80% (Brodin & Korostenski 1995, 1997) and water based lacquer is also used to a high degree as "anti-set-off-agent" in the printing process (Larsen et al. 1995). UV lacquer is excluded here due to lack of readily available data.

The composition of the generic water based lacquer is shown in Table 3.8 and based on Larsen et al. (1995, 2002), Andersen et al. (1999), and Akzo Nobel (2003b, 2004). Known potential components like anti foaming agents and softeners are excluded due to lack of data.

Table 3.8: Composition of generic water based lacquer.

Component	% w/w
Water	66
Acrylates (poly-, mono-, esters)	25
Glycerol	3
Ethanol	2
Ammonia	1
Polyethylene wax	1
2-amino-ethanol	1
Alcoholethoxylate*	1
Chloracetamide	0.04

* Here represented by undecyletherpolyoxy-ethylene (5)

According to Gruvmark (2004), water-based lacquers registered at the Danish Ecolabelling Agency either do not contain biocides or 0.016%-0.025% chloracetamid or 0.005%-0.007% bronopol.

The composition of the generic "offset lacquer" is shown in Table 3.9 and resembles a sheet fed offset printing ink without pigments.

Table 3.9: Composition of generic "offset lacquer".

Component	% w/w
Modified phenol resin*	24
Soya oil alkyd*	14
Soya oil	14
n-paraffin (heavy)**	40
Poly ethylene wax	3
Additives (incl. siccatives)***	5

* Substituted by general alkyd resin for upstream production
** Substituted by tetradecane for downstream inventory
*** Excluded due to lack of data.

3.2.13. Glue

The only glue included here is Hot Melt. It is very frequently used within the printing industry (Miljønet 2004) for finishing of catalogues, magazines and paperbacks (Brodin & Korostenski 1995, 1997; Miljønet 2004) and in combination with dispersion glue for finishing of books. The generic composition of Hot Melt is shown in Table 3.10 and based on the Hot Melt product Superflex 225 (After Print 1983), Brodin & Korostenski (1995, 1997) and (Miljønet 2004). Antioxidants are excluded due to lack of data (Larsen et al. 2006).

Table 3.10: Composition of generic Hot Melt glue.

Component	Substitute	% w/w
EVA (Ethylene-vinyl-acetate)	LDPE (Light Density Polyethylene)*	38.0
Modified resin or rosin	Alkyd resin**	48.0
Wax	Polyethylene wax***	14.0
Antioxidants	Excluded	0.15

* Assumed to be the main component in EVA (Schmidt et al. 1993)
** A modified resin like phenol formaldehyde resin is, as in the case of the generic printing ink, substituted by alkyd resin here.
*** It is assumed here that wax can be represented by polyethylene wax which is often used in wax containing raw materials for the printing industry (Larsen et al. 1995).

3.2.14. Cleaning agents

Different types of cleaning agents are used in a sheet fed offset printing company (Table 3.11). The main types include heavy aliphatic (paraffin based, low volatilization), light aliphatic (“ekstraktions benzin”, highly volatile), vegetable oil based, alcohol based, surfactants based, and different mixtures of these (Larsen et al. 1995, Akzo Nobel 1998, 2003c). Surfactants are both included in detergent-based types like shampoos and pasta for cleaning rollers and as emulsifiers in solvent-based types (Ludwiszewska 1992; Larsen et al. 1995). Destructors (ink removers) which are only used to a very limited degree (Larsen et al. 1995) are excluded here.

Table 3.11: Types of cleaning agents included in the study.

Type	% of total use*	Upstream inventory component	Downstream inventory substitute
Heavy aliphatic	24.5	n-paraffins (heavy)	Tetradecane**
Light aliphatic	24.5	n-paraffins (light)	Hexane (0.1% benzene)***
Vegetable oil based	24.5	Soya oil	Soya oil
Alcohol based	24.5	Ethanol	Ethanol
Surfactants	2.0	Alcohol ethoxylates	Undecyletherpolyoxyethylene (5)

* It is assumed here that the surfactants only account for around 2% (Larsen et al. 1995) and that the rest is shared equally between the other types.
** Tetradecane is a component of aliphatic mixtures (C10-C14) with distillation interval: 180-300°C.
***Hexane is a component in aliphatic mixtures (C5-C9) with a distillation interval of 60-140°C, i.e. “ekstraktions benzin” (Hansen & Gregersen 1986; Larsen et al. 1995) known to contain limited amounts (ca. 0.1%) of aromatics (Hansen & Gregersen 1986) here assumed to be benzene at its threshold value (0.1%) for classification when occurring in mixtures (ECC 1967 and its amendments, e.g. EC 2001).

The relative share of each of the cleaning agent types in Table 3.11 is assumed but supported by Larsen et al. (1995), Anonymous 1 (2000) and Anonymous 6 (2002). At one sheet fed printing company (Anonymous 1 2000) using widely used products, i.e. Synvex, Vegeol, Solvask and “ekstractions benzin” the exact distribution (% w/w) excluding surfactants is known, i.e. heavy aliphatic (21%), light aliphatic (23%), alcohol (29%) and vegetable oil based (27%). Based on these arguments the distribution in Table 3.11 is assessed to represent the average situation for sheet fed printing companies fairly well, at least in the Nordic countries (Larsen et al. 2006).

3.3. Consumption of raw materials

The consumption of raw materials in the material stage and the disposal stage are taken into account to a degree defined by the unit processes included and generally not as detailed as the consumption at the production stage.

If looking at the paper production, the raw materials included are mainly kaolin and wood but not, for example, adhesives and auxiliary materials (e.g. biocides). The consumption of the raw materials and energy at the production stage is shown in Table 3.12.

The consumption figures used in the generic LCA are as far as possible based on data from the technical background document for the Swan criteria (Brodin and Korostenski 1995). However, in most cases data are missing and the investigation conducted in this study is used, see Table 3.12. For paper consumption, the average value calculated in this study is used instead of the average value in Brodin & Korostenski (1995) because the value from the technical background document seems far too low, at least in the Danish printing industry according to three anonymous Danish sheet fed offset printing companies (Anonymous 4-6 2003) and the Graphic Association Denmark (Bøg 2003). The consumption of biocides for film developing and plate making is estimated on the basis of the average rinsing water consumption (see Table 3.12), and information on a typical dose of around 50 ml per 40 L rinsing water (Cederquist 2004) of a biocide agent i.e. Nautalgin C1 (Deltagraph 1997) with a known biocide content (around 2.7% Kathon®). On this basis, the biocide active ingredient (a.i.) in the rinsing water can be estimated to 33 ppm (Larsen et al. 2006).

Table 3.12: Consumption at the model sheet fed offset printing company (Brodin and Korostenski 1995). kg or m^2 per functional unit (FU).

Material/chemical	Stage	Amount per fu (range in brackets)	Amount per FU (range in brackets) *
Film (m^2/FU)	Repro	-	5.63 (1.9-9.76)
Film developer (kg/FU)	Repro	2.85 (1.19-6.00)	1.77 (0.1-3.63)
Fixer (kg/FU)	Repro	3.17 (1.25-9.66)	3.58 (0.66-9.4)
Biocide agent (kg/FU)	Repro	-	0.00019 (0.000008-0.00039) #*
Water for rinsing (kg/FU)	Repro	-	5.77 (0.24 – 11.6)
Plate (Al) (m^2/FU)	Plate making	-	4.16 (1.0 – 8.45)
Plate emulsion (kg/FU)	Plate making	-	0.015 (0.0037 – 0.031)**
Plate developer (kg/FU) ##	Plate making	0.90 (0.50-1.4)	1.22 (0.094-3.5)
Gumming agent (kg/FU)	Plate making	-	0.030 (0.0052-0.055)
Biocide agent (kg/FU)	Plate making	-	0.0012 (0.00056-0.0018) #*
Water for rinsing (kg/FU)	Plate making	-	37.4 (16.7-54.0)
Paper (kg/FU)	Printing	1,100 §§§ (1,030-1,190)	1,200§ (1,030-1,470)
Printing ink (kg/FU)	Printing	5.8 (1.8-14)	12.1 (4.5-26.5)
IPA (kg/FU)	Printing	3.93 (0.0785-5.18)	4.85 (2.84-10.4)
Fountain solution (kg/FU)	Printing	-	1.00 (0.474-1.90)
Water for dilution (kg/FU)	Printing	-	29 (11-46)
Cleaning agents total (kg/FU)	Cleaning	-	2.50 (0.30-10.6)
- veg. oil based (kg/FU)	Cleaning	-	0.61 (0.05-2.56) ###
- organic solv. based (kg/FU)	Cleaning	-	1.10 (0.56-2.33)
- aliphatic based (kg/FU)	Cleaning	-	0.61
- "ekstraktionsbenzin" (kg/FU)	Cleaning	-	0.61
- alcohol based (kg/FU)	Cleaning	-	0.61
- detergent based (kg/FU)	Cleaning	-	0.05 ***

Material/chemical	Stage	Amount per fu (range in brackets)	Amount per FU (range in brackets) [*]
Water for rinsing (kg/FU)	Cleaning	-	22 (0.26-65)
Water based lacquer (kg/FU)	Finishing	§§	4.98 (0.51-6.97)
Offset lacquer (oil based) (kg/FU)	Finishing	§§	0.22 (0.006-0.38)
Hot Melt glue (kg/FU)	Finishing	-	0.75 (0.067-1.44)
Energy consumption (kWh/FU)	Total general	-	1,210 (768-1,620)
- electricity (kWh/FU)	General	-	705 (629-858)
- district heating (kWh/FU)	General	-	176 (0-765)
- fuel oil (kWh/FU)	General	-	243 (0-486)
- natural gas (kWh/FU)	General	-	83.9 (0-304)
Water (kg/FU) Total general	Total general	-	1,160 (385-2,690)

[*] Based on inventory data from 11 offset printing industries: 1 sheet fed, 1 heatset and one cold-set-newspaper (Larsen et al. 1995), 6 sheets fed (Anonymous 1-6: Danish printing companies data from 1999, 2000 and 2002) and 2 cold-set-newspaper (Axelsson et al. 1997).
[**] Estimated based of consumption of plate area and amount of emulsion per square meter (3.7 g/m^2) (Baumann & Gräfen 1999b).
[***] Larsen et al. (1995).
[#] Kathon a.i.. Estimated on basis of content in rinsing water and rinsing water consumption.
[##] Density of Goldstar Developer (Kodak 2002b) used.
[###] Actual average of range is 0.87 but only 24.5% of total (0.245*2.5=0.61 kg/FU) is allocated, see Table 3.11.
[§] Spillage of paper for recycling 16% (4.5%-32%).
[§§] Total lacquer consumption 5.6 (3.2-8).
[§§§] Spillage of paper for recycling 9.6% (3.3%-19%).

3.4. Emissions

Emissions to air, water (and soil) from the material stage and the disposal stage are taken into account to a degree defined by the unit processes included and generally far from as detailed as the emissions at the production stage.

The emissions from the production stage included in this study are shown in Table 3.13.

Table 3.13: Emitted fractions of different materials and substances for the model sheet fed offset printing company (percentage of consumption).

Material/chemical	% to air	% to waste water	% to chemical waste	% waste for incineration	% to recycling	% with product
Film						
PET (89% w/w)	0	0	0	100	0	0
Ag (6% w/w)	0	0.43 (0.020 -0.72)	0	0	99.6	0
Br (5% w/w)[*]	-	-	-	-	-	-
Film developer	0	4.2	0	0	95.8	0
Fixer	0	19	0	0	81	0
Biocide agent (repro)	0	100	0	0	0	0
Plate (Al)	0	0	0	0	100	0
Plate emulsion	0	24	36		(40)[**]	0
Plate developer	0	40	60	0	0	0
Gumming agent	0	100	0	0	0	0
Biocide agent (plate making)	0	100	0	0	0	0

Material/chemical	% to air	% to waste water	% to chemical waste	% waste for incineration	% to recycling	% with product
Paper	0	0	0	0	16***	84
Printing ink	0	1	20	0	0	80
IPA	86	14	0	0	0	0
Fountain solution agent						
- IPA	86	14	0	0	0	0
- Glycol + biocides	0	100	0	0	0	0
Cleaning agents						
- veg. oil based	0	1	99	0	0	0
- organic solv. based						
- aliphatic based	70	1	29	0	0	0
- extractions benzine	95	0.1	4.9	0	0	0
- alcohol based	95	1	4	0	0	0
- detergent based	0	50	50	0	0	0
Water based lacquer	0	5	0	0	0	95
Offset lacquer (oil based)	0	0.1	20	0	0	79.9
Hot Melt glue#	-	-	-	-	-	-

* Excluded due to lack of data

** Assumed to be incinerated during recycling process of aluminium

*** Actually this is the paper spillage/waste at the printing company gathered with the purpose of recycling. However as for the paper that is part of the product it is assumed that 53% is recycled and 47% is incinerated according to the Danish situation in 2000 on general recycling of paper (Tønning 2002).

Quantitative useful data on emission of Hot Melt during use is not readily available. But based on the qualitative description in MiljøNet (2004) it probably primarily contributes to potential occupational health and safety problems in the workers' environment which is not included in this LCA. However air emission of organic solvent components and other organic substances created during the heating process may contribute to LCA impact categories like photochemical ozone formation and human toxicity via air.

Emission of silver to water is estimated on basis of data from the technical background document (Brodin & Korostenski 1995) i.e. a relative coverage of ion exchange equipment of 22% leading to an average emission of 42 mg Ag/m^2 film.

Water emission of film developer is also estimated on basis of Brodin & Korostenski (1995), i.e. the typical value 0.02 L film developer/m^2 film. Density of developer is assumed to be 1.055 kg/m^3 (KODAK 2001b).

Also for fixer, the water emission is calculated on basis of Brodin & Korostenski (1995) with a typical value of 0.08 L/m^2 and an assumed density of 1.31 kg/m^3 (KODAK 2000).

As it is assumed that the rinsing water for film developing and plate making is preserved with biocide agent and after recycling is emitted as wastewater to the sewage system, the biocide agent emission to water becomes 100%.

For the offset plate, it is assumed that 100% of the aluminium is recycled, and for the plate emulsion 60% ends up in the developer of which 40% ends up in the rinsing water (Larsen et al. 1995). As it is assumed that the rinsing water after recycling is emitted to the sewage system, 24% of the emulsion is emitted to water. The remaining 36% is disposed of as chemical waste together with the used developer.

Gumming solution typically ends up in either rinsing water during the plate making process (Anonymous 5 2003) or in the fountain solution during printing (Larsen et al. 1995). As both rinsing water and fountain solution are assumed to be emitted to the sewage system 100% of the gumming solution is emitted to water.

For paper, the spillage/waste amount for recycling is set to 16%. The rest follows the product (see Table 3.12 and Table 3.13). It is assumed that 53% of the paper consumption (including both spillage and product) is recycled and the rest i.e. 47% is incinerated and the heat utilised. This assumption is based on the Danish situation in 2000 (Tønning 2002).

Printing ink emitted to water (e.g. via fountain solution) is assumed to be 1% of ink consumption (Larsen et al. 1995). The percentage ink disposed as chemical waste is estimated to 20% (range: 2.4%-45.9%) on the basis of data from Larsen et al. (1995), Anonymous 1-2 (2000), Anonymous 3 (2002) and Anonymous 5 (2003).

86% of the IPA consumption is assumed to be emitted to air, either as a separate chemical or as part of the fountain solution agent (Larsen et al. 1995). The rest (14%) is assumed to be emitted to the sewage system as part of the used fountain solution. All other components of the fountain solution (biocides and diethylene glycol) are assumed to be fully (100%) emitted to water.

For cleaning agents (see Table 3.13), the emissions to air and water are mainly based on Larsen et al. (1995), and the rest is assumed to be disposed of as chemical waste. As a minor part of the cleaning is done on dampening form rollers with cloth, 50% of the surfactants are assumed to be emitted to water. The rest is assumed to be part of cleaning agents (e.g. as emulsifiers in solvent based types) for which emission to water is very limited (0.1-1%) (Larsen et al. 1995). However, as low/none volatile solvents may be part of detergent based types for cleaning dampening form rollers with cloth, emission to water of vegetable oil and low volatile aliphatics is set to 1% whereas emission to water of the highly volatile “ekstraktions benzin” is set to 0.1%. Emission of alcohol to water is set to 1% because of high water solubility. The part of the cleaning agent not emitted to air or water is assumed to be disposed of as chemical waste.

On the basis of data from Anonymous 4 (2003), the part of water-based lacquer emitted to water is set to 5% of consumption (due to both cleaning and disposal of lacquer waste). The rest is assumed to be part of the product. For the offset lacquer (oil based) the emission to water is assumed to be only 0.1% of consumption due to a lower number of cleaning cycles (no colour change) and handling of waste as chemical waste (Larsen et al. 1995).

4. Impact assessment

4.1. Conventional assessment

4.1.1. Methodology

The impact assessment methodology used here is the one defined by the ReCiPe method (Goedkoop et al. 2008). The impact categories assessed are shown in Sections 4.1.6 (for the midpoint level) and 4.1.7 (for the endpoint level).

The GaBi tool version 4.4 (PE- LBP 2008) is here used to perform the calculations in the different steps of the impact assessment, i.e. classification, characterisation, normalisation, and weighting, but the LCI modelling has been done in a spreadsheet model.

4.1.2. Classification

Emissions (or other exchanges) mapped in the inventory were assigned to the relevant impact categories, e.g. CO_2 and CH_4 emission were assigned to climate change and the CH_4 emission was also assigned to photochemical oxidant formation.

4.1.3. Characterisation

For each impact category, a category indicator (CI) result was calculated by summing up the results of each assigned emission quantity (Q) multiplied by its corresponding characterisation factor (CF) within that impact category:

$CI_{\text{impact category A}} = Q_{1A}*CF_{1A} + Q_{2A}*CF_{2A} + ... + Q_{nA}*CF_{nA}$

The category indicator results for all the impact categories included represent the characterised Life Cycle Impact Assessment (LCIA) profile of the generic printed matter. This profile can be presented as such or as normalized values to assist comparisons across impact categories.

The characterisation factors applied in this study were taken from ReCiPe (Goedkoop et al. 2008) included in the GaBi 4.4 tool database.

4.1.4. Normalisation

In order to provide an impression of the relative magnitude of the potential impacts of emissions or resources consumption and facilitate interpretation (Jolliet et al. 2003), the category indicator results can be related to reference information by applying normalisation factors. As dully noted by Heijungs (2005) different references can be defined, but a commonly used reference is the average yearly environmental load in a country, continent, or global, divided by the number of its inhabitants.

In the present report, normalisation refers to the ratio between characterised results and a reference situation per capita yielding the normalised impact score for each of the impact categories. The reference situation is obtained by the total impact potential of the reference region (i.e. characterised total emissions or resources consumed) divided by the number of its inhabitants in the reference year, and expressed in units of person·yr or person-equivalents (PE).

These normalisation references (NR) per impact category thus express the average impact per capita in the reference region and year.

The NRs applied to normalise ReCiPe's category results were taken from Goedkoop et al. (2013) for year 2000 – see Table 4.20 (page 46) for midpoint indicators and Table 4.23 (page 49) for endpoint to damage normalisation.

Normalisation was done on spreadsheet-based calculations.

4.1.5. Weighting

Weight attribution to the normalised category indicator results is used to set an indication of seriousness of each category for comparison. In the present study no distinct weighting was assigned to the different categories, meaning that weighting factor was assigned to 1 to all categories.

4.1.6. ReCiPe midpoints

Characterisation at the midpoint level was done for the following impact categories:

Table 4.1: Midpoint indicators in ReCiPe (Goedkoop et al. 2008).

Impact category	Unit
Agricultural land occupation	m^2·yr
Climate change	kg CO_2 eq
Fossil depletion	kg oil eq
Freshwater ecotoxicity	kg 1,4-DB eq
Freshwater eutrophication	kg P eq
Human toxicity	kg 1,4-DB eq
Ionising radiation	kg U235 eq
Marine ecotoxicity	kg 1,4-DB eq
Marine eutrophication	kg N-eq
Metal depletion	kg Fe eq
Natural land transformation	m^2
Ozone depletion	kg CFC-11 eq
Particulate matter formation	kg PM10 eq
Photochemical oxidant formation	kg NMVOC
Terrestrial acidification	kg SO_2 eq
Terrestrial ecotoxicity	kg 1,4-DB eq
Urban land occupation	m^2(tr)
Water depletion	m^3

4.1.7. ReCipe endpoints

Characterisation at the endpoint level was done for the following impact categories:

Table 4.2: Endpoint indicators in ReCiPe (Goedkoop et al. 2008).

Impact category	Unit
Agricultural land occupation	species·yr
Climate change Ecosystems	species·yr
Climate change Human Health	DALY
Fossil depletion	$
Freshwater ecotoxicity	species·yr
Freshwater eutrophication	species·yr
Human toxicity	DALY

Impact category	Unit
Ionising radiation	DALY
Marine ecotoxicity	species·yr
Metal depletion	$
Natural land transformation	species·yr
Ozone depletion	DALY
Particulate matter formation	DALY
Photochemical oxidant formation	DALY
Terrestrial acidification	species·yr
Terrestrial ecotoxicity	species·yr
Urban land occupation	species·yr

4.2. Assessment of the new life cycle impact categories developed in LC-IMPACT

The newly developed methodologies in the LC-IMPACT that were found relevant for the case study on paper production and printing are included in Table 4.3.

Table 4.3: Impact indicators based on the new assessment methodologies developed in LC-IMPACT project.

Impact category	Indicator	Unit	Type	Relevant to
Land use	BDP (Regional absolute impacts)	$PDF_{regional}$*yr	Endpoint	Paper production
	Forestry (Human Health impacts)	DALY	Endpoint	
	Forestry (Ecosystems Health impacts)	PDF*m^2*yr	Endpoint	
	Soil Erosion to Resources	MJ_{Se}*m^2*yr	Endpoint	
	Soil Erosion to Ecosystems	NPPD*m^2*yr	Endpoint	
Water use	Wetland Biodiversity	Species-eq*yr	Endpoint	Paper production
	River Biodiversity	PDF*m^3*yr	Endpoint	
Whole effluent toxicity	WET (from COD)	PDF*m^3*yr	Endpoint	Paper and printing
Photochemical ozone formation	Ozone formation	kg	Midpoint	Printing
	Human Health Damage	DALY	Endpoint	
	Ecosystems Damage	PAF*m^2*yr	Endpoint	
Fine particulate matter formation	--	*No CF available*	--	Printing
Indoor exposure to solvents	--	*No CF available*	--	Printing
Noise	Human Exposure	Person-Pa*sec	Midpoint	Printing

A short description of the methodologies, the inventory flows, applied characterisation factors, and estimated impact scores are included in the following sections.

4.2.1. Land use

This impact category was found relevant for the paper production stage and its methodology applies to the estimation of impacts from land use on:

- Biodiversity Depletion Potential (BDP) from Land Use (4.2.1.1)
- Land Use impacts from Forestry (4.2.1.2);
- Land Occupation impacts from Soil Erosion (4.2.1.3).

4.2.1.1. Biodiversity Depletion Potential (BDP) from Land Use

4.2.1.1.1. Brief description

(*taken from LC-IMPACT Deliverable D1.2 – De Baan et al. 2012a, De Baan et al. 2012b. Additional guidance for application from De Baan 2012, supporting publication: De Baan et al. 2013)*

Land occupation is here addressed as an important driver for biodiversity loss. Biodiversity is a complex and multifaceted concept, involving several hierarchical levels (i.e. genes, species, ecosystems), biological attributes (i.e., composition, structure, function) and a multitude of temporal and spatial dynamics. Biodiversity assessments therefore have to simplify this complexity into a few facets, which are quantifiable with current knowledge and data. Existing land use LCIA methods assess land use impacts on biodiversity on a global scale, quantifying the biodiversity value of reference habitat of different biomes based on vascular plant species richness, ecosystems scarcity, and ecosystems vulnerability. The new methodology proposes to apply a regionalized global method based on a broader taxonomic coverage, answering the need for inclusion of a spatial heterogeneity of biodiversity to deal with the non-uniform and variable reactions of ecosystems and species to disturbances (such as land use).

The developed method is based on the framework for Life Cycle Impact Assessment (LCIA) of land use, developed by the UNEP/SETAC Life Cycle Initiative working group, which distinguishes three types of land use impacts: transformation impacts (caused by land use change), occupation impacts (occurring during the land use activity), and permanent impacts (i.e. irreversible impacts on ecosystems, which occur when an ecosystem cannot fully recover after disturbance). The authors have focused on the occupation impacts.

The biomes defined by the World Wide Fund for Nature (WWF) were used as spatial unit for biogeographic differentiation, representing the world's 14 major terrestrial habitat types. Land use types were classified based on the UNEP/SETAC LULCIA proposal.

A global quantitative analysis of peer-reviewed biodiversity surveys were combined with national biodiversity monitoring data to assess land use impacts across multiple taxonomic groups and world regions, using a set of species-based biodiversity indicators. The indicator relative species richness is used to calculate characterisation factors for occupation impacts of terrestrial ecosystems expressed as a Biodiversity Damage Potential (BDP). Overall, the impact of land use on biodiversity was assessed by comparing the relative difference of biodiversity of a land use *i* with a (semi-) natural reference situation.

4.2.1.1.2. Inventory flows

The relevant flows to the paper production processes identified and used in the present study relate to the background processes of forest land occupation and transformation for the paper production in the material stage, were quantified as (Hemerobie ecoinvent):

{Occupation, arable, non-irrigated} = 26.43 m^2*yr
{Occupation, construction site} = 0.08 m^2*yr
{Occupation, dump site} = 1.03 m^2*yr
{Occupation, dump site, benthos} = 0.06 m^2*yr
{Occupation, forest, intensive} = 3,274.29 m^2*yr
{Occupation, forest, intensive, normal} = 1,533.57 m^2*yr
{Occupation, forest, intensive, short-cycle} = 3.18 m^2*yr
{Occupation, industrial area} = 0.59 m^2*yr
{Occupation, industrial area, benthos} = 5.38E-04 m^2*yr
{Occupation, industrial area, built up} = 0.79 m^2*yr

{Occupation, industrial area, vegetation} = 0.50 m^2*yr
{Occupation, mineral extraction site} = 0.89 m^2*yr
{Occupation, permanent crop, fruit, intensive} = 7.45 m^2*yr
{Occupation, shrub land, sclerophyllous} = 0.02 m^2*yr
{Occupation, traffic area, rail embankment} = 0.38 m^2*yr
{Occupation, traffic area, rail network} = 0.43 m^2*yr
{Occupation, traffic area, road embankment} = 69.07 m^2*yr
{Occupation, traffic area, road network} = 1.06 m^2*yr
{Occupation, urban, discontinuously built} = 0.06 m^2*yr
{Occupation, water bodies, artificial} = 1.31 m^2*yr
{Occupation, water courses, artificial} = 0.43 m^2*yr

- **Sum {occupation} = 4,921.63 m^2*yr**

{Transformation, from arable} = 5.66E-04 m^2
{Transformation, from arable, non-irrigated} = 4.85E+01 m^2
{Transformation, from arable, non-irrigated, fallow} = 9.26E-05 m^2
{Transformation, from dump site, inert material landfill} = 1.91E-03 m^2
{Transformation, from dump site, residual material landfill} = 1.19E-03 m^2
{Transformation, from dump site, sanitary landfill} = 1.30E-03 m^2
{Transformation, from dump site, slag compartment} = 1.72E-04 m^2
{Transformation, from forest} = 1.37E-01 m^2
{Transformation, from forest, extensive} = 3.33E+01 m^2
{Transformation, from forest, intensive, clear-cutting} = 1.14E-01 m^2
{Transformation, from industrial area} = 1.18E-03 m^2
{Transformation, from industrial area, benthos} = 3.66E-06 m^2
{Transformation, from industrial area, built up} = 1.30E-06 m^2
{Transformation, from industrial area, vegetation} = 2.22E-06 m^2
{Transformation, from mineral extraction site} = 3.10E-02 m^2
{Transformation, from pasture and meadow} = 1.14E-02 m^2
{Transformation, from pasture and meadow, intensive} = 3.96E-02 m^2
{Transformation, from sea and ocean} = 5.88E-02 m^2
{Transformation, from shrub land, sclerophyllous} = 6.80E-03 m^2
{Transformation, from tropical rain forest} = 1.14E-01 m^2
{Transformation, from unknown} = 2.75E-01 m^2
{Transformation, to arable} = 2.22E-02 m^2
{Transformation, to arable, non-irrigated} = 4.86E+01 m^2
{Transformation, to arable, non-irrigated, fallow} = 1.34E-04 m^2
{Transformation, to dump site} = 7.55E-03 m^2
{Transformation, to dump site, benthos} = 5.88E-02 m^2
{Transformation, to dump site, inert material landfill} = 1.91E-03 m^2
{Transformation, to dump site, residual material landfill} = 1.19E-03 m^2
{Transformation, to dump site, sanitary landfill} = 1.30E-03 m^2
{Transformation, to dump site, slag compartment} = 1.72E-04 m^2
{Transformation, to forest} = 1.86E-02 m^2
{Transformation, to forest, intensive} = 2.18E+01 m^2
{Transformation, to forest, intensive, clear-cutting} = 1.14E-01 m^2
{Transformation, to forest, intensive, normal} = 1.09E+01 m^2
{Transformation, to forest, intensive, short-cycle} = 1.14E-01 m^2
{Transformation, to heterogeneous, agricultural} = 6.43E-03 m^2
{Transformation, to industrial area} = 8.16E-03 m^2
{Transformation, to industrial area, benthos} = 5.24E-05 m^2

{Transformation, to industrial area, built up} = 1.54E-02 m^2
{Transformation, to industrial area, vegetation} = 1.04E-02 m^2
{Transformation, to mineral extraction site} = 3.11E-01 m^2
{Transformation, to pasture and meadow} = 5.78E-04 m^2
{Transformation, to permanent crop, fruit, intensive} = 1.05E-01 m^2
{Transformation, to sea and ocean} = 3.66E-06 m^2
{Transformation, to shrub land, sclerophyllous} = 4.57E-03 m^2
{Transformation, to traffic area, rail embankment} = 8.95E-04 m^2
{Transformation, to traffic area, rail network} = 9.84E-04 m^2
{Transformation, to traffic area, road embankment} = 4.66E-01 m^2
{Transformation, to traffic area, road network} = 5.16E-03 m^2
{Transformation, to unknown} = 1.49E-03 m^2
{Transformation, to urban, discontinuously built} = 1.18E-03 m^2
{Transformation, to water bodies, artificial} = 4.27E-02 m^2
{Transformation, to water courses, artificial} = 5.07E-03 m^2

- **Sum {Transformation} = 165.24 m^2**

4.2.1.1.3. Characterisation factors for regional absolute impacts

The chosen method to assess land use impacts to BDP is described by De Baan et al. (2012a, b, c) as regional absolute impacts expressed in $PDF_{regional}$ to fit the specificity of the available data and study scope.

To estimate the regional absolute impacts for land occupation, transformation, and permanent impacts, the assessment is done at regional scale. The total potential species extinction of all land use occurring within one ecosystem (=WWF ecoregion) is modelled using an adapted species-area relationship (matrix calibrated species-area relationship). This total species loss is then allocated to all the land use types depending on their intensity (=suitability for species) and the percentage of converted area that is occupied by this land use type within each ecoregion.

Distinction is made between reversible and irreversible species loss. Reversible impacts are calculated based on the potential loss of non-endemic species (i.e. species that also occur in other ecoregions and can potentially be reintroduced if they get regionally extinct). This is used to derive occupation and transformation impacts, which are considered to be reversible. Irreversible impacts are based on the potential loss of endemic species, i.e. species that only occur within one ecoregion and thus get globally extinct. These impacts are used to calculate permanent impacts.

Forestry and paper production processes are assigned to Sweden in the present case study. To obtain a representative country CF the 4 ecoregions that Sweden is part of were accounted for and their respective CFs weight averaged by land area, as per the calculations shown in Table 4.4.

Table 4.4: Calculations of the Characterisation Factors (CF) for land Occupation (*Occ*), Transformation (*Trans*) and Permanent (*Perm*) impacts applicable to Sweden, based on the available CFs for Land use type "*Used forests*" of the relevant ecoregions (based on De Baan et al. 2012c)

Biome (eco_code)	Area in Biome (%)	Biome Area (km^2)	CF_{Occ} $(PDF_{regional})/[m^2]$	CF_{trans} $(PDF_{regional})\cdot[yr/m^2]$	CF_{perm} $(PDF_{regional})\cdot[yr/m^2]$
PA0405*	2.0	112,696.94	8.43E-11	1.02E-08	n/a
PA0436**	27.1	842,115.06	1.67E-11	2.13E-09	n/a
PA0608***	59.5	2,155,374.22	3.95E-12	1.16E-09	n/a
PA1110****	11.5	235,767.18	1.55E-11	3.64E-09	n/a
Country CF (weight averaged) =			**2.84E-12**	**6.25E-10**	n/a
Default applicable CF (World) =			--	--	**6.66E-06**

*PA0405 = Baltic mixed forests (ecoregion) from Temperate Broadleaf and Mixed Forests (Biome)
** PA0436 = Sarmatic mixed forests (ecoregion) from Temperate Broadleaf and Mixed Forests (Biome)
***PA0608 = Scandinavian and Russian taiga (ecoregion) from Boreal Forests/Taiga (Biome)
****PA1110 = Scandinavian Montane Birch forest and grasslands (ecoregion) from Tundra (Biome)
n/a = not available

4.2.1.1.4. BDP Impact scores

To calculate impact scores for land use occupation, transformation, or permanent impacts (Table 4.5), the identified CF is multiplied by the land use occupation flow from the life cycle inventory given as time (t_{Occ}) and area (A_{Occ}) required for a certain land use activity for land occupation, or simply area (A_{trans}) by a certain land use activity for land transformation and permanent impacts, applying the following calculations:

Total <u>Occ</u>upation impact = CF_{Occ} * {Area occupied [m^2]} * {Time occupied [years]}
Total <u>Trans</u>formation impact = CF_{trans} * {Area transformed [m^2]}
Total <u>Perm</u>anent impact = CF_{perm} * {Area transformed [m^2]}
Where:
CF_{Occ}: [potential loss of **non-endemic** species/m^2] = [potential **regional** loss species /m^2]
CF_{trans}: [potential loss of **non-endemic** species/m^2 * year] = [potential **regional** loss species /m^2 * year]
CF_{perm}: [potential loss of **endemic** species/m^2 * year] = [potential **global** loss species /m^2 * year]

Table 4.5: Estimation of Impact scores from land Occupation (*Occ*), Transformation (*Trans*) and Permanent (*Perm*) impacts, from available relevant Characterisation Factors (CF) and Life Cycle Inventory (LCI) flows.

Impact	Applicable CF	LCI unit flow	Impact score (CF*LCI)
<u>Occ</u>upation impact	2.84E-12 $PDF_{regional}/m^2$	4,921.63 m^2*yr	1.40E-08 $PDF_{regional}$*yr
<u>Trans</u>formation impact	6.25E-10 $PDF_{regional}$*yr/m^2	165.24 m^2	1.03E-07 $PDF_{regional}$*yr
<u>Perm</u>anent impact	6.66E-06 $PDF_{regional}$*yr/m^2	165.24 m^2	1.10E-03 $PDF_{regional}$*yr

4.2.1.2. Land Use impacts from Forestry

4.2.1.2.1. Brief description

(taken from LC-IMPACT Deliverable D1.2 – Muchada et al. 2012)

A notable effect of bioenergy use is in the way that extraction processes of biomass e.g. forest wood for biofuel use or pulp production in the present case, can cause changes in terrestrial carbon stocks and in the overall carbon balance. This impact category is expressed by a global, spatial-explicit method that quantifies the effects of changes in forests wood resource extraction for bioenergy, on the carbon balance, which lead to climate change and subsequent damage to biodiversity and human health. The CF represents the change in forest carbon stock per every extra cubic metre of wood extracted – midpoint CF unit: tC·yr/m^3 wood.

4.2.1.2.2. Inventory flow

The relevant flows, i.e. volume (m^3) of wood (per FU) to feed the paper production aggregated process identified and used in the present study were quantified as:

{Wood} = 3.97E-05 m^3
{Wood, hard, standing} = 2.16E+00 m^3
{Wood, primary forest, standing} = 1.18E-03 m^3
{Wood, soft, standing} = 1.72E+00 m^3

- **Total {Wood} = 3.87 m^3**

4.2.1.2.3. Characterisation factors

The estimated midpoint Characterisation Factors (CF_m) represent the change in forest carbon stock per every extra cubic metre of wood extracted (Van Zelm 2012):

- **Midpoint CF (tC·yr/m^3 wood):** Sweden = 6.46E+01

Endpoint characterisation factors (CF_e) were determined for the damage on human health in Disability Adjusted Life Years (DALY) related to malaria, malnutrition, drowning, diarrhoea, and cardio-vascular diseases (DALY/m^3 wood) and potentially disappeared fraction (PDF) of some selected species, including birds, butterflies, mammals, and plants for terrestrial ecosystems (PDF·yr·m^2/m^3 wood) caused by wood extraction in managed forests.

Global damage to human health due to increase in cubic metre of wood extracted from that country (Van Zelm 2013):

- **Endpoint CF for Human health damage (DALY/m^3 wood):** Sweden = 1.37E-03

Global damage to ecosystems health due to increase in cubic metre of wood extracted from that country (Van Zelm 2013):

- **Endpoint CF for Ecosystems health damage (PDF·m^2·yr/m^3 wood):** Sweden = 1.35E-11

4.2.1.2.4. Forestry impact scores

The calculation of the impact scores from Forestry (Table 4.6) refers to the multiplication of the relevant CF with the identified LCI flow (used m^3 of wood).

Table 4.6: Estimation of Impact scores from forestry in Sweden from available relevant Characterisation Factors (CF) and Life Cycle Inventory (LCI) unit flows.

Impact	Applicable CF	LCI unit flow	Impact score (CF*LCI)
Midpoint score	6.46E+01 tC·yr/m^3 wood	3.87 m^3 wood	2.50E+02 tC·yr
Human Health damage	1.37E-03 DALY/m^3 wood	3.87 m^3 wood	5.32E-03 DALY
Ecosystems Health damage	1.35E-11 PDF·m^2·yr/m^3 wood	3.87 m^3 wood	5.22E-11 PDF·m^2·yr

4.2.1.3. Land Occupation impacts from Soil Erosion

4.2.1.3.1. Brief description

(*taken from LC-IMPACT Deliverable D1.2 – Núñez et al. 2012a. Additional guidance for application from Núñez 2012a, b. Supporting publication: Núñez et al. 2012b)*

This method aims at estimating potential environmental damages at the endpoint level due to soil erosion during land occupation (land transformation is not addressed). It is suitable for any type of land use. Two endpoint indicators are included: one for Damage to Resources (ΔR, unit: megajoules solar energy, i.e., emergy, MJ_{se}), and the other for Damage to Ecosystems (ΔEQ unit: decimal percentage of net primary production depletion, NPPD).

Damage to resources (ΔR) is expressed as surplus energy needed to make the resource available at some point in the future. This is a suitable unit to evaluate soil depletion, which indicates the anticipated energy removal from nature to provide a unit of soil eroded during land occupation. Instead of using energy units (MJ-equivalents), the new approach uses emergy units (MJ-solar equivalents). Unlike the energy metric, emergy accounts for quality differences of the energy used to generate a product or service by converting raw units (e.g., kg soil, m^3 water) to a common basis, i.e., units of solar energy. The effect of soil erosion on soil resource depletion (ΔR) is expressed as follows with units of MJ-solar equivalent soil loss integrated by unit of area and time of land occupation:

- If soil loss = 0, ΔR= 0
- If soil loss > 0, $\Delta R = \underbrace{A \times t \times \text{Soil loss}}_{\text{LCI}} \times \underbrace{\frac{SD_{ref} - SD_i}{SD_{ref}} \times SEF_{soil}}_{\text{CF}} = MJ_{se} \cdot m^2 \cdot yr$

The effect of soil erosion on ecosystems quality (ΔEQ) is expressed using a growth-based value: NPPD (potential net primary production depletion). For an occupation of 1 m^2 and 1 year, NPPD ranges from 0 to 1 (percentage expressed as a decimal).

The effects of soil erosion on ecosystems quality (ΔEQ) are expressed using a growth-based value:

- If $SOC_{loss} = 0$, $\Delta EQ = 0$
- If $SOC_{loss} > 0$, $\Delta EQ = \underbrace{A \times t \times \frac{aSOC_{loss} + b}{100}}_{\text{LCI}} \times \underbrace{\frac{NPP_{0,i}}{NPP_{0,ref}}}_{\text{CF}} = NPPD \cdot m^2 \cdot yr$

4.2.1.3.2. Inventory flow

The relevant flow to the paper production processes identified and used in the present study relate to the forest land occupation, which was quantified as described earlier (in Section 4.2.1.1.2, page 30):

- **Sum {occupation} = 4,921.63 m^2*yr**

Other relevant LCI data from the present case study include:

- Land occupation type: Forest land, intensive use, normal cycle;
- Soil erosion in Sweden: 34 $g \cdot m^{-2} \cdot yr^{-1}$ (average value, after Ulén et al., 2012);
- Topsoil Organic carbon content (% weight): 5.27 considering the Podzols dominant soil group in Sweden, from Harmonized World Soil Database (HWSD, FAO et al., 2009);

4.2.1.3.3. Characterisation factors

The characterisation factors were available for a specific location (upon request given local coordinates), country, continent, and global default (Table 4.7). The country aggregation was used in the present case study, as there is no identified source location for wood/pulp and the applicable Ecoinvent process is generic (aggregated), hence CF for Sweden was applied.

Table 4.7: Characterisation Factors (CF) available for the Soil Erosion impact category for two different endpoints.

Endpoint	Aggregation scale	CF
Damage to Resources (ΔR)	Local (for specific coordinates)	Not applicable
	Country (Sweden)	***13.40 MJ_{se}/g_{soil}***
	Continent (Europe)	14.50 MJ_{se}/g_{soil}
	Default (Global)	15.60 MJ_{se}/g_{soil}
Damage to Ecosystems (ΔEQ)	Local (for specific coordinates)	Not applicable
	Country (Sweden)	***0.34 [-]***
	Continent (Europe)	0.35 [-]
	Default (Global)	0.31 [-]

4.2.1.3.4. Erosion impact scores

The estimated impact scores for the Soil Erosion category are presented in Table 4.8 below.

Table 4.8: Estimation of impact scores due to Soil Erosion in Sweden for the paper production part of the present case study.

Endpoint	Aggregation scale	Impact score (CF*LCI)
Damage to Resources (ΔR)	Country (Sweden)	2.24E+06 $MJ_{se}\cdot m^2\cdot yr$
Damage to Ecosystems (ΔEQ)	Country (Sweden)	5.38E+01 NPPD$\cdot m^2\cdot yr$

4.2.2. Water use

This impact category was found relevant for the paper production stage and its methodology applies to surface water (SW) and groundwater (GW) consumption, covering:

- Impacts on wetland biodiversity from surface water ($CF_{WL,SW}$) and groundwater ($CF_{WL,GW}$) withdraw (4.2.2.3);
- Impacts on river biodiversity (CF_{river}) (4.2.2.4).

4.2.2.1. Brief description

(taken from LC-IMPACT Deliverable D1.3 – Verones et al 2012a, Verones et al. 2012b. Additional guidance for application from Hellweg et al. 2012)

Wetlands are complex ecosystems that provide multiple services such as water purification, buffering of water flows, resources for human uses (e.g., food, plants, water, building materials and medicines) as well as habitats for a wide range of biodiversity, of which a considerable part is dependent or linked to wetlands. Additionally, more than 70% of the global freshwater withdrawals are used for agriculture, thus the pressure on wetlands is twofold from a water perspective: 1) active drainage for land gains, and 2) hydrological changes due to the abstraction of surface and groundwater. In the same line, human-induced changes in water consumption are likely to reduce the species richness of freshwater ecosystems.

In the LC-IMPACT project, a new scientifically sound methodology for the assessment of groundwater and surface water use was developed to deliver characterisation factors (CFs) for the environmental impact of water use on natural wetland vegetation, taking into account local conditions. The methods address impacts to human health (in terms of DALY/m^3) and impacts to ecosystems (in terms of PDF$\cdot$yr$\cdot m^3/m^3$ as well as absolute species loss per m^3).

The methodology implies the quantification of surface water (SW) and groundwater (GW) consumption. The amount of SW consumed has an impact on the biodiversity of wetlands of international importance ($CF_{WL,SW}$) downstream the place of use, on the biodiversity of river systems (CF_{river}), and on human health (CF_{HH}). Similarly, GW consumed has an impact on groundwater-fed wetlands ($CF_{WL,GW}$) and human health (CF_{HH}).

4.2.2.2. Inventory flows

In accordance to the method description and CFs available from Verones (2012), the water sources used in the paper production processes have to be identified and the amount consumed per functional unit quantified.

The case study deals with a generic paper production process (aggregated) from Ecoinvent in GaBi (*RER: paper, woodfree, coated, at integrated mill*), therefore no specific location can be assigned to the water sources, hence the need to define the spatial aggregation scale to the country average (Sweden).

The classification of the water source types (SW or GW) is difficult due to the identification of the flows resulting from GaBi modelling, e.g. 96.8% of the water flows included in the mentioned Ecoinvent aggregated process are generically assigned to "Water [Water]" – only the remaining 3.2% are specifically assigned to SW (ca. 2.0%, river and lake water), GW (ca. 0.9%), and other sources (ca. 0.3% for sea water, and salt water).

For the estimation of the impacts on biodiversity of river systems only 1.9% of the total water consumed is readily identified as surface water (Water (river water) [Water]). Therefore, an assumption was introduced regarding a user-defined *pro rata* % of SW and GW from the gross unspecified amount (Water [Water]) (Table 4.9) was applied here to the estimation of impacts on wetlands biodiversity, human health, and river biodiversity, as a modified LCI flow.

The basis for the *pro rata* calculation is the typical water source shares in Sweden (Statistics Sweden 2013).

Table 4.9: Re-classification of water sources into modified LCI flows (Flow*) of surface water (SW*) and groundwater (GW*) by application of a *pro rata* from Swedish statistics (Statistics Sweden 2013) of water sources to the unspecified category (Water [Water]).

Original LCI flows	**Amount LCI (m^3)**	**Contrib (%)**	**Source ID**	**Modified LCI Flow (*w/ country statistics*)**	
Water (Total)	169.75	--	--	Fraction	Flow*
Water [Water]	164.33	96.81	Gen	(SWE)	**m^3**
Water (river water) [Water]	3.27	1.93	SW	Surface water (SW*)	
Water (ground water) [Water]	1.58	0.93	GW	0.937	**157.22**
Water (sea water) [Water]	0.47	0.28	Oth	Groundwater (GW*)	
Water, salt, sole [Water]	0.07	0.04	Oth	0.001	**1.67**
Water (lake water) [Water]	0.03	0.02	SW	Other sources	
				0.063	10.87

4.2.2.3. Impacts on wetland biodiversity

4.2.2.3.1. Characterisation factors

The characterisation factors (Table 4.10) for wetlands of international importance (CF_{WI}) were provided for the country scale (Sweden, averaged for the existing wetlands with surface- and groundwater consumption) as the paper production process is not assigned to a specific location and an aggregated process is used in the modelling.

Table 4.10: Averaged characterisation factors for Sweden for the estimation of the impacts on wetlands of international importance (CF_{WI}) upon consumption of surface water (SW) or groundwater (GW) per animal group.

Impacts on wetlands from consumption of:	CF species-eq*yr/m^3	Impact group
Surface water ($CF_{WI,SW}$)	7.61E-09	Waterbirds
	8.02E-09	Non-residential birds
	1.31E-10	Water-dependent mammals
	2.72E-12	Reptiles
	5.09E-11	Amphibians
Groundwater ($CF_{WI,GW}$)	5.78E-09	Waterbirds
	4.20E-09	Non-residential birds
	2.03E-11	Water-dependent mammals
	1.12E-12	Reptiles
	2.59E-12	Amphibians

4.2.2.3.2. Wetland biodiversity impact scores

The impact scores (IS) are obtained by multiplying the relevant unit LCI flow by the corresponding CF (Table 4.11). The IS can be aggregated after the characterisation into a general unspecified target group (water dependent animals).

Table 4.11: Impact scores (IS) on wetlands of international importance upon consumption of surface water (SW) or groundwater (GW) per animal group and aggregated impact group. Uncertainty included.

Impact group	IS species-eq*yr	Impacts on wetlands from consumption of:
Waterbirds	1.20E-06	Surface water ($IS_{WI,SW}$)
Non-residential birds	1.26E-06	
Water-dependent mammals	2.05E-08	
Reptiles	4.27E-10	
Amphibians	8.00E-09	
Aggregated (SW)	**2.49E-06**	
Waterbirds	9.63E-09	Groundwater ($IS_{WI,GW}$)
Non-residential birds	6.99E-09	
Water-dependent mammals	3.37E-11	
Reptiles	1.87E-12	
Amphibians	4.31E-12	
Aggregated (GW)	**1.67E-08**	

4.2.2.4. Impacts on river biodiversity

Human-induced changes in water consumption are likely to reduce the species richness of freshwater ecosystems. The method for estimating characterisation factors for water consumption is based on the loss of native freshwater fish species using a species-river discharge curve for 214 global river basins (Hellweg et al. 2012).

4.2.2.4.1. *Characterisation factors*

No Swedish rivers (geographical scope relevant for the case study) are included in the available CFs listing, so the default CF of $5.00 \cdot 10^{-4}$ $PDF \cdot m^3 \cdot yr/m^3$ is applied (Huijbregts 2012).

4.2.2.4.2. *River biodiversity impact scores*

Table 4.12: Impact scores (IS) of freshwater consumption on river's biodiversity.

Impact	Applicable CF	LCI unit flow	Impact score (CF*LCI)
River biodiversity loss	5.00E-04 $PDF \cdot m^3 \cdot yr/m^3$	157.22 m^3	7.86E-02 $PDF \cdot m^3 \cdot yr$

4.2.3. Whole Effluent Toxicity (WET)

This impact category was found relevant for both the paper production stage and the printing stage and its methodology applies to waterborne organic emissions.

4.2.3.1. Brief description

(taken from LC-IMPACT Deliverable D2.2 – Raptis et al. 2012)

Existing aquatic ecotoxicity fate and effect models used in LCIA have been developed explicitly for individual chemicals and inadequately account for the ecotoxicity of complex chemical mixtures, such as industrial effluents. Commonly measured parameters include organic sum-parameters, such as total organic carbon (TOC), chemical oxygen demand (COD) and biochemical oxygen demand (BOD). The proposed methodology for WET provides a means of developing fate and effect models for TOC, an all-encompassing measure of organic content.

Freshwater ecotoxicity characterisation factors ($\mathrm{CF}_{\mathrm{w}_{\mathrm{TOC}}}$) are calculated as a product of relevant fate, $\mathrm{FF}_{\mathrm{w,w}}$, exposure, XF_{w}, and effect, EF_{w}, factors, and are dependent on a set of key measurements, especially with regard to the effect factor, $\mathrm{EF}_{\mathrm{w}_{\mathrm{TOC}}}$.

The proposed methodology lends itself for easy use in LCA studies involving industrial effluents as part of their emissions, since ecotoxicity is attributed to TOC, a commonly measured organic sum-parameter, thus avoiding the need for extensive single chemical data in the inventory phase, or assumptions regarding the effluent composition.

While awaiting publication permission from a complete WET study for pulp and paper mill effluents, the fate factor for TOC for similar effluents has been calculated via the USEtox fate model. Environmental fate parameters used as inputs to the USEtox model were individually estimated, either directly from experimental studies, or from empirical relations. The expected residence time of TOC from pulp and paper mill effluents between 7.7 and 23.2 days for the scenarios considered, which was averaged to 15.5 days for application in the present case study.

Conversion from available industrial COD data regarding and the model input TOC was achieved by applying the correlation COD=49.2+3.0*TOC developed by Dubber & Gray (2010).

4.2.3.2. Inventory flow

The inventory flow identified for this category was obtained from industry data, i.e. COD concentration in rinse water discharged from the platemaking process, converted to TOC using the correlation by Dubber & Gray (2010), and scaled to FU (see Table 4.13). This estimated value of TOC was used to feed the platemaking process in the average printing stage and complemented by ecoinvent data for the stage's remaining processes.

Table 4.13. Calculations to estimate TOC inventory flow for the platemaking process in the printing stage for the model printing company to be applied in the WET impact category.

Parameter		Amount	Unit
COD from rinse water	[ ]	31,950.00	mg/L
TOC from rinse water	[ ]	10,633.60	mg/L
Rinse water	Volume	38,680.77	L
TOC discharged	Mass	411.32	kg
Annual production (avg)	Mass	1,033.58	Ton
TOC per FU	**Mass**	**0.40**	**kg/ton = kg/FU**

The resulting inventory flow for the printing stage totals 0.94 kg TOC/FU (which includes the calculated company data above) and 1.31 kg TOC/FU for the paper production process (from ecoinvent in GaBi).

4.2.3.3. Characterisation factors

As mentioned above, the $FF_{w,w}$ ranges from 7.7 d to 23.2 depending on the considered scenario for emissions to continental freshwater. These results are averaged to 15.5 d for application in the present case study.

Due to dissemination/publication restrictions from industry partners the $EF_{W_{TOC}}$ is not further explained and the given value is applied:

$EF_{W_{TOC}}$ = 3.31 PAF·m^3/kg [TOC]

And the resulting $CF_{W_{TOC}}$= 51.3 PAF·m^3·d/kg

4.2.3.4. Impact scores

The estimated impact scores for the ecotoxicity of whole effluents are presented in Table 4.14 next.

Table 4.14: Impact scores (IS) of ecotoxicity of whole effluents (TOC=Total Organic Carbon).

Impact: WET of emissions to continental freshwater	Applicable CF	LCI unit flow (TOC)	Impact score (CF*LCI)
Process: Paper production	51.3 PDF·m^3·d/kg 0.14 PDF·m^3·yr/kg	1.31 kg	6.70E+01 PDF·m^3·d 1.84E-01 PDF·m^3·yr
Process: Printing	51.3 PDF·m^3·d/kg 0.14 PDF·m^3·yr/kg	0.94 kg	4.83E+01 PDF·m^3·d 1.32E-01 PDF·m^3·yr

The CF for the WET impact category was developed for the paper production stage based on emissions data and conditions from pulp and paper mills. However, the same CF was applied here to the printing stage as well. Although not correct, this application was set as a necessary assumption in order to get a working impact score for the assessment for the printing stage of the product system. The uncertainty of this application was not estimated but the misapplication is recognised.

The subsequent interpretation of the impact scores is only for the characterised scores as no normalisation reference was developed, therefore no major influence in the overall interpretation is further introduced.

4.2.4. Photochemical ozone formation

This impact category was found relevant for the printing stage and its methodology applies to the endpoints human health and ecosystems damage.

4.2.4.1. Brief description

(taken from LC-IMPACT Deliverable D3.5 – Azevedo et al. 2012)

A spatially explicit assessment of NO_x and NMVOC with regard to photochemical ozone formation (POF) has been conducted for Europe. The impact indicators are impacts on human health and impacts on natural vegetation.

The endpoint characterisation factors for damage to natural vegetation (ecosystems damage) were derived on a spatially explicit scale for 65 European regions. The characterisation factors are defined as the change in ozone damage on natural vegetation due to a change in emission of NOx and NMVOC, and consist of a fate and an effect factor. The fate factors were determined with source-receptor relationships based on the EMEP atmospheric model for each of the 65 source regions on a 0.5x0.5 degree receptor grid resolution. The effect factors were based on a lognormal relationship between the potentially affected fraction of plant species and ground level ozone exposure. The sensitivity distributions were derived using experimentally derived species-specific dose-response relationships.

Characterisation factors regarding human health are defined as the change in ozone damage expresses as disability adjusted life years (DALY) and YOLL due to a change in emission of NOx and NMVOC, and consist of a fate and an effect factor. The fate factors were also determined with source-receptor relationships based on the EMEP atmospheric model for each of the 65 European source regions. Regarding human health the ozone metric SOMO35 was used to calculate impacts due to mortality and morbidity in Europe for the years 2010 and 2020.

4.2.4.2. Characterisation factors

The characterisation factors for human health damage are available per region (Sweden + Denmark) and per country (Denmark) for ecosystems damage (Table 4.15).

Table 4.15: Characterisation Factors (CF) available for human health damage (midpoint and endpoint) and ecosystems damage (endpoint with EMEP lognormal method) from photochemical ozone formation emissions (NOx and NMVOC).

Human Health at midpoint	**iF NOx**	**iF NMVOC**
Country	ppm (mg/kg) NOx	ppm (mg/kg) NMVOC
Sweden, Denmark	0.04	0.03
Human Health at endpoint	**CF NOx**	**CF NMVOC**
Country	DALY/kg NOx	DALY/kg NMVOC
Sweden, Denmark	1.20E-08	9.00E-09
Natural Ecosystems at endpoint	**CF EMEP lognormal NOx**	**CF EMEP lognormal NMVOC**
Country	PAF*m^2*yr/kg NOx	PAF*m^2*yr/kg NMVOC
Denmark	0.726	0.966

4.2.4.3. Inventory flow

The relevant flows to the case study refer to the emitted NOx to air and NMVOC to air, which were quantified as:

- {Nitrogen oxides to air} = 1.05 kg
- {Group NMVOC to air} = 0.29 kg

4.2.4.4. Impact scores

The estimated impact scores for the photochemical ozone formation emissions are presented in Table 4.16 next.

Table 4.16: Impact scores (IS) from photochemical ozone formation emissions.

Indicator	Impact score from NOx	Impact score (from NMVOC)	Total impact score
Midpoint:			
- Ozone formation	4.18E-08 kg	8.61E-09 kg	5.04E-08 kg
Endpoint:			
- Human Health Damage	1.25E-08 DALY	2.58E-09 DALY	1.51E-08 DALY
- Ecosystems Damage	0.76 PAF·m^2·yr	0.28 PAF·m^2·yr	1.04 PAF·m^2·yr

4.2.5. Fine particulate matter formation (indoor exposure to particles)

This impact category was found relevant for the printing stage and its methodology applicable to the endpoint human indoor exposure to fine particulate matter.

4.2.5.1. Brief description

Intake fractions from both indoor and outdoor exposure are part of the characterisation factor (CF), within the same impact category "human toxic effects", following the USEtox methodology (Hellweg et al. 2009): $CF = iF \cdot EF$

Where *iF* is the intake fraction [$kg_{intake}/kg_{emitted}$] and *EF* the effect factor [cases/ kg_{intake}].

In the Life Cycle Impact Assessment phase, the characterisation factors are multiplied with the emissions reported in the inventory phase to determine an overall impact score for potential human-toxic effects (Hellweg et al. 2009).

4.2.5.2. Impact

Inventory data was partially gathered, but insufficient to feed the intake fraction model, and no EF was available, therefore no CF was calculated and no impact estimation was possible.

4.2.6. Indoor exposure to solvents

This impact category was found relevant for the printing stage and its methodology applicable to the endpoint human indoor exposure to solvents.

No CFs were found available and therefore no impact estimation was possible.

4.2.7. Noise impact to humans

This impact category was found relevant for the printing stage and its methodology applies to indoor exposure to noise in an occupational exposure perspective.

4.2.7.1. Brief description

(taken from LC-IMPACT Deliverable D3.6 – Cucurachi et al. 2012. Additional guidance for application from Cucurachi 2012 and CFs listed in Cucurachi & Heijungs 2012)

Noise is a serious stressor affecting the health of millions of citizens. It has been suggested that disturbance by noise is responsible for a substantial part of the DALY-score for human health. However, no recommended approach to address noise impacts was proposed by the ILCD reference handbook, nor characterisation factors and appropriate inventory data are available in databases. This new methodology fills the gap of the absence of noise as an impact category in LCA and presents characterisation factors for noise impacts at a European level (i.e. EU27).

Sounds emitted by a source are complex, and fluctuate in amplitude and frequency content. The relationships between sound energy level and frequency are required for the meaningful analysis of a sound spectrum. This newly proposed methodology proposes to decompose the sound emitted by a source according to the one-third octave bands centre frequencies in which its spectrum can be decomposed. The method can be applied to outdoor sound emissions as well as to indoor or localised occupational sound emissions. This latter situation covers the needs of the printing case study in the LC-IMPACT project. It refers to the exposure to sound emissions which take place in an indoor environment (e.g. a print shop, a production line in a factory) and here considered as “occupational”. Therefore, they are specifically oriented at investigating the effects of sound emissions (and noise) on e.g. machinery and equipment operators or, in general, all the categories of workers operating with indoors equipment which produces a sound energy of variable intensity.

4.2.7.2. Inventory flow

The sound power levels are converted from dB to watt by: $W_i = 10^{-12} \times 10^{\frac{Lw_i}{10}}$

where W is the sound power of the source (or of the full set of active sources) in watt, Lw is the sound power level per each octave band *i*. The formula applies also to an unspecified frequency and an unspecified time of emission (i.e. *i* = unspecified).

Then the time that the functional unit is active in the specific compartment is multiplied to the sound power levels to calculate the elementary flows are calculated by: $m_{i,c} = W_i \times time_c$

where m (the inventory flow) is the sound emission in joule (watt*sec) specified (or unspecified) per octave band and in a certain compartment *c*. Once again, *i* may be unspecified. $time_c$ in second, can be calculated based on the production rate of the system (i.e. kg/s) and the relative output (i.e. kg).

For the present case study the following data and calculations (Table 4.17) were applied for the estimation of the inventory flow.

Table 4.17: Calculations of the inventory flow per period of day from sound power level dB(A) to sound emission in Joule (m) for average measured sound levels from operating machinery.

Exposure to:		**Sound power level**		**Time to flow** [a]	**LCI flow (m)**
	unit	*dB(A)*	*watt*	*Sec*	*watt*sec=J*
Average machinery noise		79.8	9.55E-04	5.17E+04	49.40
Time allocation coefficient [b]		Day: 0.50		Evening: 0.17	Night: 0.33
Time allocated LCI flow		**24.70 watt*sec**		**8.23 watt*sec**	**16.47 watt*sec**

[a] Number of workers * time of exposure until production of FU.
[b] Day 12/24 hrs; Evening 4/24 hrs; Night 8/24 hrs.

4.2.7.3. Characterisation factors

The characterisation factors are provided for eight sound octaves (1-8, and unspecified frequency), three periods of day (day, evening, night, and unspecified time of day), and five typified locations (urban, suburban, rural, industrial, indoor, and unspecified location).

As no frequencies (octaves) were identified in the sound measurements available from the covered printing houses, the CFs applied in the present case study were:

- sound[octave_unspecified,day,indoor] = 4.82E+05 person-Pa/W
- sound[octave_unspecified,evening,indoor] = 8.62E+05 person-Pa/W
- sound[octave_unspecified,night,indoor] = 1.62E+06 person-Pa/W

4.2.7.4. Impact scores

The estimated impact scores for the noise category in the specified conditions are included in Table 4.18 next.

Table 4.18: Calculations of the impact scores for the three inventoried flows for occupational exposure to noise in printing houses.

Flow ID	Period	Flow (watt*sec=J)	CF (person-Pa/W)	Impact score (person-Pa*sec)
Average exposure per FU				
sound[octave_unspecified,day,indoor]	*Day*	24.70	4.82E+05	1.19E+07
sound[octave_unspecified,evening,indoor]	*evening*	8.23	8.62E+06	7.10E+06
sound[octave_unspecified,night,indoor]	*night*	16.47	1.62E+06	2.67E+07
			Total impact score: SUM =	**4.57E+07**

4.2.8. Other impact assessment methodologies newly developed in LC-IMPACT

In addition to the impact assessment methodologies described in the previous sections other impact categories were also addressed in the LC-IMPACT framework. These newly developed methodologies that were found not relevant to the present case study on paper production and printing are: mineral resource use, fossil resource use, marine resource use (fish), acidification, and aquatic eutrophication.

4.2.9. Normalisation references

The LC-IMPACT new impact categories applied the normalisation references provided by the method developers – see Table 4.27 (page 52) for midpoint indicators and Table 4.30 (page 55) for endpoint indicators.

4.3. Results of the impact assessment with ReCiPe method

4.3.1. Impacts scores at midpoint

The characterisation results of the product system for sheet fed offset material at midpoint following the assessment by ReCiPe methodology are presented per impact category and divided into the main life cycle stages: Paper production, printing, and end-of-life (EOL) (Table 4.19). 'Offset product' refers to the total impact of the product system, and EOL includes recycling (with avoided production of virgin fibres and combustion of fossil fuels), and incineration (with recovered energy) (see also 2.2.5).

As the goal is to test the applicability of the new assessment methods and not to fully analyse the paper and printing life cycle, the assessment detail shown is limited to these 3 stages, although the assessment has covered all its life cycle stages (see Figure 2.2 in page 13).

Table 4.19: Impact characterisation scores at midpoint for the whole product system (offset product), and main life cycle stages: paper production, printing, and end-of-life (EOL).

Midpoint Impact Indicator [unit]	Offset product	Paper production	Printing	EOL
Agricultural land occupation [m2a]	4,792.51	4,844.94	15.89	-68.32
Climate change [kg CO2-Equiv.]	3,974.09	3,180.50	650.43	143.15
Fossil fuel depletion [kg oil eq]	656.64	533.99	269.83	-147.18
Freshwater ecotoxicity [kg 1,4-DB eq]	4.38	3.79	1.08	-0.48
Freshwater eutrophication [kg P eq]	0.03	0.03	0.01	-0.01
Human toxicity [kg 1,4-DB eq]	182.85	127.93	22.34	32.58
Ionising radiation [kg U235 eq]	-23,817,970.23	101,257,769.42	55,417,115.03	-180,492,854.69
Marine ecotoxicity [kg 1,4-DB eq]	4.61	2.03	2.77	-0.18
Marine eutrophication [kg N-Equiv.]	2.45	2.33	0.47	-0.35
Metal depletion [kg Fe eq]	42.12	51.55	10.08	-19.51
Natural land transformation [m2]	0.80	0.86	0.09	-0.15
Ozone depletion [kg CFC-11 eq]	8.06E-05	9.19E-05	3.85E-05	-4.97E-05
Particulate matter formation [kg PM10 eq]	3.06	3.06	0.59	-0.59
Photochemical oxidant formation [kg NMVOC]	6.00	5.67	1.21	-0.88
Terrestrial acidification [kg SO2 eq]	6.34	6.11	1.68	-1.46
Terrestrial ecotoxicity [kg 1,4-DB eq]	0.15	0.11	0.06	-0.03
Urban land occupation [m2a]	81.22	74.94	8.89	-2.62
Water depletion [m3]	674.49	3,961.86	3,024.15	-6,311.52

The individual contribution of each of the main life cycle stages to the midpoint indicators score is shown in Figure 4.1., where an overall dominance of the paper production stage is visible for the majority of the impact categories.

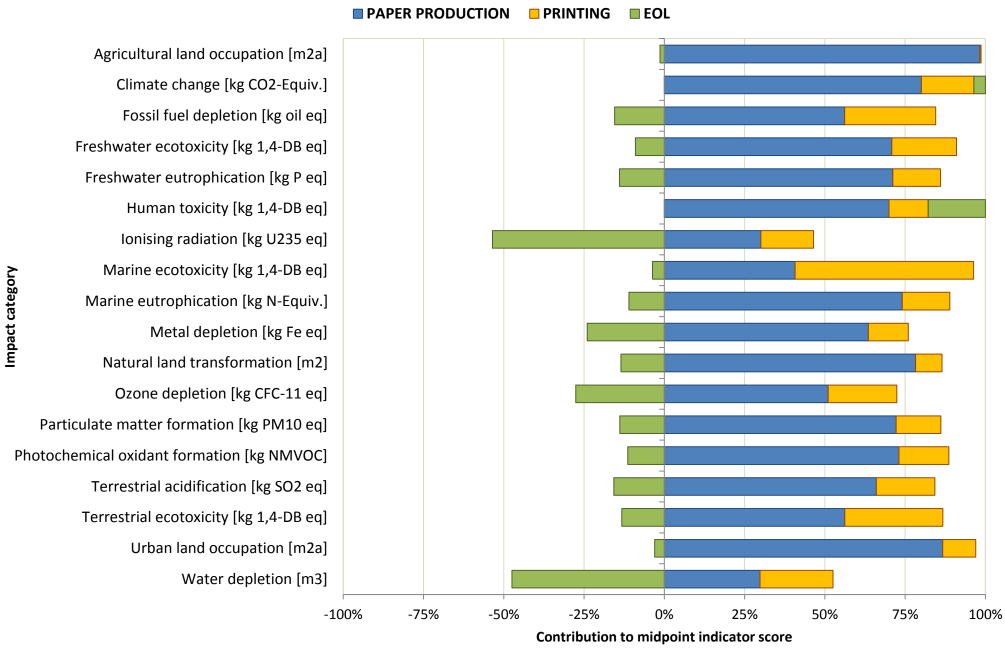

Figure 4.1: Main life cycle stages' contributions to the midpoint indicator score for the ReCiPe's impact category.

4.3.2. Normalisation at midpoint

The normalisation references used for the normalisation of the characterised impact scores were compiled from ReCiPe and are included in Table 4.20, together with details on the reference spatial resolution and year.

Table 4.20: Normalisation references (NR) at midpoint (mp) for the ReCiPe impact categories.

Midpoint Impact Indicator [unit]	NR (mp)	Unit	Resolution, year	Source
Agricultural land occupation [m2a]	4.52E+03	m2a/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Climate change [kg CO2-Equiv.]	1.12E+04	kg CO2 eq/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Fossil fuel depletion [kg oil eq]	1.56E+03	kg oil eq/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Freshwater ecotoxicity [kg 1,4-DB eq]	1.09E+01	kg 1,4-DB eq/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Freshwater eutrophication [kg P eq]	4.15E-01	kg P eq/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Human toxicity [kg 1,4-DB eq]	5.92E+02	kg 1,4-DB eq/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Ionising radiation [kg U235 eq]	6.26E+03	kg U235 eq/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Marine ecotoxicity [kg 1,4-DB eq]	8.50E+00	kg 1,4-DB eq/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Marine eutrophication [kg N-Equiv.]	1.01E+01	kg N eq/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Metal depletion [kg Fe eq]	7.13E+02	kg Fe eq/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Natural land transformation [m2]	1.61E-01	m2/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Ozone depletion [kg CFC-11 eq]	2.20E-02	kg CFC-11 eq/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Particulate matter formation [kg PM10 eq]	1.49E+01	kg PM10 eq/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Photochemical oxidant formation [kg NMVOC]	5.31E+01	kg NMVOC/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Terrestrial acidification [kg SO2 eq]	3.44E+01	kg SO2 eq/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Terrestrial ecotoxicity [kg 1,4-DB eq]	8.20E+00	kg 1,4-DB eq/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Urban land occupation [m2a]	4.07E+02	m2a/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Water depletion [m3]	-- [a]	-- [a]	-- [a]	-- [a]

[a] Not available.

The impact scores at midpoint were normalised and the results included in Table 4.21 for the global product system (offset product), graphically shown in Figure 4.2 and per main life cycle stage: paper production, printing, and end-of-life (EOL), for all the considered impact categories, illustrated in Figure 4.3.

Both the land use impacts and emissions related impacts are dominated by the paper production stage. The chemicals related impacts are also dominated by the paper production stage but the printing share is increased. This might be related to the fact that the paper production stage has an aggregated process in the assessment, which includes transport and average energy mix, while the printing stage is directly obtained from industry data, lacking transport related emissions and relying on Danish energy mix data, together with a higher use (and emission) of chemicals that are applied in the various stages that compose the printing stage.

Table 4.21: Normalised impact scores at midpoint (unit: person equivalent, PE) per impact category and main life cycle stage.

Midpoint Indicator	Offset product [PE]	Paper production [PE]	Printing [PE]	EOL [PE]
Agricultural land occupation	1.06E+00	1.07E+00	3.52E-03	-1.51E-02
Climate change	3.54E-01	2.84E-01	5.80E-02	1.28E-02
Fossil fuel depletion	4.22E-01	3.43E-01	1.73E-01	-9.46E-02
Freshwater ecotoxicity	4.03E-01	3.48E-01	9.90E-02	-4.44E-02
Freshwater eutrophication	7.27E-02	7.18E-02	1.50E-02	-1.41E-02
Human toxicity	3.09E-01	2.16E-01	3.77E-02	5.50E-02
Ionising radiation	-3.80E+03	1.62E+04	8.85E+03	-2.88E+04
Marine ecotoxicity	5.43E-01	2.39E-01	3.25E-01	-2.17E-02

Midpoint Indicator	Offset product [PE]	Paper production [PE]	Printing [PE]	EOL [PE]
Marine eutrophication	2.42E-01	2.31E-01	4.62E-02	-3.44E-02
Metal depletion	5.90E-02	7.23E-02	1.41E-02	-2.73E-02
Natural land transformation	4.95E+00	5.31E+00	5.59E-01	-9.18E-01
Ozone depletion	3.66E-03	4.18E-03	1.75E-03	-2.26E-03
Particulate matter formation	2.05E-01	2.05E-01	3.97E-02	-3.94E-02
Photochemical oxidant formation	1.13E-01	1.07E-01	2.27E-02	-1.66E-02
Terrestrial acidification	1.84E-01	1.78E-01	4.90E-02	-4.25E-02
Terrestrial ecotoxicity	1.77E-02	1.35E-02	7.35E-03	-3.20E-03
Urban land occupation	2.00E-01	1.84E-01	2.19E-02	-6.43E-03
Water depletion	-- [a]	-- [a]	-- [a]	-- [a]

[a] Not available due to lack of a normalisation reference.

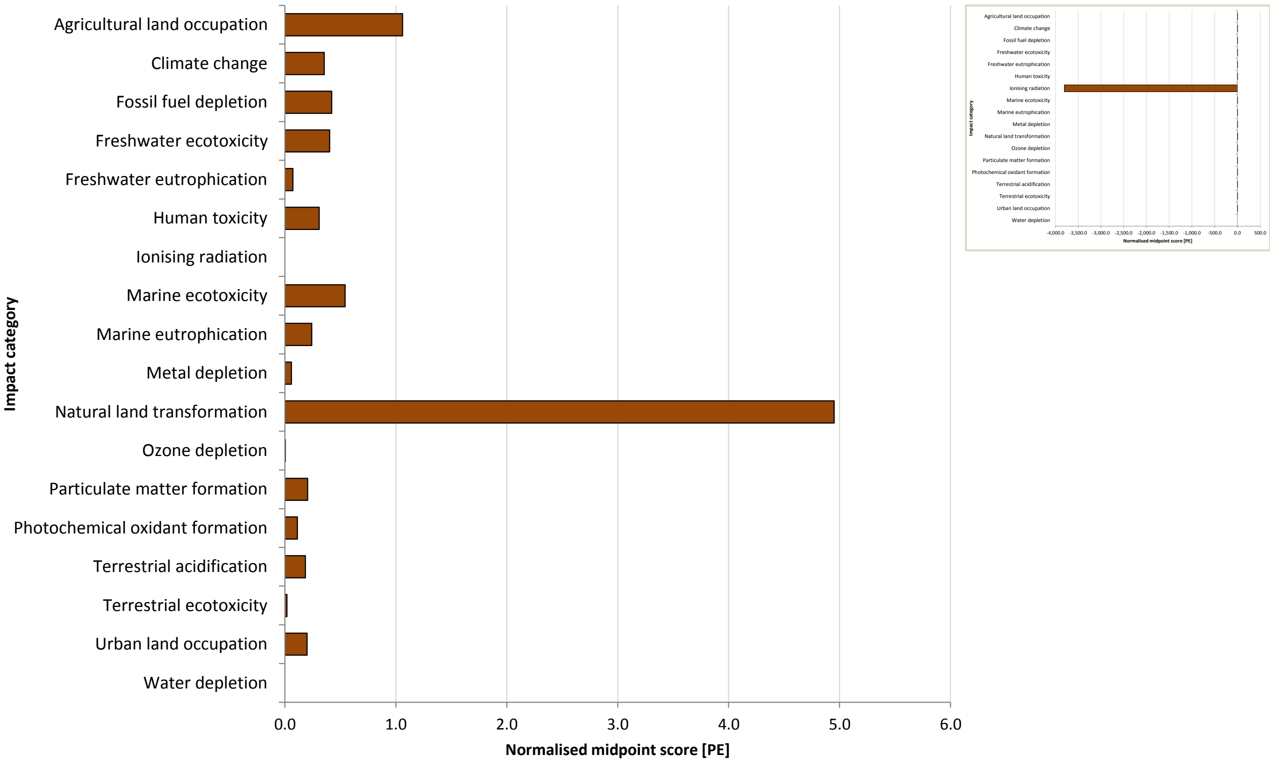

Figure 4.2: Normalised impact scores at midpoint (unit: person equivalent, PE) for the overall product system (offset product) per ReCiPe's impact category. The embedded smaller graphic depicts the overall results with the ionising radiation peak (not displayed in the larger graphic for interpretation purposes).

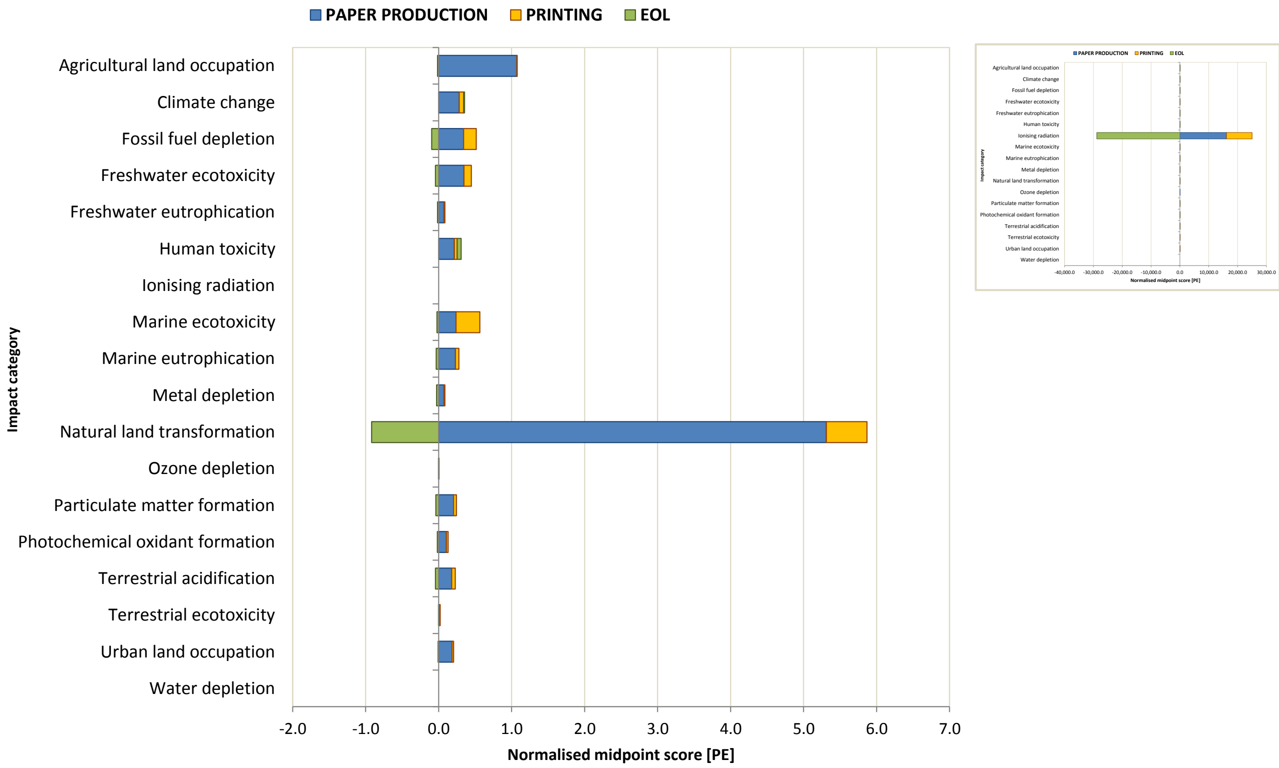

Figure 4.3: Normalised impact scores at midpoint (unit: person equivalent, PE) for ReCiPe's impact categories and the contribution from the main life cycle stages. The smaller graphic depicts the overall results with the ionising radiation peak (not included in the larger graphic for interpretation purposes).

4.3.3. Impact scores at endpoint

Impact scores were also calculated at the endpoint (Table 4.22) per impact category and main life cycles stages of the product system.

Table 4.22: Impact characterisation scores at endpoint for the whole product system (offset product), and main life cycle stages: paper production, printing, and end-of-life (EOL).

Endpoint Impact Indicator [unit]	Offset product	Paper production	Printing	EOL
Agricultural land occupation [species.yr]	5.39E-05	5.45E-05	2.36E-07	-8.17E-07
Climate change Ecosystems [species.yr]	3.15E-05	2.52E-05	5.16E-06	1.14E-06
Climate change Human Health [DALY]	5.57E-03	4.45E-03	9.11E-04	2.00E-04
Fossil depletion [$]	1.05E+04	8.57E+03	4.33E+03	-2.36E+03
Freshwater ecotoxicity [species.yr]	1.14E-09	9.85E-10	2.80E-10	-1.26E-10
Freshwater eutrophication [species.yr]	1.32E-09	1.31E-09	2.69E-10	-2.56E-10
Human toxicity [DALY]	1.28E-04	8.92E-05	1.56E-05	2.28E-05
Ionising radiation [DALY]	-3.90E-01	1.66E+00	9.09E-01	-2.96E+00
Marine ecotoxicity [species.yr]	3.69E-12	1.62E-12	2.21E-12	-1.47E-13
Metal depletion [$]	3.01E+00	3.68E+00	7.20E-01	-1.39E+00
Natural land transformation [species.yr]	7.04E-06	8.05E-06	7.17E-07	-1.73E-06
Ozone depletion [DALY]	2.07E-07	2.40E-07	9.32E-08	-1.26E-07
Particulate matter formation [DALY]	7.96E-04	7.95E-04	1.54E-04	-1.53E-04
Photochemical oxidant formation [DALY]	2.34E-07	2.21E-07	4.71E-08	-3.45E-08
Terrestrial acidification [species.yr]	3.68E-08	3.55E-08	9.76E-09	-8.47E-09
Terrestrial ecotoxicity [species.yr]	1.84E-08	1.41E-08	7.67E-09	-3.33E-09
Urban land occupation [species.yr]	1.57E-06	1.45E-06	1.72E-07	-5.05E-08

The individual contribution of each of the main life cycle stages to the endpoint indicator score is shown in Figure 4.4 (note that equal individual contributions are found for the normalised scores).

As previously noted, the paper production stage dominates several impact categories, including the land use related categories (very high contributions), and also energy and emissions related categories. Only some of the chemicals related categories (namely the ecotoxicity related indicators) reveal a more balanced contribution from the materials and production stages.

Although not evident, EOL scores are mainly related to avoided energy production by the incinerated fraction and some avoided use of chemicals by the recycled fraction of the disposal stage.

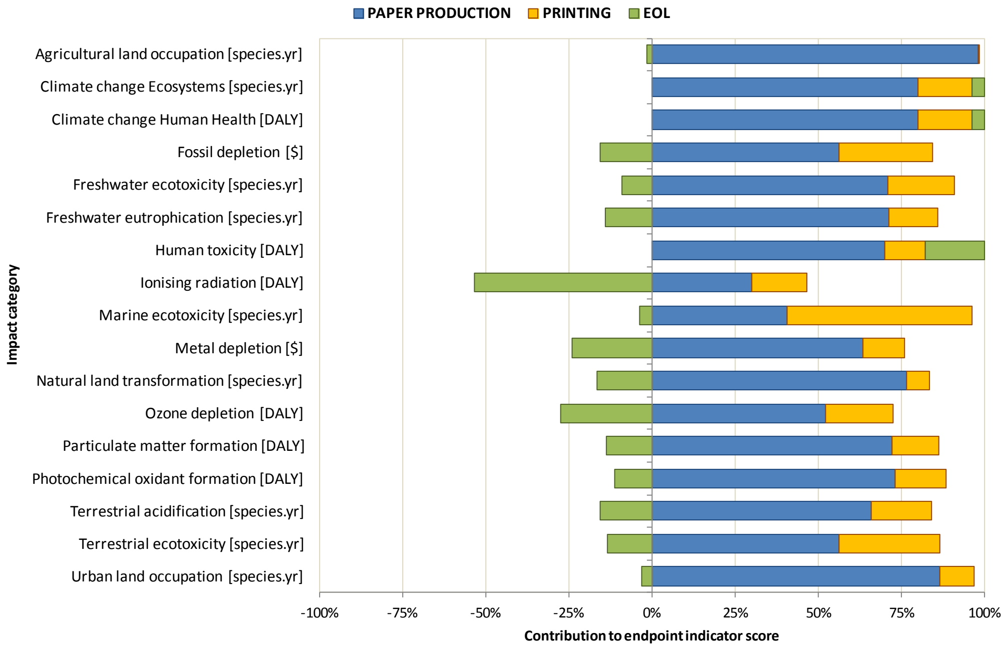

Figure 4.4: Main life cycle stages' percentual contributions to the endpoint indicator score for the ReCiPe's impact category.

4.3.4. Normalisation from endpoint to damage

The normalisation references used for the normalisation of the characterised impact scores aggregated into damage areas of protection (AoP) at endpoint were compiled from ReCiPe and are included in Table 4.23, together with details on the reference spatial resolution and year used.

Table 4.23: Normalisation references (NR) from endpoint (ep) to damage level for the ReCiPe impact categories (units: __/person/year, or /PE, person equivalent).

Damage category [unit]	NR (ep)	Unit	Resolution, year	Source
Ecosystems [m2a]	1.81E-04	Species.yr/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Human Health [kg CO2-Equiv.]	2.02E-02	DALY/p/yr	EUR(H), y2000	Goedkoop et al. 2013
Resources [kg oil eq]	3.08E+02	$/p/yr	EUR(H), y2000	Goedkoop et al. 2013

The endpoint scores were aggregated as proposed by the ReCiPe method (Goedkoop et al. 2012) and shown in Table 4.24. The endpoint scores aggregated into AoP were normalised using the references from Table 4.23 and the results included in Table 4.25. The contribution from each main life cycle stage for the damage category score is shown in Figure 4.5 and how much each life cycle stage is contributing to the damage categories in Figure 4.6. The damage scores are dominated by the paper production stage.

Table 4.24: Aggregation key for the endpoint indicators into damage areas of protection (AoP).

Endpoint Impact Indicator [unit]	Damage AoP
Agricultural land occupation [species.yr]	Ecosystems
Climate change Ecosystems [species.yr]	Ecosystems
Climate change Human Health [DALY]	Human Health
Fossil depletion [$]	Resources
Freshwater ecotoxicity [species.yr]	Ecosystems
Freshwater eutrophication [species.yr]	Ecosystems
Human toxicity [DALY]	Human Health
Ionising radiation [DALY]	Human Health
Marine ecotoxicity [species.yr]	Ecosystems
Metal depletion [$]	Resources
Natural land transformation [species.yr]	Ecosystems
Ozone depletion [DALY]	Human Health
Particulate matter formation [DALY]	Human Health
Photochemical oxidant formation [DALY]	Human Health
Terrestrial acidification [species.yr]	Ecosystems
Terrestrial ecotoxicity [species.yr]	Ecosystems
Urban land occupation [species.yr]	Ecosystems

Table 4.25: Damage scores for ReCiPe's areas of protection (AoP) for the whole product system (offset product), and main life cycle stages: paper production, printing, and end-of-life (EOL). No specific weighting applied (or weighting factor=1).

AoP	Offset product [PE]	Paper production [PE]	Printing [PE]	EOL [PE]
Ecosystems	5.20E-01	4.93E-01	3.48E-02	-8.13E-03
Human Health	-1.90E+01	8.25E+01	4.51E+01	-1.47E+02
Resources	3.42E+01	2.78E+01	1.41E+01	-7.68E+00

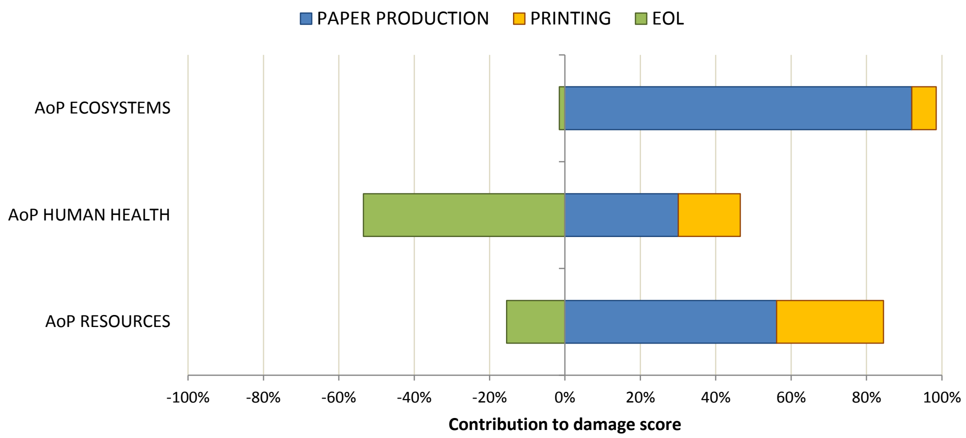

Figure 4.5: Main life cycle stages' percentual contributions to each damage category scores.

The damage to ecosystems might be related to the transport (that is missing in the printing stage) and the land use impacts. Some contribution from the printing stage to this damage category might be expected from the use of chemicals in the various auxiliary processes in the production stage, but the scores are dominated by the ionising radiation category. The damage to resources is mostly affected by the fossil fuels depletion category with effect on the avoided energy production (mostly thermal generation from coal) by the incinerated paper fraction in EOL and the transport in the paper production stage (because an aggregated process is used here contrary to the printing stage).

EOL contributions are related to avoided production of virgin fibres through the recycled fraction, hence less land use impacts, fuel and energy consumption, and the avoided production of energy through the incinerated fraction in the damage to human health category. Nevertheless the ionising radiation indicator scores about 5-7 orders of magnitude higher than the remaining.

The high share of the ionising radiation indicator originated in the electricity production stage may also result from a normalisation imbalance from using normalisation factors from countries with higher share of nuclear power generation than the ones referring to the inventory flow used. Most of the energy consuming processes are assigned to the printing stage, which takes place in Denmark – the electricity mix includes imported electricity from nuclear generation (10% of the total consumption) while producing none internally (World Nuclear Association 2013). EOL also shows a high share of damage to AoP Human Health as it includes avoided energy production by incineration of printed matter.

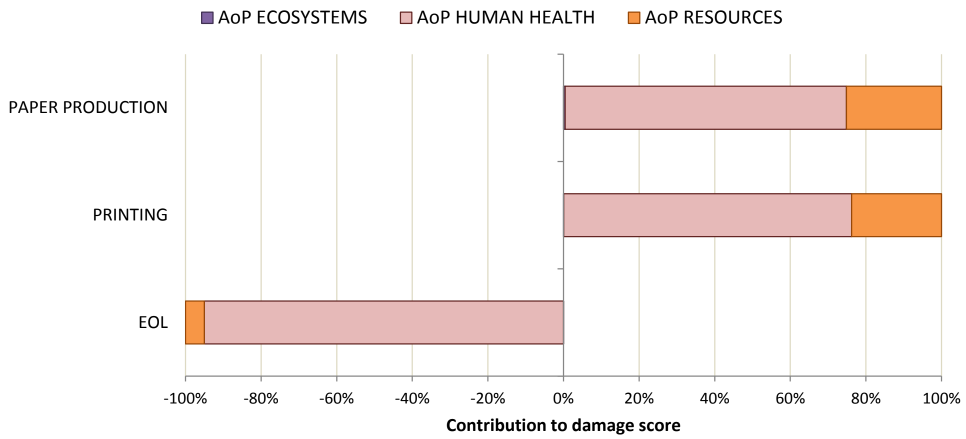

Figure 4.6: The percentual contribution from each of the main life cycle stages to the damage categories scores.

4.4. Results of the new impact assessment methods from LC-IMPACT

4.4.1. Impact scores at midpoint

The characterised scores of the product system for sheet fed offset printed matter at midpoint following the new assessment methods proposed by LC-IMPACT are presented per impact category and divided into the main life cycle stages: Paper production, printing, and end-of-life (EOL) (Table 4.26).

Table 4.26: Impact characterisation scores at midpoint for the whole product system (offset product), and main life cycle stages: paper production, printing, and end-of-life (EOL), for the newly developed impact assessment methods in LC-IMPACT.

Midpoint Impact Indicator [unit]	Offset product	Paper production	Printing	EOL
Forestry [tC.yr]	228.36	250.19	-- [a]	-2.18E+01
Photochemical ozone formation [kg Ozone]	5.73E-02	-- [b]	5.04E-08	5.73E-02
Noise [pers-Pa.sec]	21,466,767.71	-- [b]	45,673,973.84	-24,207,206.14

[a] The results shown are referring to the assessment of the paper production stage only.
[b] The results shown are referring to the assessment of the printing stage only.

In the noise category, for the estimation of the impact score of the recycling stage, an impact due to avoided paper production was assumed corresponding to the same unit flow as for the printing stage but scaled and inverted, i.e. the same impact but *-0.53 (inverted as the impact is avoided, and scaled to 53% of paper recycled).

The individual contribution of each of the main life cycle stages to the new midpoint indicators score is shown in Figure 4.7.

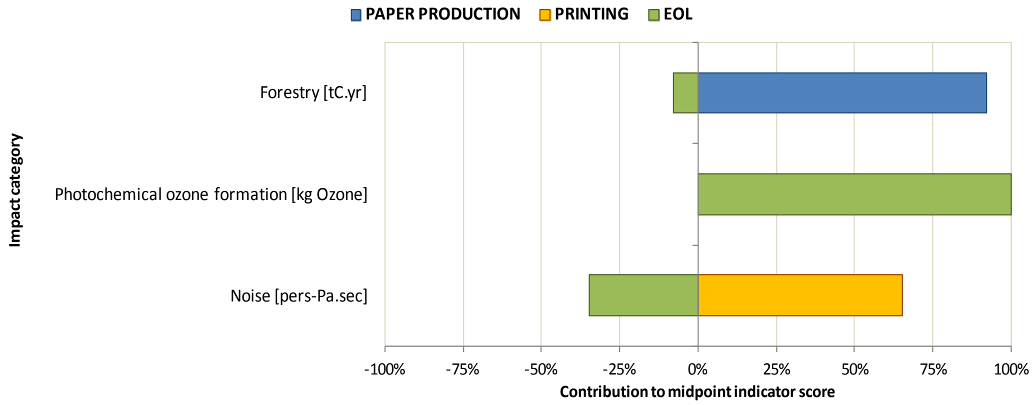

Figure 4.7: Main life cycle stages' percentual contributions to the midpoint indicator score for the LC-IMPACT's new impact categories.

The scores analysis is limited, as forestry is only assessed for the paper production stage and photochemical ozone formation is only assessed for the printing stage. In the estimation of the photochemical ozone formation indicator, EOL refers to incineration, i.e. avoided energy production, and it exceeds the characterised impact score of the original production. It means that the EOL incineration has a lower impact than energy production for this midpoint category. EOL in the noise indicator is simply a fixed fraction of the original impact (53% avoided).

4.4.2. Normalisation at midpoint

The normalisation references used for the normalisation of the characterised impact scores from the LC-IMPACT assessment methods were compiled from the method developers and are included in Table 4.27, together with details on the reference spatial resolution and year.

The characterised scores at midpoint were normalised and the results included in Table 4.28 for the global product system (offset product), graphically shown in Figure 4.8, and per main life cycle stage: paper production, printing, and end-of-life (EOL), for all the considered impact categories, illustrated in Figure 4.9.

Table 4.27: Normalisation references (NR) at midpoint (mp) for the new LC-IMPACT impact categories.

Midpoint Impact Indicator [unit]	NR (mp)	Unit	Resolution, year	Source
Forestry [tC.yr]	4.93E+02	tC/pers	SWE(H), y2011	Van Zelm 2013
Photochemical ozone formation [kg Ozone]	2.54E+00	kg/p/yr	EUR, y2010	Preiss 2013
Noise [pers-Pa.sec]	3.03E+08	person-Pa.sec/yr	EUR, y2009	Cucurachi & Heijungs 2013

Table 4.28: Normalised impact scores at midpoint (unit: person equivalent, PE) per LC-IMPACT´s new impact category and main life cycle stage.

Midpoint Indicator	Offset product [PE]	Paper production [PE]	Printing [PE]	EOL [PE]
Forestry [tC.yr]	4.63E-01	5.07E-01	-- [a]	-4.42E-02
Photochemical ozone formation [kg Ozone]	2.26E-02	-- [b]	1.99E-08	2.26E-02
Noise [pers-Pa.sec]	7.08E-02	-- [b]	1.51E-01	-7.98E-02

[a] The results shown are referring to the assessment of the paper production stage only.
[b] The results shown are referring to the assessment of the printing stage only.

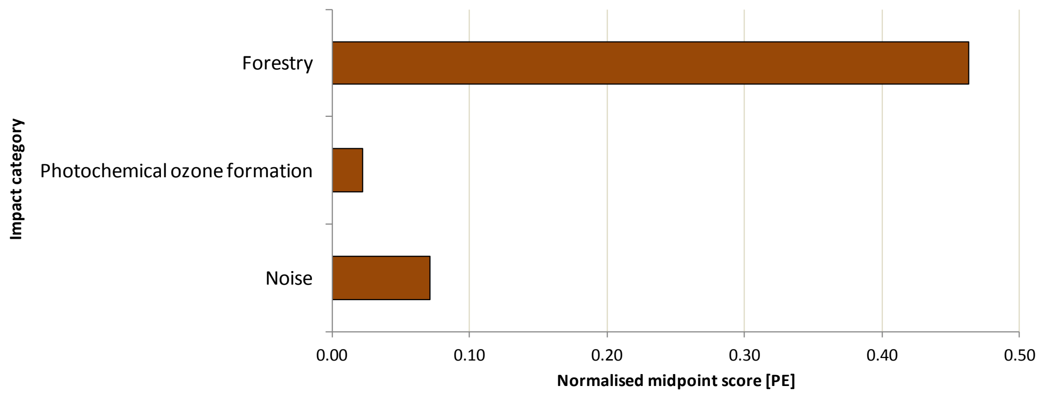

Figure 4.8: Normalised impact scores at midpoint (unit: person equivalent, PE) for the overall product system (offset product) per LC-IMPACT’s new impact category.

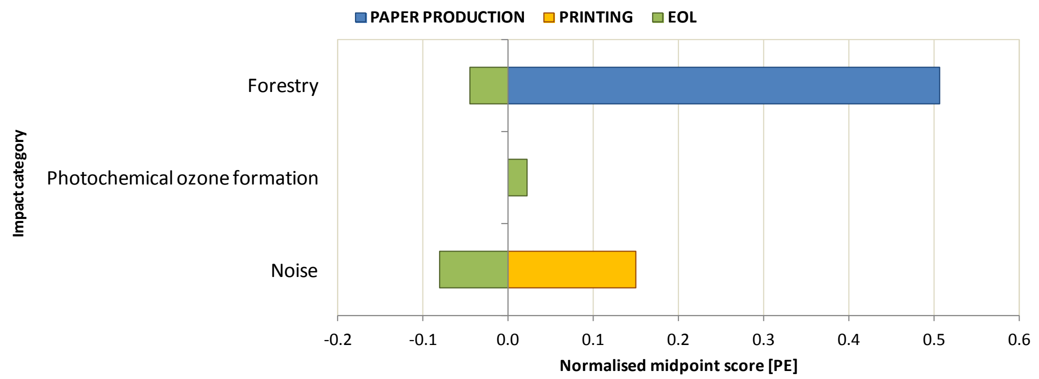

Figure 4.9: Normalised impact scores at midpoint (unit: person equivalent, PE) for the LC-IMPACT’s new impact category and the contribution from the main life cycle stages.

The normalised scores analysis is limited, as forestry is again only assessed for the paper production stage and photochemical ozone formation is only assessed for the printing stage. Normalisation at midpoint is not changing the interpretation of the scores before normalisation.

4.4.3. Impact scores at endpoint

Impact scores were also calculated at the endpoint (Table 4.29) per LC-IMPACT’s new impact category and main life cycles stages of the product system, also shown in Figure 4.10.

Table 4.29: Impact characterisation scores at endpoint for the whole product system (offset product), and main life cycle stages: paper production, printing, and end-of-life (EOL) after assessment with the newly developed assessment method in LC-IMPACT.

Endpoint Impact Indicator [unit]	Offset product	Paper production	Printing	EOL
LU Occupation BDP [PDFregional.yr]	1.38E-08	1.40E-08	-- [a]	-1.72E-10
LU Transformation BDP [PDFregional.yr]	8.88E-08	1.03E-07	-- [a]	-3.42E-10
LU Permanent Impacts BDP [PDFregional.yr]	9.46E-04	1.10E-03	-- [a]	-3.65E-06
Forestry Human Health [DALY]	4.86E-03	5.32E-03	-- [a]	-4.64E-04
Forestry Ecosystems Health [PDF.m2.yr]	4.76E-11	5.22E-11	-- [a]	-4.55E-12
Soil erosion Resources [MJse.m2.yr]	2.21E+06	2.24E+06	-- [a]	-2.77E+04
Soil erosion Ecosystems [NPPD.m2.yr]	5.30E+01	5.38E+01	-- [a]	-6.64E-01
Surface water use Wetlands Biodiversity [species-eq.yr]	2.05E-06	2.49E-06	-- [a]	-4.39E-07
Groundwater use Wetlands Biodiversity [species-eq.yr]	-9.56E-08	1.67E-08	-- [a]	-1.12E-07
Water use River Biodiversity [PDF.m3.yr]	6.47E-02	7.86E-02	-- [a]	-1.39E-02
Whole effluent toxicity [PDF.m3.yr]	-1.32E-02	1.84E-01	1.32E-01	-3.29E-01
Photochemical ozone formation Human Health [DALY]	3.23E-08	-- [b]	1.51E-08	1.72E-08
Photochemical ozone formation Ecosystems [PAF.m2.yr]	2.20E+00	-- [b]	1.04E+00	1.16E+00

[a] The results shown are referring to the assessment of the paper production stage only.
[b] The results shown are referring to the assessment of the printing stage only.

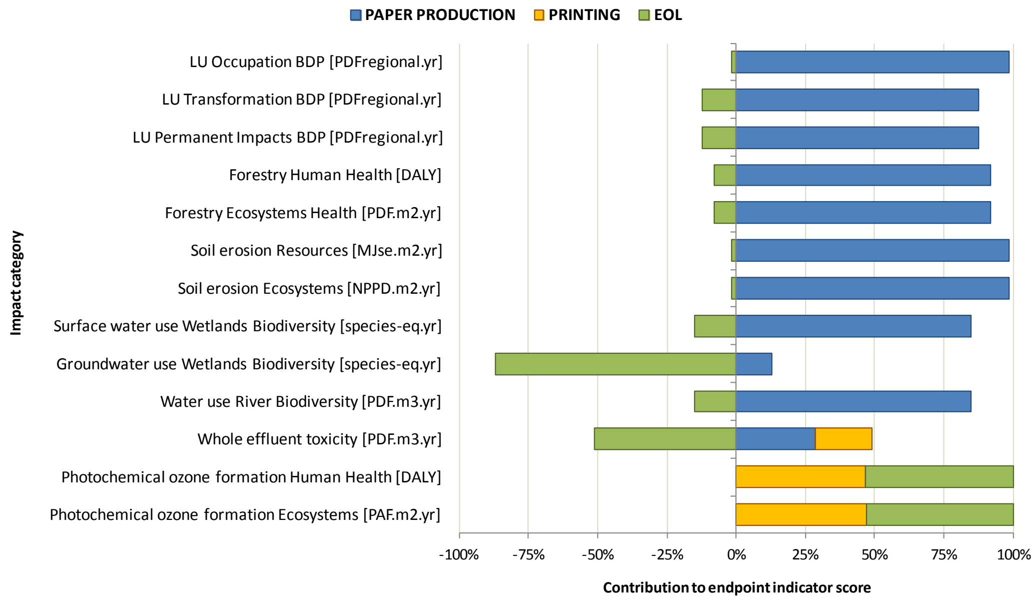

Figure 4.10: Main life cycle stages' percentual contributions to the endpoint indicator score for the LC-IMPACT's new impact category.

Easily noticed are the units at which the indicators are presented at endpoint. Because of the effect of the application of the newly developed characterisation factors, the inventory flows are converted into impact scores at endpoint delivered in several diverse units, of which some are not 'standard' units, i.e. the ones expected at this level.

4.4.1. Normalisation at endpoint

As mentioned before, the non-compatible units cannot be readily further aggregated from endpoint to damage score estimation, which is an option for the analysis of results of endpoint modelling. These units include PDF.yr, PDF.m^2.yr, PDF.m^3.yr, PAF.m^2.yr, MJse.m^2.yr, and NPPD.m^2.yr) and they cannot be (readily) aggregated and normalised (with damage NFs) as suitable conversions are required.

Nevertheless, these scores can be normalised (applying the emissions based NFs) for comparison among the LC-IMPACT categories only. Only those indicators already expressed in DALY and species.yr can be readily further grouped into damage areas of protection. Adequate aggregation with ReCiPe's endpoint scores can deliver an integrated analysis of the product system with both assessment methods.

The normalisation references used here were compiled from the various method developers and are included in Table 4.30, together with details on the reference spatial resolution and year.

Table 4.30: Normalisation references (NR) at endpoint (ep) for the newly developed impact categories from LC-IMPACT.

Endpoint Impact Indicator [unit]	NR (ep)	Unit	Resolution, year	Source
LU Occupation BDP [PDFregional.yr]	-- [a]	-- [a]	-- [a]	-- [a]
LU Transformation BDP [PDFregional.yr]	-- [a]	-- [a]	-- [a]	-- [a]
LU Permanent Impacts BDP [PDFregional.yr]	-- [a]	-- [a]	-- [a]	-- [a]
Forestry Human Health [DALY]	1.05E-02	DALY/p/yr	SWE(H), y2011	Van Zelm 2013
Forestry Ecosystems Health [PDF.m2.yr]	1.03E-10	species.m2/p	SWE(H), y2011	Van Zelm 2013
Soil erosion Resources [MJse.m2.yr]	1.59E+08	MJse.m2/p	World, *y2000* [b]	Núñez et al. 2013
Soil erosion Ecosystems [NPPD.m2.yr]	5.89E+02	NPPD.m2/p	World, *y2000* [b]	Núñez et al. 2013
Surface water use Wetlands Biodiversity [species-eq.yr]	1.78E-05	species-eq/p	EUR, y2000	Verones 2013
Groundwater use Wetlands Biodiversity [species-eq.yr]	4.28E-06	species-eq/p	EUR, y2000	Verones 2013
Water use River Biodiversity [PDF.m3.yr]	5.44E-01	species.yr.m3/p	World, y1995	Hanafiah et al. 2011
Whole effluent toxicity [PDF.m3.yr]	-- [a]	-- [a]	-- [a]	-- [a]
Exposure to solvents	-- [c]	-- [c]	-- [c]	-- [c]
Indoor exposure to fine particles	-- [c]	-- [c]	-- [c]	-- [c]
Photochemical ozone formation Human Health [DALY]	7.61E-07	DALY/p/yr	EUR, y2010	Preiss 2013
Photochemical ozone formation Ecosystems [PAF.m2.yr]	1.40E+02	species.m2/p	EUR, y2010	Preiss 2013

[a] Normalisation reference not available.
[b] Unspecified year of soil losses (an annual average was used), but the population reference is from y2000.
[c] Characterisation factors not developed.

The normalisation references provided and shown above are calculated based on annual emissions (or consumptions) per capita. However, the reference situation varies significantly between the various categories, either considering the reference region (country, Europe, or World) and the reference year (1995, 2000, 2010, or 2011).

The impact scores at endpoint were normalised with the NRs above. However, this normalisation is not leading to any further aggregation and it is simply to obtain a common unit for internal comparison (i.e. within the new impact categories results), for illustration, and error-checking purposes.

The LC-IMPACT project framework is not including a real endpoint aggregation/normalisation (i.e. from midpoint to damage) for all indicators, and the units of some of the resulting endpoint characterisation are not compatible with ReCiPe's (and with each other) for an adequate grouping (summing up) into damage AoP.

Nevertheless, the results are shown in Table 4.31 for the global product system (offset product), depicted in the graphic in Figure 4.11, and per main life cycle stage: paper production, printing, and end-of-life (EOL), for all the new impact categories from LC-IMPACT, and illustrated in Figure 4.12.

Table 4.31: Normalised endpoint scores (unit: person equivalent, PE) for the newly developed impact categories in LC-IMPACT per life cycle stage.

Endpoint Indicator	Offset product [PE]	Paper production [PE]	Printing [PE]	EOL [PE]
LU Occupation BDP	-- [a]	-- [a]	-- [a]	-- [a]
LU Transformation BDP	-- [a]	-- [a]	-- [a]	-- [a]
LU Permanent Impacts BDP	-- [a]	-- [a]	-- [a]	-- [a]
Forestry Human Health	4.63E-01	5.07E-01	-- [b]	-4.42E-02
Forestry Ecosystems Health	4.63E-01	5.07E-01	-- [b]	-4.42E-02
Soil erosion Resources	1.39E-02	1.41E-02	-- [b]	-2.07E-04
Soil erosion Ecosystems	9.00E-02	9.13E-02	-- [b]	-1.34E-03

Surface water use Wetlands Biodiversity	1.15E-01	1.39E-01	-- [a]	-2.46E-02
Groundwater use Wetlands Biodiversity	-2.23E-02	3.89E-03	-- [a]	-2.62E-02
Water use River Biodiversity	1.19E-01	1.45E-01	-- [b]	-2.55E-02
Whole effluent toxicity	-- [a]	-- [a]	-- [a]	-- [a]
Exposure to solvents	-- [c]	-- [c]	-- [c]	-- [c]
Indoor exposure to fine particles	-- [c]	-- [c]	-- [c]	-- [c]
Photochemical ozone formation Human Health	4.25E-02	-- [d]	1.99E-02	2.26E-02
Photochemical ozone formation Ecosystems	1.57E-02	-- [d]	7.41E-03	8.31E-03

[a] Not available as no normalisation references are available.
[b] The results shown are referring to the assessment of the paper production stage only.
[c] Not available due to assessment method incompleteness.
[d] The results shown are referring to the assessment of the printing stage only.

The indicators exposure to solvents and fine particles are not assessed due to lack of characterisation factors, while the land use and WET to freshwater indicators have no normalisation reference data.

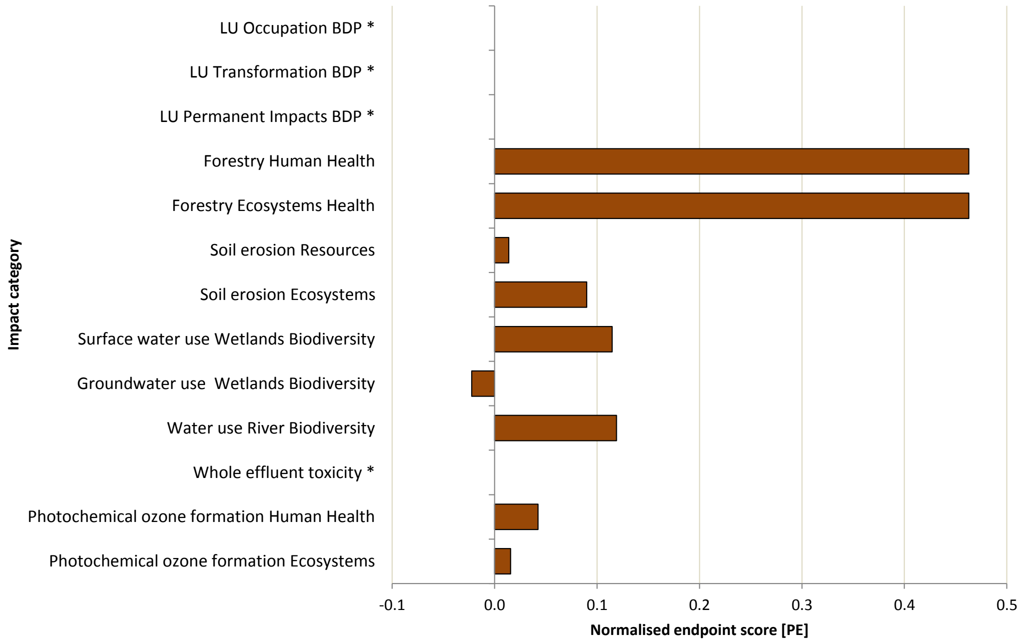

Figure 4.11: Normalised impact scores at endpoint for the newly developed LC-IMPACT categories (unit: person equivalent, PE) for the overall product system (offset product) (* *not available*).

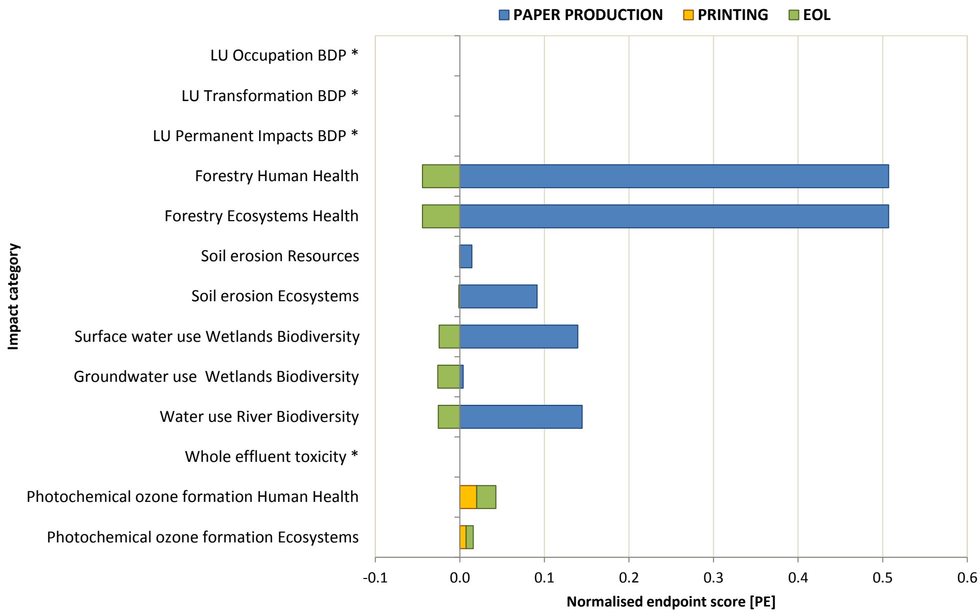

Figure 4.12: Normalised impact scores at endpoint for the newly developed LC-IMPACT categories (unit: person equivalent, PE) including the contribution of the main life cycle stages (**not available*).

Despite the availability of normalisation references (emissions-based per capita in the present case) the normalisation done above is not conducing to impact estimation at damage to AoP as defined in the ReCiPe method (Goedkoop et al. 2012). Some of the new impact indicators are not presented at a suitable unit compatible with aggregation into damage to AoP.

An attempt to assess the impact at damage level was done here. For the necessary grouping the following indicators were excluded:

- LU Occupation BDP [PDFregional.yr]
- LU Transformation BDP [PDFregional.yr]
- LU Permanent Impacts BDP [PDFregional.yr]
- Forestry Ecosystems Health [PDF.m^2.yr]
- Soil erosion Resources [MJse.m^2.yr]
- Soil erosion Ecosystems [NPPD.m^2.yr]
- Water use River Biodiversity [PDF.m^3.yr]
- Whole effluent toxicity [PDF.m^3.yr]
- Exposure to solvents (due to incomplete characterisation)
- Indoor exposure to fine particles (due to incomplete characterisation)
- Photochemical ozone formation Ecosystems [PAF.m^2.yr]

The remaining indicators were grouped into AoP for further normalisation as follows:

Table 4.32: Aggregation key for the LC-IMPACT new endpoint indicators into damage areas of protection (AoP).

Endpoint Impact Indicator [unit]	Damage AoP
Forestry Human Health [DALY]	Human Health
Surface water use Wetlands Biodiversity [species-eq.yr]	Ecosystems
Groundwater use Wetlands Biodiversity [species-eq.yr]	Ecosystems
Photochemical ozone formation Human Health [DALY]	Human Health

These endpoint indicators were normalised with the NRs included in Table 4.23 for each of the corresponding AoP.

4.5. Combined damage assessment at AoP

The damage to AoP scores for the combined assessment methods (endpoint ReCiPe indicators plus some of the new endpoint LC-IMPACT indicators) are included in Table 4.33 and shown in Figure 4.13 and Figure 4.14.

The results show similar contributions as previously for the ReCiPe damage assessment (shown in Figure 4.5 and Figure 4.6) simply revealing an expected small increase in damage to AoP Ecosystems and Human Health, based on the relevance criteria used for the assessment of the main life cycle stages, but with no significant changes to the percentual contribution results. No changes in damage score to AoP Resources as no LC-IMPACT new indicator is present.

Table 4.33: Damage scores for the combined damage assessment into ReCiPe's areas of protection (AoP) for the whole product system (offset product), and main life cycle stages: paper production, printing, and end-of-life (EOL). No specific weighting applied (or weighting factor=1).

AoP	Offset product [PE]	Paper production [PE]	Printing [PE]	EOL [PE]
Ecosystems	5.20E-01	4.93E-01	3.48E-02	-8.13E-03
Human Health	-1.90E+01	8.25E+01	4.51E+01	-1.47E+02
Resources	3.42E+01	2.78E+01	1.41E-01	-7.68E+00

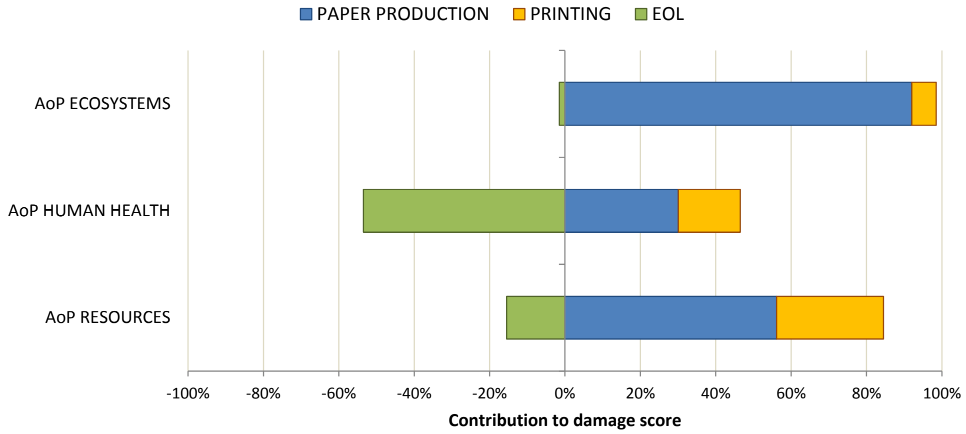

Figure 4.13: Main life cycle stages' percentual contributions to each damage category scores after the combined damage assessment with ReCiPe and LC-IMPACT new endpoint indicators.

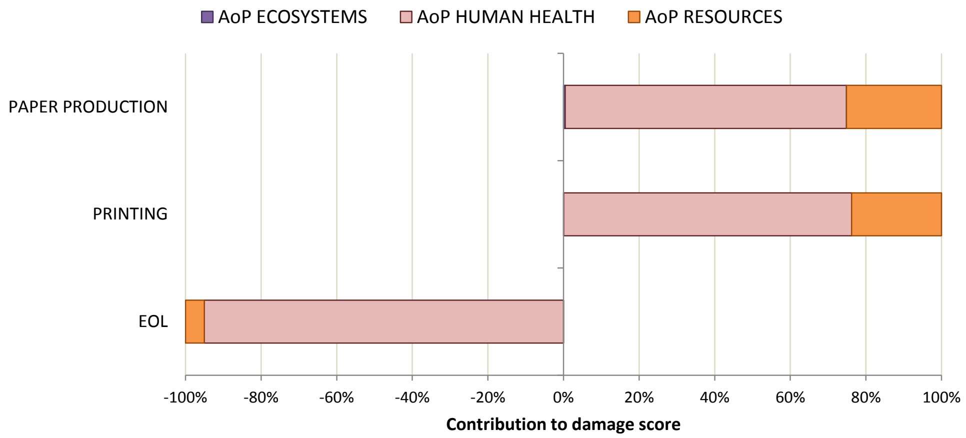

Figure 4.14: The percentual contribution from each of the main life cycle stages to the damage categories scores after the combined damage assessment with ReCiPe and LC-IMPACT new endpoint indicators.

5. Interpretation

As defined in the Goal and Scope, this case study on paper production and printing is not intended to present a detailed analysis of the paper production and printing product system beyond the main life cycle stages considered within. It is focused on the assessment and analysis of the impacts following the ReCiPe method and introducing the new impact assessment methodologies developed in LC-IMPACT by means of using the inventory flows from that product system and testing the applicability and consistency of the new indicators.

Based on the conventional assessment with ReCiPe, the main results at the midpoint show a dominant contribution from the paper production stage (see Figure 4.1, page 45) confirmed at endpoint (see Figure 4.4, page 49) and at damage scores for the considered AoPs (see Figure 4.5, page 50). The analysis of the impacts at damage level shows that the paper production stage contributes significantly to the three AoPs and comparatively dominates the specific contribution to the AoP Ecosystems. The printing stage has a higher share to both Human Health and Resources related impact categories, while EOL is predominant in avoiding Human Health related impacts (as impacts from avoided paper production dominate the impacts arising from disposal by incineration at a 90/10 ratio, dominated by the ionising radiation indicator in the avoided energy production).

5.1. Introducing the new impact indicators

The introduction of new midpoint indicators does not provide a clear basis for comparative analysis as forestry was only assessed for the paper production stage, photochemical ozone formation was only assessed for the printing stage, and human exposure to noise was only assessed for the printing stage and in addition, not completely assessed for the EOL stage. At the endpoint level, the new indicators reveal the same inconsistency in the covered life cycle stages.

The results for new endpoint indicators that show an incomplete method output (mismatching units) are actually expressing an impact score at a late point in the cause-effect. Although technically defined as an endpoint (e.g. PDF) these are not entirely usable, as the units are not comparable without a suitable conversion. With the exception of impact to ecosystems from the water use indicators (expressed in species-eq·yr) and impacts to human health from forestry and photochemical ozone formation (expressed in DALY), all the other indicators lack a fully developed 'endpoint' method. An indicator expressed in PDF·m^3·yr, for instance, still needs a significant conversion (with associated assumptions) by integrating the impacted volume (or the assumption of an average depth to estimate an impacted area) and an adequate species density to finally reach an harmonised unit (species·yr in the used example, as the ReCiPe method was chosen for this study) allowing further comparative analysis and facilitating interpretation – and ultimately concluding on the usability of the newly developed indicator method for the specific category). The incompleteness of the methods is relative to the desired harmonised unit – either PDF.m^2.yr or species.yr for instance, thus solely related to the fact that different units are being obtained with the present versions of the methodologies.

Furthermore, the absence of a relevant midpoint normalisation phase hinders an important feature of the LCA tool – the comparative analysis across stages and impact categories. The developed normalisation references are directly applicable to the individual midpoint indicators delivering a normalisation into average impact per capita, which was the normalisation option chosen for the present study and expressing the results in PE (person-equivalent or person·year). However, the comparison of midpoint normalised scores is strongly limited by the reduced number of category indicators and overestimates either the paper production or the printing stage, depending on the indicator, caused by the inconsistency on the included stages per indicator (either only assessed for the paper production or only for the printing). The definition of the stage relevance and focus of the inventory and assessment was defined in the early stages of the LC-IMPACT project. The purpose of a similar normalisation at endpoint is however limited to internal comparison and error-checking.

One the one hand there is no consistency in the life cycle stages covered by the assessment (which is applicable for both the midpoint and endpoint characterisation), and on the other hand the indicators' scores obtained are not suitable for further aggregation into damage AoPs (due to the generally mismatching units, and which is highly relevant for the interpretation phase). Therefore, these two aspects ultimately hinder the overall usability of the newly developed indicators in a LCIA perspective, the interpretation of the results, and the interest as decision support information.

Scientifically, the methods developed in the LC-IMPACT framework described in the available deliverables reports and published elsewhere in scientific journals, seem appropriate and robust, covering the necessary and adequate cause-effect chain elements and are sufficiently environmentally relevant to be included in the set of indicators/categories in LCIA. While appearing scientifically and technically sound, generally the methods are not fully developed (with the exceptions noted earlier) and do not deliver the best unit to the indicator showing that a final phase of harmonisation in terms of modelled endpoint is still needed before a further round of applicability testing and validation is conducted.

Ultimately, the questions reside in whether (1) it is worth investing in data acquisition to feed the new categories considering their (possible) contribution to the global impact assessment of the product system or there is no added value, and (2) how the overall results with these new indicators improve the relevance (environmental, geographical, or other) of the conclusions of the study to make it useful as a decision supporting tool (LCA).

Due to the limited number of new fully developed (harmonised) endpoint indicators added to the combined assessment there are no significant changes to the impact assessment of the paper production and printing product system. The development of the new assessment methods, although relevant for the individual indicator, shows little expression and contribution to the final results. The number of midpoint indicators is scarce due to the decision of which life cycle stages to include, thus revealing little application, while for the endpoint a significant number of indicators were not successfully delivered for damage to AoP assessment: from the possible 15 indicators developed, 2 did not conclude the characterisation phase, and 9 are not fully developed, lacking still some further unit conversion. Only 4 indicators contribute for the combined assessment method, and for these no noticeable changes are found.

5.2. Consistency in normalisation references

In the same line of effort, consistency in normalisation references should be pursued for midpoint normalisation, including spatial and temporal references and whether these are 'emissions' or 'emissions per capita'-based normalisation references.

This need arises from the fact that analysing the available/provided normalisation references one can verify the diversity of reference years (emissions or consumption, and population), spatial resolution (country, Europe, and World), standardised sources for reference data (e.g. avoiding different available sources for population data, or census vs. estimation based data), criteria in the inclusion of cultural perspectives for the CF or NF estimations (egalitarian, hierarchical, individualist, or none), and inconsistency in uncertainty reporting for the impact models and normalisation.

5.3. Transparency

An overview of the interface between the new methods development (mainly environmental models and impacts estimation) and the case studies' needs (especially for the inventory and interpretation phases) is influenced by the quantity and quality of the available supporting information. A practical analysis tends to show that the new methods are thoroughly described (in the deliverable reports and associated publications) while application guidance is not provided with the necessary detail. For obvious reasons, the focus falls in the method development, its data quality and uncertainty, features and environmental relevance of the models, which are highly important aspects in the development perspective. However, the full methods description is not necessarily useful for the case studies application, i.e. the information given to any LCA practitioner should not be focused on the particularities of the method development and the quality of the achieved results. Instead, the most relevant information to the application, e.g. the specificities of the necessary unit flows, clear definition of the applicable conditions for an efficient data acquisition for the inventory phase, method parameters, spatial scales, suitable CFs, units, and necessary supplementary calculations, should be provided.

In order to achieve an adequate detachment from method development to application, clear and concise information should be made available for practitioners and stakeholders in general. This was attempted in the LC-IMPACT project, and not entirely achieved, by the compilation of guidance documents or cookbooks – either by not covering the whole set of new methods or by lacking practical and clear information in the shared documentation.

Improvements can be implemented by solving inconsistencies between the deliverable documents, the guidance documents, and the available/provided auxiliary spreadsheets, especially in what regards to units. Additionally, the lack of follow-through calculations (when applicable) should also be avoided, and explanation of applicable values and necessary supplementary calculations for characterisation, normalisation, or estimation of intermediate parameters, included.

A note is added here to recall that an LCA practitioner is not necessarily an expert on all the impact categories, or keen on scientific research to cope with less transparent methods or factors, or in possession of available resources and time to improve the inventory and characterisation phases, especially when considering the diversity of case studies in the industry field.

5.4. Additional considerations

The estimation of whole effluent toxicity (aquatic ecotoxicity) if based on the toxicity correlations to TOC emissions to freshwater. The lack of readily available TOC measurement was supplanted by the use of COD values from industry and converted to TOC. This COD-TOC conversion should be further investigated and validated for the specific case of pulp and paper mill discharges prior to method implementation. The method was developed for pulp and paper mills and correlates toxicity and organic carbon emitted and should be used in the specified scope of application. In the present case study the toxicity estimation was applied for the paper production stage for which it seems applicable. However, it was extended to the printing stage by application of the developed CF to TOC emissions (actually COD) from a model (average) printing house with a specific printing method. This extension is, in fact, an assumption with a non-assessed associated uncertainty, but found necessary to obtain a working unit flow for the impact estimation of the printing stage, which was defined relevant in the project framework. Although inadequate, the misapplication of the assessment method was acknowledged.

The WET indicator is, in its essence, a freshwater ecotoxicity indicator and may be seen as complementary to the freshwater toxicity impact indicator in ReCiPe. For endpoint-damage normalisation purposes, the normalisation factor developed in ReCiPe (Goedkoop et al. 2013) should be applicable to get from the endpoint to the damage AoP. However, the method does not provide a fully usable endpoint, i.e. the unit of the estimated endpoint is not compatible with the normalisation factor, still lacking a conversion from the actual PDF·m^3·yr to species·yr (unless a different damage metric is chosen).

Worth of note is also the photochemical ozone formation indicator (from LC-IMPACT) that delivers a similar characterised score at endpoint (same order of magnitude) as the photochemical oxidant formation indicator (from ReCiPe). This fact shows that even though the methods show different midpoints (kg ozone vs. kg NMVOC) the new characterisation factors for NOx and NMVOC applied together deliver similar endpoint scores.

6. Conclusions and general comments

This study and the interpretation of its results were originally not focused on performing a conventional LCA with full analysis of sensitivity, uncertainty, or robustness. Instead, it aims at comparing a traditional (ReCiPe) and an extended (LC-IMPACT) assessment to test the applicability of the new impact assessment methods (feasibility, completeness, relevance) and their contribution to the final results of the assessment of the product system under consideration.

At the end, the main conclusions should provide useful information to assess a) whether the methods are sufficiently developed and applicable, and b) if it is worth considering their contribution to the global impact assessment of the product system, i.e. if the results with these new indicators enhance the overall assessment of the product system either by improving the relevance (environmental, geographical, or other) of the selected categories or the improvement of information provided with such tool (LCA) to the decision making process.

An overall analysis of the new methodologies introduced in the impact assessment phase, although scientific valid, is not clear about their applicability and relevance as it has not been clearly demonstrated. Due to a limited number of newly introduced midpoint indicators (assessed in this case study) and a significant number of new endpoint indicators not entirely concluded, it is not possible to conclude on the value added to the impact assessment brought by these new assessment methods. It is however acknowledged that with a small extra effort in converting and standardising units for the considered endpoint indicators this analysis can conclude with more confidence.

7. References

7.1. Life cycle inventory data

Agfa. 2002. UNIFIN. MSDS. Last revision: 29/05/2002 (in Danish).

Akzo Nobel. 1998. Vegeol CEG. AW300100. MSDS: Revision date: 12/11/1998. Akzo Nobel Inks A/S.

Akzo Nobel. 2003a. Aqualith S. AQ100100. MSDS: Revision date: 19/05/2003. Aqualith A. AQ100101. MSDS: Revision date: 20/05/2003. Akzo Nobel Inks A/S.

Akzo Nobel. 2003b. Aqualac 1. WLS00128. MSDS: Revision date: 27/10/2003. Aqualac 1. WLS00127. MSDS: Revision date: 10/10/2003. Matlak. WLS00126. MSDS: Revision date: 16/10/2003. Akzo Nobel Inks A/S.

Akzo Nobel. 2003c. Synvex. AA340100. MSDS: Revision date: 11/03/2003. Solvask. AW250100. MSDS: Revision date: 27/03/2003. Akzo Nobel Inks A/S.

Akzo Nobel. 2004. Personal communication with Frank Pedersen Akzo Nobel Inks A/S.

Andersen, L. K., Nikolajsen, M. H. (2003). Life Cycle Assessment of chemicals at the Brdr. Hartmann A/S. Thesis elaborated at the Danish engineering education at The Technical University of Denmark. Supervisor: Michael Hauschild. IPL-048-03.

Andersen P, Larsen HF, Trepile G, Trepile L, Bøg C. 1999. The use of water based inks in screen printing. *Environmental Project No. 508* (in Danish). Danish Ministry of the Environment and Energy. Danish Environmental Protection Agency.

Anonymous 1. 2000. Danish sheet fed offset printing company. Data based on inventory from 1999.

Anonymous 2. 2000. Danish sheet fed offset printing company. Data based on inventory from 1999.

Anonymous 3. 2002. Danish sheet fed offset printing company. Data based on inventory from 1999 and 2000.

Anonymous 4. 2003. Danish sheet fed offset printing company. Data based on inventory from 2002.

Anonymous 5. 2003. Danish offset printing company with sheet fed offset included. Data based on inventory from 2002.

Anonymous 6. 2003. Danish sheet fed offset printing company. Data based on inventory from 2002.

APR. 2003. The Association of Postconsumer Plastic Recyclers. http://plasticsrecycling.org/ guidelines-density.asp (16/08/2006).

Axelsson U, Dalhielm R, Marcus O. 1997. Miljöprofilering – livscykelanalyser av grafiske produkter, del 2. TEKNIKRAPPORT nr. 3/97. IMT.

Baumann W, Gräfen M. 1999a. Emission Scenario Document. Photographic Industry. IC10. Institute for Environmental Research. University of Dortmund. 11/19/99.

Baumann W, Gräfen M. 1999b. Emission Scenario Document. Printing Industry. IC15 (‘others’). Institute for Environmental Research. University of Dortmund. 11/19/99.

Baumann W, Rothard T. 1999: "Druckereichemikalien; Daten und Fakten zum Umweltschuts" 2. Uberarbeitete and ergänzte Auflage. Springer-Verlag. ISBN 3-540-66046-1.

Bøg C. 2003. Personal communication with Carsten Bøg, the Graphic Association Denmark.

Brodin L, Korostenski J. 1995. Miljøbelastningar från grafisk industri i Sverige. Grafiska Miljögruppen. Report version 2 (15-04-1995). Report to SFS.

Brodin L, Korostenski J. 1997. Miljøbelastningar från grafisk industri i Sverige: Screen-, Flexo-, Digitaltryck och Efterbearbetning. Preliminär rapport. Kompletterad och reviderad version. Grafiska Miljögruppen. Report version 3 (18-06-1997). Report to SFS.

Cederquist P. 2004. Personal communication with Preben Cederquist. Deltagraph A/S.

Deltagraph. 1997. Nautalgin C1 (Fuji-Hunt). MSDS: Revision date: 13/08/1997. Deltagraph A/S.

EC. 2001. Adapting to technical progress for the 28th time Council Directive 67/548/EEC on the approximation of laws, regulation and administrative provisions relating to the classification, packaging and labelling of dangerous substances (Commission Directive 2001/59/EC, August 6).

EEC. 1967. Approximation of laws, regulations and administrative provision relating to the classification, packaging and labelling of dangerous substances (Council Directive 1967/548/EEC, June 27).

Frees N, Hansen MS, Ottosen LM, Tønning K, Wenzel H. 2004. Opdatering af vidensgrundlaget for de miljømæssige forhold ved genanvendelse af papir og pap. Draft report (No. 13) to the Danish EPA. January 2004.

Gruvmark J. 2004. Personal communication with Jesper Gruvmark, Danish Ecolabelling.

Hansen TB, Gregersen P. 1986. Organiske opløsningsmidler. Environmental project No. 70 (in Danish). Danish Ministry of the Environment. Danish Environmental Protection Agency.

Herbst W, Hunger K. 1993. Industrial Organic Pigments. VCH. Weinheim.

Hoechst. 1994. Sheets with various thicknesses of Ozasol printing plates. Hoechst Danmark A/S. Personal communication.

IAI. 2003. The International Aluminium Institute. http://www.worldaluminium.org/production/processing/properties.html (16/08/2006).

Kjærgaard P. 1997. Anlæg til reduktion af kemikalie og spildevandsudledning fra fotoprocesser. Juni 1997 (in Danish). Danish Ministry of the Environment and Energy. Danish Environmental Protection Agency.

KODAK. 2000. KODAK 3000 Automix Fixer and Replenisher. MSDS: Approval date: 11/22/2000. Kodak.

KODAK. 2001a. KODAK Recording 2000 film RRD, RRD7... Technical Information Instruction Sheet, revised 6-01. TI2395.

KODAK. 2001b. KODAK RA 2000 Developer and Replenisher. MSDS: Approval date: 10/01/2001. Kodak.

KODAK. 2002a. Kodak Polychrome Graphics Positive Offset Plate. Article Information Sheet. Kodak Polychrome Graphics, Bunschoten. Drs. ACH van Peski. March 6, 2002.

KODAK. 2002b. Goldstar Developer. MSDS: Issue date: 02/04/2002. Kodak Polychrome Graphics.

KODAK. 2003. KODAK Concentrate and Ready-to-use Developer and Fixers. Technical Information Data Sheet. Revised 01-03. TI2536. Kodak.

Lapp O, Krafft W, Frenken H, Lührig H, Winiker R. 2000. Photography. Polyester. Ullmann's Enclyopedia of Industrial Chemistry. Article Online Posting Date: June, 15, 2000.

Larsen HF, Hauschild M, Hansen MS. 2006. Ecolabelling of printed matter – part II: Life cycle assessment of model sheet fed offset printed matter. Working Report no. 24. Danish Environmental Protection Agency.

Larsen HF, Helweg C, Pedersen AR, Andersen M, Wallström E, Hoffmann L. 2002. Evaluation of Best Available Technology (BAT) in washing off water-based flexographic inks in the packaging printing industry (book in Danish with English summary). *Environmental Project No. 730*. Danish Ministry of the Environment and Energy, Denmark. Danish Environmental Protection Agency.

Larsen HF, Tørsløv J, Damborg A. 1995. Areas of intervention for cleaner technology in the printing industry - assessment of waste water (book in Danish with English summary). Environmental Project No. 284. Danish Ministry of the Environment and Energy. Danish Environmental Protection Agency.

Larsen HF, Tørsløv J, Damborg A. 1996. Areas of intervention for cleaner technology in the Danish printing industry - focus on waste water problems. Wat. Sci. Tech. Vol. 33(6): 29-37.

Ludwiszewska J. 1992. Grafiske branchen och dess kemikalieanvänding: Exempel från nogra företag inom Hälsingborgs kommun – Miljö- och Hälsoskyddskontoret Hälsingborg Kommun. Rapport 1/92 + Bilagsdel.

Miljønet. 2004. MiljøNet. Graphic Association Denmark (in Danish). Retrieved from http://www.miljonet.org/ (16/08/2006).

Muskopf JW. 2000. Epoxy Resins. Phenol and Cresol Epoxy Novolacs. Ullmann's Enclyopedia of Industrial Chemistry. Article Online Posting Date: June, 15, 2000.

Schmidt A, Hansen LE, Hoffmann L, Larsen J, Elvestad K. 1993. Miljøvurdering af EVA. Environmental project No. 228 (in Danish). Danish Environmental Protection Agency.

Seedorff L, Kjølholt J, Andersen HV, Jensen MM. 1993. Miljøvurdering af fotokemikalier. Environmental project No. 218 (in Danish). Danish Environmental Protection Agency.

Silfverberg E, LarsenHF, Virtanen J, Webjørnsen S, Wriedt S. 1998. Best available techniques (BAT) for the printing industry. *TemaNord 1998:593*. Nordic Council of Ministers, Copenhagen 1998.

Tønning K. 2002. Statistik for returpapir og pap 2000. Environmental project No. 683 (in Danish). Danish Environmental Protection Agency.

7.2. Characterisation

7.2.1. References for land use impacts

De Baan L, Alkemade R, Koellner T. 2012a. Chapter 1. Land use impacts on biodiversity in LCA: a global approach. In L. De Baan, A Emanuelsson, MAJ Huijbregts, G Kindermann, T Koellner, D Maia de Souza, PAN Muchada, P Muñoz, M Núñez, M Obersteiner, RK Rosenbaum, E Schmid, M van der Velde, R van Zelm, F Ziegler. *Recommended assessment framework, method and characterisation factors for land resource use impacts: phase 2 (report and model + factors).* Deliverable D2.1, version 31/08/2012. www.lc-impact.eu.

De Baan L, Alkemade R, Koellner T. 2012b. Land use impacts on biodiversity in LCA: a global approach. Int J Life Cycle Assess. Online 24 April 2012. DOI 10.1007/s11367-012-0412-0.

De Baan L, Alkemade R, Koellner T. 2012c. “CF_Database_BDP.xlsx” – list of characterisation factors (Biodiversity Depletion Potential (BDP). Impact of land use on biodiversity expressed as species richness), version 19/06/2012. www.lc-impact.eu.

De Baan L, Mutel CL, Curran M, Hellweg S, Koellner T. 2013. Land use in LCA: Global characterization factors based on regional and global potential species extinctions. *Submitted to Environmental Science & Technology*.

De Baan L. 2012a. How to apply the land use impact assessment method on biodiversity? Guidance document: *Cook-book for LC-IMPACT case studies*, version 08/11/2012. www.lc-impact.eu.

De Baan L. 2012b. “deBaan_Local_CF_Occupation_Final(2).xlsx” – list of characterisation factors (local relative impacts for a range of species groups). www.lc-impact.eu.

De Baan L. 2012c. “deBaan_Regional_CF_Mammals_prelim.xlsx” – list of characterisation factors (regional absolute impacts for mammals), version 08/11/2012. www.lc-impact.eu.

FAO, IIASA, ISRIC, ISSCAS, JRC. 2009. Harmonized World Soil Database (version 1.1). Available at http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/index.html?sb=20, retrieved on 20/02/2013.

Muchada PAN, van Zelm R., van der Velde M, Kindermann G, Huijbregts MAJ. 2012. Chapter 3. Climate related impacts and benefits from wood extraction on a global scale. In L De Baan, A Emanuelsson, MAJ Huijbregts, G Kindermann, T Koellner, D Maia de Souza, PAN Muchada, P Muñoz, M Núñez, M Obersteiner, RK Rosenbaum, E Schmid, M van der Velde, R van Zelm, F Ziegler. *Recommended assessment framework, method and characterisation factors for land resource use impacts: phase 2 (report and model + factors).* Deliverable D1.2, version 31/08/2012. www.lc-impact.eu.

Núñez M, Antón A, Muñoz P, Rieradevall J. 2012a. Chapter 5. Inclusion of soil erosion impacts in life cycle assessment on a global scale: application to energy crops in Spain. In L De Baan, A Emanuelsson, MAJ Huijbregts, G Kindermann, T Koellner, D Maia de Souza, PAN Muchada, P Muñoz, M Núñez, M Obersteiner, RK Rosenbaum, E Schmid, M van der Velde, R van Zelm, F Ziegler. *Recommended assessment framework, method and characterisation factors for land resource use impacts: phase 2 (report and model + factors).* Deliverable D2.1, version 31/08/2012. www.lc-impact.eu.

Núñez M, Antón A, Muñoz P, Rieradevall J. 2012b. Inclusion of soil erosion impacts in life cycle assessment on a global scale: application to energy crops in Spain. *The International Journal of Life Cycle Assessment*. *In press*: DOI 10.1007/s11367-012-0525-5.

Núñez M. 2012a. “CFs_soil_erosion_Núñez_et_al_2012.xlsx” – list of characterisation factors (local relative impacts for a range of species groups). www.lc-impact.eu.

Núñez M. 2012b. Method to evaluate soil erosion. Guidance document: *Cook-book for LC-IMPACT case studies*, version 26/11/2012. www.lc-impact.eu.

Ulén B, Bechmann M, Øygarden L, Kyllmar K. 2012. Soil erosion in Nordic countries – future challenges and research needs, Acta Agriculturae Scandinavica, Section B - Soil & Plant Science 62(sup2): 176-184.

Van Zelm R. 2013. "Characterisation factors for Forestry_LC-Impact.xls" – list of characterisation factors (Midpoint CF, Endpoint CF for Human Health damage, and Endpoint CF for Ecosystem Health damage). www.lc-impact.eu.

7.2.2. References for water use impacts

Hellweg S, Pfister S, Verones F, Huijbregts M, Núñez M. 2012. Method and characterisation factors for water resource use impacts – Guidance document for the application of the newly developed methodology on water use. www.lc-impact.eu.

Huijbregts M. 2012. "Table Eco-River CFs.xlsx" – List of characterisation factors (river basins). www.lc-impact.eu.

Verones F, Pfister S, Hellweg S. 2012a. Chapter 1. Quantifying area changes due to consumptive water uses in wetlands of international importance. In A Anton, S Hellweg, R Juraske, L Milà i Canals, M Núñez, S Pfister, C Raptis, D Saner, F Stössel, F Verones. Recommended assessment framework, method and characterisation factors for water resource use impacts: phase 2. Deliverable 1.3., version 27/08/2012. www.lc-impact.eu.

Verones F, Pfister S, Saner D, Hellweg S. 2012b. Chapter 2. Quantifying the effects of consumptive water use on wetlands of international importance. In A Anton, S Hellweg, R Juraske, L Milà i Canals, M Núñez, S Pfister, C Raptis, D Saner, F Stössel, F Verones. Recommended assessment framework, method and characterisation factors for water resource use impacts: phase 2. Deliverable 1.3., version 27/08/2012. www.lc-impact.eu.

Verones F. 2012. "CFs_wetlands_for_review.xlsx" and "CFs_Sweden_Denmark.xlsx" – List of characterisation factors. www.lc-impact.eu.

7.2.3. References for whole effluent toxicity

Dubber D, Gray NF. 2010. Replacement of chemical oxygen demand (COD) with total organic carbon (TOC) for monitoring wastewater treatment performance to minimize disposal of toxic analytical waste. Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering 45(12): 1595-1600.

Raptis CE, Juraske R, Hellweg S. 2012. Chapter 3. Aquatic ecotoxicity of whole effluents. In R.K. Rosenbaum, A. Anton, B. Ciuffo, P. Fantke, L. Golsteijn, M.Z. Hauschild, S. Hellweg, A.J. Hendriks, H.W.M. Hendriks, M.A.J. Huijbregts, S. Humbert, O. Jolliet, R. Juraske, A. Kounina, M. Margni, D. Marinov, G. Musters, M. Owsianiak, D. Pennington, A.F.H. Pilière, A. Ragas, C.E. Raptis, S. Sala, E. Sevigne Itoiz, M. Trombetti, R. van Zelm. Recommended assessment framework, method and characterisation factors for ecotoxicity and human toxicity. Deliverable 2.2., version 31/08/2012. www.lc-impact.eu.

7.2.4. References for photochemical ozone formation

Azevedo LB, Friedrich R, van Goethem TMWJ, Huijbregts MAJ, Preiss P, Roos J, van Zelm R. 2012. D3.5 (Month 33): Recommended assessment framework, method and characterisation factors for human health and ecosystem impacts of photochemical ozone formation: phase 2 (report, model and factors). Deliverable 3.5., version 31/08/2012. www.lc-impact.eu.

7.2.5. References for fine particulate matter formation

Hellweg S, Demou E, Bruzzi R, Meijer A, Rosenbaum RK, Huijbregts MAJ, McKone TE. 2009. Integrating Human Indoor Air Pollutant Exposure within Life Cycle Impact Assessment. Environmental Science & Technology 43 (6): 1670-1679.

Additional information from: Walser T, Haeni C, Demou E, Hellweg S. Exposure to Ultrafine Particles in a Printing Shop.

7.2.6. References for noise impact to humans

Cucurachi S, Heijungs R, Ortiz ST. 2012. Recommended assessment framework, method and characterisation factors for noise impacts. Deliverable D3.6. www.lc-impact.eu.

Cucurachi S, Heijungs R. 2012. “CFs_3.6_noise.xlsx” – List of characterisation factors (CF_humannoise). www.lc-impact.eu.

Cucurachi S. 2012. “The use of CFs_indoor_mobile.doc” – guidance document for the use of noise CFs for an indoor/occupational environment. www.lc-impact.eu.

7.3. Normalisation

Cucurachi S, Heijungs R. 2013. Normalisation factors for noise impacts in Europe and the World. Criteria and results (Deliverable 3.6). Version 06/03/2013. Available at http://www.lc-impact.wikispaces.net/file/detail/normalisation_noise_final_reviewed.docx.

Goedkoop MJ, Heijungs R, Huijbregts M, De Schryver A, Struijs J, Van Zelm R. 2013. ReCiPe 2008: A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. http://www.lcia-recipe.net/. Normalisation sheet. Version 1.08 - February 2013. Available at https://sites.google.com/site/lciarecipe/file-cabinet/ReCiPe108.xlsx?attredirects=0&d=1

Hanafiah MM, Xenopoulos MA, Pfister S, Leuven RS, Huijbregts MA. 2011. Characterization factors for water consumption and greenhouse gas emissions based on freshwater fish species extinction. Environmental Science and Technology 45(12): 5272-5278. doi: 10.1021/es1039634.

Heijungs R. 2005. On the use of units in LCA. International Journal of Life Cycle Assessment 10(3): 173-176.

Jolliet O, Margni M, Charles R, Humbert S, Payet J, Rebitzer G, Rosenbaum R. 2003. IMPACT 2002+: A New Life Cycle Impact Assessment Methodology. International Journal of Life Cycle Assessment 8(6): 324-330.

Núñez M, Antón A, Muñoz P, Rieradevall J. 2013. Normalisation factors for soil erosion at the global scale. Available at http://www.lc-impact.wikispaces.net/file/detail/D1.6_Ch6_CF_NF.xlsx

Preiss P. 2013. Normalisation Factors of WP 3.3. Available at http://www.lc-impact.wikispaces.net/file/detail/WP33_Normalisation%20Factors.docx.

Van Zelm R. 2013. Normalisation factors for Forestry. Available at http://www.lc-impact.wikispaces.net/file/detail/Normalization%20factors%20for%20Forestry_LC-Impact_new26March2013.xlsx.

7.4. General

Goedkoop MJ, Heijungs R, Huijbregts M, De Schryver A, Struijs J, Van Zelm R. 2013. ReCiPe 2008: A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. First edition (revised). Report I: Characterisation. Available at http://www.lcia-recipe.net/.

PE, LBP: GaBi 4 Software – System and Databases for Life Cycle Engineering. Compilation 4.4.142.1, DB version 4.131. Stuttgart, Echterdingen 1992-2008.

World Nuclear Association. 2013. Nuclear Energy in Denmark. Retrieved from http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/Denmark/#.UWGu51cmSt9 (07/04/2013).

EC (European Commission), JRC (Joint Research Centre), IES (Institute for Environment and Sustainability). 2010. International Reference Life Cycle Data System (ILCD) Handbook – General guide for Life Cycle Assessment – Detailed guidance. First edition March 2010. EUR 24708 EN. Luxembourg. Publications Office of the European Union. 110 pp.

8. Appendices

8.1. Appendix I – Inventory sources

The inventory sources are taken from Larsen et al. (2006) and shortly described below.

PULP AND PAPER PRODUCTION

Data, inputs and emissions from Ecoinvent based on the aggregated process *RER: paper, woodfree, coated, at integrated mill.*

REPRO PROCESS

Film, repro: Material Safety Data Sheet from Kodak giving the material "Estar". Available at www.kodak.com. The material Estar is PET (Lapp et al. 2000). KODAK (2001a), Baumann & Gräfen (1999a), APR (2003)

Silver and halides: Emission Scenario Document (p. 26). Photographic industry, IC10. Assessment of the environmental release of photochemicals (Baumann & Gräfen 1999a)

Film developer (KODAK RA2000): Material Safety Data Sheet from Kodak available at www.kodak.com (KODAK 2001b, 2003)

Film fixer (KODAK RA3000): Material Safety Data Sheet from Kodak available at www.kodak.com (KODAK 2000, 2003)

Biocides: Kjærgaard (1997), Larsen et al. (1995, 2002), Andersen et al. (1999), Gruvmark (2004), Deltagraph (1997)

Process water: Data about Danish water works is available in the EDIP LCV tool: K32506 (Miljøstyrelsen 1999).

PLATE MAKING

Aluminium plate: Production of aluminium from *European Aluminium Association (2000). Environmental Profile Report for the European Aluminium Industry* Available on request at the webpage of the European Aluminium Association at www.aluminium.org"

Plate emulsion: Larsen et al. (1995), Baumann & Gräfen (1999b), Muskopf (2000), Baumann & Rothardt (1999), Ludwiszewska (1992) and KODAK 2002a)

Plate developer: Larsen et al. (1995).

Gumming agent: Larsen et al. (1995) and Agfa (2002).

Biocide: See *Repro*.

Remelting of aluminium: See *Aluminium plate*.

Process water: See *Repro*.

PRINTING

IPA: Personal communication with Ian Kersey, BP Chemicals, 2003 (confidential)

Printing ink Composition: Larsen et al. (1995)

CI pigment yellow 14 and CI pigment blue 15: Andersen & Nikolajsen (2003).

Carbon black: SimaPro version 5.1 (2002). PRé Consultants, Amersfoort, The Netherlands. Available at internet at www.pre.nl. Original reference here "Emissieregistratie process 1532 (1993)". Elaborating information is available in SimaPro: Data is from the Dutch bureau of emission registrations (emissieregistratie). Data is generated by Delft University of Technology. As a comment is mentioned "Environmental assessment for the production of carbon black in the Netherlands. Average data for 1993".

Modified phenolic resin and soya oil alkyd: Data available in EDIP LCV tool (Miljøstyrelsen 1999).

Soya oil: von Däniken A, Chudacoff M (1995). Vergleichende ökologische Bewertung von Anstrichstoffen im Baubereich. Band 2: Daten. Schriftenreihe Umwelt nr. 232. Bern: Bundesamt für Umwelt, Wald und Landschaft (BUWAL).

n-paraffin (heavy): Franke et. al. 1995. A Life Cycle Inventory for the Production of Petrochemical Intermediates in Europe. Tenside Surf. Det. 32 (1995) 5.

Polyethylene wax: See *water based lacquer*.

Diethylene glycol: von Däniken A, Chudacoff M (1995). Vergleichende ökologische Bewertung von Anstrichstoffen im Baubereich. Band 2: Daten. Schriftenreihe Umwelt nr. 232. Bern: Bundesamt für Umwelt, Wald und Landschaft (BUWAL).

FINISHING

- Water based lacquer

Ethanol: Personal communication with Ian Kersey, BP Chemicals, 1995 (confidential).

Ammonia: Production data in EDIP tool (Miljøstyrelsen 1999): Primary reference is: *European Fertilizer Manufacturers Association (1995): Production of Ammonia. Booklet no. 1.*

Polyethylene wax: Production data in EDIP tool (Miljøstyrelsen 1999): Primary source is LDPE from *Vergleichende ökologische Bewertung von Anstrichstoffen im Baubereich BUWAL, Schriftenreihe Umwelt Nr. 232, 1995*.

Alcoholethoxylate: Production data with 7EO chains from: *Dall'Acqua, S., Fawer, M., Fritschi, R., Allenspach, C. (1999): Life Cycle Inventories for the Production of Detergent Ingredients. EMPA-Bericht Nr. 244. St. Gallen, 1999*.

Acrylic resin: Production data in EDIP tool Miljøstyrelsen (1999): Primary reference is *Vergleichende ökologische Bewertung von Anstrichstoffen im Baubereich BUWAL, Schriftenreihe Umwelt Nr. 232, 1995*. Data and energy scenarios are revised by Niels Frees, IPU.

- Offset lacquer

See *printing ink* (excluding pigments).

Hot Melt glue: Composition from Miljønet (2004).

EVA: LDPE is main ingredient in EVA according to (Schmidt et al. 1993) and is used as production data.

LDPE: Boustead (2003). Eco-profiles of the European plastics industry. Polyolefins. APME, Brussels.

Phenolic formaldehyde resin: Miljøstyrelsen (1999): EDIP tool. "Alkyd bindemiddel" used as model for production.

Polyethylene wax: See *water based lacquer*.

CLEANING

Soya oil: von Däniken A, Chudacoff M (1995). Vergleichende ökologische Bewertung von Anstrichstoffen im Baubereich. Band 2: Daten. Schriftenreihe Umwelt nr. 232. Bern: Bundesamt für Umwelt, Wald und Landschaft (BUWAL).

n-paraffines: Franke et. al. 1995. A Life Cycle Inventory for the Production of Petrochemical Intermediates in Europe. Tenside Surf. Det. 32 (1995) 5.

"Ekstraktionsbenzin": Hansen & Gregersen (1986).

Benzene: Franke et. al. 1995. A Life Cycle Inventory for the Production of Petrochemical Intermediates in Europe. Tenside Surf. Det. 32 (1995) 5.

Ethanol: Personal communication with Ian Kersey, BP Chemicals, 1995 (confidential).

Alcoholethoxylate: See *water based lacquer*.

Process water: See *Repro*.

ENERGY CONSUMPTION AT PRINTING INDUSTRY

Electricity consumption: Data is available in EDIP LCV tool (Miljøstyrelsen 1999): Data from "Energi E2", which is a Danish producer of electricity. Revised by Niels Frees, IPU.

District heating: Data is available in EDIP LCV tool (Miljøstyrelsen 1999): Data from "Energi E2" revised by Niels Frees, IPU.

Heating with fuel oil: Data is available in EDIP LCV tool (Miljøstyrelsen 1999)

Heating with natural gas: Data is available in EDIP LCV tool (Miljøstyrelsen 1999)

RECOVERY/DISPOSAL

Amount of paper for recycling: Tønning (2002).

Recovery of paper: In Frees et. al. (2004) a process is constructed via information from a Danish company recycling offset paper. Recovery process is per kg output. In Frees et al. (2004) recovery to "cycluspapir" which is a fine quality printing paper based on recycled paper: Input: 116kg; Output: 97kg; 97/116=83.6%, hence in database 0.836kg of paper recovery process and avoided production of paper is included per kg of paper sent to recovery.

Paper production from primary materials is used as avoided production.

Incineration of paper: Data is available in EDIP LCV tool (Miljøstyrelsen 1999).

An energy recovery of 78% is assumed. The energy recovered is assumed to replace an equivalent amount of energy from primary fuel, which is natural gas.

8.2. Appendix II – Mass balances and LCI calculations

Data for the activities at the model printing company shown together with data provided by offset printing companies.

Table 8.1: Mass balance and scaling to functional unit in model printing company for sheet fed printed matter (offset product) (Larsen et al. 2006).

				Emissions and waste handling											
				-to air		-to ww		-chem. waste		-recycling		vol. waste		-incineration	
1	ton generic sheet fed offset printed matter (fu)														
1	**Piece**	**Repro (per fu)**													
5.63	**m2**	**Film, Repro**													
0.137	kg	PET	*89%*											0.77	kg
0.01	kg	Ag	*6%*			2.4E-04	kg			0.0561	kg				
0.007	kg	Br	*5%*												
2.85	**kg**	**Film developer**				**4.2%**				**95.8%**					
0.91	kg	Water				0.10805	kg			2.485	kg				
0.035	kg	Potassium sulfite				0.00419	kg			0.096	kg				
0.020	kg	Diethylene glycol				0.0023957	kg			0.0551	kg				
0.018	kg	Hydroquinon				0.00210	kg			0.048	kg				
0.0076	kg	Sodium sulphite				0.00090	kg			0.021	kg				
0.0076	kg	Potassium carbonate				0.00090	kg			0.021	kg				
0.0025	kg	4-hydroxymethyl-4-methyl-1-phenyl-3-pyrazolidinone				0.00030	kg			0.007	kg				
3.17	**kg**	**Fixer**				**18.6%**				**81.4%**					
0.81	kg	Water				0.48	kg			2.09655	kg				
0.14	kg	Ammonium thiosulfate				0.082	kg			0.3579	kg				
0.026	kg	Sodium acetate				0.016	kg			0.06817	kg				
0.0066	kg	Boric acid				0.0039	kg			0.01704	kg				
0.0066	kg	Ammonium sulfite				0.0039	kg			0.01704	kg				
0.0066	kg	Acetic acid				0.0039	kg			0.01704	kg				
0.0033	kg	Sodium bisulfite				0.0019	kg			0.00852	kg				
0.00019	**kg**	**Biocide**				**100%**									
0.25	kg	2-methyl-3-isothiazolon				0.00005	kg								
0.75	kg	5-chlor-2-methyl-3-isothiazolon				0.00014	kg								
5.77	**kg**	**Water for rinsing**													
0.77	**kg**	**Incineration of PET**													
1	**Piece**	**Platemaking (per fu)**						5.48E-01	kg						
4.16	**m2**	**Plate for printing of offset product**													
0.90	kg	Aluminium								3.44	kg	0.30	kg		
0.015	**kg**	**Plate emulsion**				**24%**		**36%**						**40%**	
0.01	kg	2-diazo-1(2H)-naphthalinon-derivative				3.6E-05	kg	5.4E-05	kg					6.0E-05	
0.34	kg	Polyvinylalcohol				1.2E-03	kg	1.8E-03	kg					2.0E-03	
0.64	kg	Phenolformaldehydharpiks				2.3E-03	kg	3.5E-03	kg					3.8E-03	
0.01	kg	Additives				1.8E-05	kg	2.7E-05	kg					3.0E-05	
0.90	**kg**	**Plate developer**				**40%**		**60%**							
0.90	kg	Water				0.32579	kg	4.9E-01	kg						
0.08	kg	Na2SiO3				0.02896	kg	4.3E-02	kg						
0.02	kg	NaOH				0.00724	kg	1.1E-02	kg						
0.0300	**kg**	**Gumming agent**				**100%**									
0.85	kg	Water				0.02552	kg								
0.05	kg	CMC				0.00150	kg								
0.05	kg	Citric acid				0.00150	kg								
0.05	kg	Na-dodecyl-diphenyloxid-disulphonate				0.00150	kg								
0.00133	kg	Biocide													
0.25	kg	2-methyl-3-isothiazolon				0.000010	kg								
0.75	kg	5-chlor-2-methyl-3-isothiazolon				0.000030	kg								
0.00125	**kg**	**Biocide**				**100%**									
0.25	kg	2-methyl-3-isothiazolon				0.00031	kg								
0.75	kg	5-chlor-2-methyl-3-isothiazolon				0.00093	kg								
37.42	**kg**	**Water for rinsing**													
3.44	**kg**	**Remelting of aluminium**													
3.44	**kg**	**Avoided production of primary aluminium**													

						Emissions and waste handling											
						-to air		**-to ww**		**-chem. waste**		**-recycling**		**vol. waste**		**-incineration**	
1	**Piece**	**Printing (per fu)**				Chemical waste sum				1.14	kg						
	3.93	**kg**	**IPA**			3.392	kg	0.536	kg								
	5.80	**kg**	**Printing Ink**					**1%**		**19.6%**							
		0.085	kg	CI pigment yellow 14													
		0.075	kg	CI pigment blue 15		5%		0.0029	kg	0.0567	kg						
			kg	CI pigment red 57:1		5%		0.0029	kg	0.0567	kg						
			kg	CI pigment yellow 12		6%		0.0035	kg	0.0681	kg						
		0.030	kg	Carbon black		3%		0.0017	kg	0.0340	kg						
		0.200	kg	Modif.phenolharpikser				0.012	kg	0.23	kg						
		0.120	kg	Soyaoliealkyder				0.00696	kg	0.14	kg						
		0.120	kg	Soya oil				0.00696	kg	0.14	kg						
		0.290	kg	n-parrafin (heavy)				0.017	kg	0.33	kg						
		0.030	kg	wax				0.00174	kg	0.03	kg						
		0.050	kg	Additives, incl sikkatives				0.0029	kg	0.06	kg						
	1.004	**kg**	**Fountain solution concentrate**			**86%(IPA)**		**100%(÷IPA)**									
		0.03	kg	IPA		0.026	kg	0.0041	kg	*0.004*	kg						
		0.03	kg	Diethylene glycol		0.000	kg	0.030	kg								
		0.0025	kg	2-brom-2-nitropropane-1,3-diol (biocide)				0.002511	kg								
		0.0006	kg	Biocide													
			0.25	kg	2-methyl-3-isothiazolon			0.0001507	kg								
			0.75	kg	5-chlor-2-methyl-3-isothiazolon			0.000452	kg								
		0.9369	kg	Water													
	28.83	**kg**	**Water for dilution**														
1	**Piece**	**Finishing (per fu)**				Chemical waste sum				0.04	kg						
	4.98	**kg**	**Water based lacquer**					**5%**									
		0.25	kg	Acrylates (poly-, mono-, esters)				0.0622									
		0.03	kg	Glycerol				0.0075									
		0.02	kg	Ethanol				0.0050									
		0.01	kg	Ammonia				0.0025									
		0.01	kg	Polyethylene wax				0.0025									
		0.01	kg	2-amino-ethanol				0.0025									
		0.01	kg	Alcoholethoxylate (undecyletherpolyoxy-ethylen(5))				0.0025									
		0.0004	kg	2-chloroacetamide (biocide)				0.0001									
		0.6596	kg	Water													
	0.22	**kg**	**"Offset lacquer"**					**0.1%**		**19.6%**							
		0.24	kg	Modif.phenolharpikser				0.00005	kg	0.010	kg						
		0.14	kg	Soyaoliealkyder				0.00003	kg	0.006	kg						
		0.14	kg	Soyaolie				0.00003	kg	0.006	kg						
		0.40	kg	n-paraffin (heavy)				0.0001	kg	0.017	kg						
		0.03	kg	polyethylene wax				0.00001	kg	0.001	kg						
		0.05	kg	Additives, incl siccatives				0.00001	kg	0.002	kg						
	0.75	**kg**	**Hotmelt glue**														
		0.38	kg	EVA	LDPE used												
		0.48	kg	Resin	Phenolic formaldehyde resin												
		0.14	kg	Wax													
		0.0015	kg	Antioxidant													
1	**Piece**	**Cleaning (per fu)**				Chemical waste sum				0.87	**kg**						
	0.61	kg	Soyaolie (veg.)					0.0061	kg	0.61	kg						
	0.61	kg	n-parafines (heavy)			0.42	kg	0.0061	kg	0.19	kg						
	0.61	kg	"Ekstraktionsbenzin"														
		0.999	kg	n-parafines (light)		0.58	kg	0.00061	kg	0.030	kg						
		0.001	kg	Benzene (aromatic)		0.00058	kg	6.11E-07	kg	0.000030	kg						
	0.61	kg	Ethanol (alcohol based)			0.58	kg	0.0061	kg	0.024	kg						
	0.050	kg	Alcoholethoxylate (undecyletherpolyoxy-ethylen(5))				kg	0.025	kg	0.025	kg						
	21.98	kg	Water for rinsing														
1	**Piece**	**Energy consumption at printing company (per fu)**															
	176.1	kWh	District heating														
	21.606	kg	Heating with fuel oil														
	6.25	kg	Heating with natural gas														
	705.32	kWh	Electricity consumption														
1	**Piece**	**Disposal after use**															
	634.24	kg	Paper to recycling														
	634.24	kg	Avoided production of paper														
	562.4	kg	Incineration of paper														
1	**Piece**	**Paper for 1 ton offset product**															
	1196.7	**kg**	**Paper**									**196**	kg (paper recycling at model printing company)				
1	**Piece**	**Water consumption excl. process water**															
	94.01	**litres**	**Water**														

8.3. Appendix III – Aggregated inventory list

Table 8.2: Inventory list – Resources consumption.

		[unit]
RESOURCES	**1.57E+05**	[kg]
Energy resources	**1.10E+03**	[kg]
Non renewable energy resources	**1.10E+03**	[kg]
Crude oil (resource)	***1.43E+02***	[kg]
Hard coal (resource)	***2.00E+02***	[kg]
Lignite (resource)	***6.01E+02***	[kg]
Natural gas (resource)	***1.56E+02***	[kg]
Uranium (resource)	1.01E+03	[MJ]
Nuclear energy	1.44E-01	[MJ]
Uranium free ore (BUWAL)	2.15E+00	[MJ]
Uranium natural	1.00E+03	[MJ]
Renewable energy resources	**2.05E-02**	[kg]
Biomass	6.81E-04	[kg]
Energy, calorific value, in organic substance	4.06E+04	[MJ]
Energy, gross calorific value, in biomass, primary forest	1.09E+01	[MJ]
Energy, kinetic (in wind), converted	1.55E+02	[MJ]
Energy, potential (in hydropower reservoir), converted	-8.85E+01	[MJ]
Energy, solar, converted	2.65E+00	[MJ]
Primary energy from geothermics	6.85E-03	[MJ]
Primary energy from hydro power	1.15E+00	[MJ]
Primary energy from hydro power (BUWAL)	6.85E-01	[MJ]
Primary energy from solar energy	7.68E-02	[MJ]
Primary energy from waves	5.53E-06	[MJ]
Primary energy from wind power	5.13E-01	[MJ]
Renewable fuels	6.30E-07	[kg]
Wood	3.97E-05	[m3]
Wood, hard, standing	2.16E+00	[m3]
Wood, primary forest, standing	1.01E-03	[m3]
Wood, soft, standing	1.39E+00	[m3]
Land use		
Hemerobie ecoinvent		
Occupation, arable, non-irrigated	2.84E+01	[m2*yr]
Occupation, construction site	7.52E-03	[m2*yr]
Occupation, dump site	6.27E+00	[m2*yr]
Occupation, dump site, benthos	4.72E-02	[m2*yr]
Occupation, forest, intensive	3.27E+03	[m2*yr]
Occupation, forest, intensive, normal	1.48E+03	[m2*yr]
Occupation, forest, intensive, short-cycle	2.74E+00	[m2*yr]
Occupation, industrial area	7.25E-01	[m2*yr]
Occupation, industrial area, benthos	4.39E-04	[m2*yr]
Occupation, industrial area, built up	6.22E-01	[m2*yr]
Occupation, industrial area, vegetation	3.25E-01	[m2*yr]
Occupation, mineral extraction site	3.05E+00	[m2*yr]
Occupation, permanent crop, fruit, intensive	5.87E+00	[m2*yr]
Occupation, shrub land, sclerophyllous	1.82E-02	[m2*yr]
Occupation, traffic area, rail embankment	3.73E-01	[m2*yr]
Occupation, traffic area, rail network	4.12E-01	[m2*yr]
Occupation, traffic area, road embankment	6.85E+01	[m2*yr]
Occupation, traffic area, road network	8.24E-01	[m2*yr]
Occupation, urban, discontinuously built	5.14E-02	[m2*yr]
Occupation, water bodies, artificial	1.37E+00	[m2*yr]
Occupation, water courses, artificial	1.31E-01	[m2*yr]

Transformation, from arable	1.46E-03	[m2]
Transformation, from arable, non-irrigated	5.10E+01	[m2]
Transformation, from arable, non-irrigated, fallow	4.50E-04	[m2]
Transformation, from dump site, inert material landfill	1.30E-03	[m2]
Transformation, from dump site, residual material landfill	8.07E-04	[m2]
Transformation, from dump site, sanitary landfill	-2.54E-04	[m2]
Transformation, from dump site, slag compartment	1.78E-03	[m2]
Transformation, from forest	9.88E-02	[m2]
Transformation, from forest, extensive	3.28E+01	[m2]
Transformation, from forest, intensive, clear-cutting	9.78E-02	[m2]
Transformation, from industrial area	6.53E-04	[m2]
Transformation, from industrial area, benthos	3.46E-06	[m2]
Transformation, from industrial area, built up	-2.10E-05	[m2]
Transformation, from industrial area, vegetation	-3.58E-05	[m2]
Transformation, from mineral extraction site	1.08E-01	[m2]
Transformation, from pasture and meadow	3.61E-01	[m2]
Transformation, from pasture and meadow, intensive	4.16E-02	[m2]
Transformation, from sea and ocean	4.72E-02	[m2]
Transformation, from shrub land, sclerophyllous	3.91E-03	[m2]
Transformation, from tropical rain forest	9.78E-02	[m2]
Transformation, from unknown	3.78E-01	[m2]
Transformation, to arable	3.22E-02	[m2]
Transformation, to arable, non-irrigated	5.14E+01	[m2]
Transformation, to arable, non-irrigated, fallow	5.08E-04	[m2]
Transformation, to dump site	4.81E-02	[m2]
Transformation, to dump site, benthos	4.72E-02	[m2]
Transformation, to dump site, inert material landfill	1.30E-03	[m2]
Transformation, to dump site, residual material landfill	8.07E-04	[m2]
Transformation, to dump site, sanitary landfill	-2.54E-04	[m2]
Transformation, to dump site, slag compartment	1.78E-03	[m2]
Transformation, to forest	1.66E-02	[m2]
Transformation, to forest, intensive	2.18E+01	[m2]
Transformation, to forest, intensive, clear-cutting	9.78E-02	[m2]
Transformation, to forest, intensive, normal	1.04E+01	[m2]
Transformation, to forest, intensive, short-cycle	9.78E-02	[m2]
Transformation, to heterogeneous, agricultural	7.98E-03	[m2]
Transformation, to industrial area	1.35E-02	[m2]
Transformation, to industrial area, benthos	4.08E-05	[m2]
Transformation, to industrial area, built up	1.06E-02	[m2]
Transformation, to industrial area, vegetation	6.67E-03	[m2]
Transformation, to mineral extraction site	3.43E-01	[m2]
Transformation, to pasture and meadow	3.00E-04	[m2]
Transformation, to permanent crop, fruit, intensive	8.27E-02	[m2]
Transformation, to sea and ocean	3.46E-06	[m2]
Transformation, to shrub land, sclerophyllous	3.63E-03	[m2]
Transformation, to traffic area, rail embankment	8.67E-04	[m2]
Transformation, to traffic area, rail network	9.53E-04	[m2]
Transformation, to traffic area, road embankment	4.62E-01	[m2]
Transformation, to traffic area, road network	4.69E-03	[m2]
Transformation, to unknown	6.51E-02	[m2]
Transformation, to urban, discontinuously built	1.02E-03	[m2]
Transformation, to water bodies, artificial	4.12E-02	[m2]
Transformation, to water courses, artificial	1.23E-03	[m2]
Volume occupied, final repository for low-active radioactive waste	2.91E-06	[m3]
Volume occupied, final repository for radioactive waste	7.50E-07	[m3]
Volume occupied, underground deposit	1.00E-04	[m3]

Occupation		
Biotic Production	1.09E-05	[kg]
Erosion Resistance	2.04E-04	[kg]
Groundwater Replenishment	4.94E-03	[mm*m2]
Mechanical Filtration	4.35E-01	[cm*m3]
Physicochemical Filtration	2.46E-04	[cmol*m2*a/kg]
Transformation		
Biotic Production	5.79E-06	[kg/yr]
Erosion Resistance	-6.19E-07	kg/a
Groundwater Replenishment	-1.17E-03	[mm*m2/yr]
Mechanical Filtration	-6.16E-05	[cm*m2/d]
Physicochemical Filtration	-1.17E-05	[cmol*m2/kg]
Material resources	**1.56E+05**	[kg]
Non renewable elements	**2.06E+01**	[kg]
Aluminum	3.72E+00	[kg]
Cadmium	3.53E-04	[kg]
Cerium	-3.03E-15	[kg]
Chromium	1.92E-01	[kg]
Cobalt	1.01E-06	[kg]
Copper	1.77E-01	[kg]
Fluorine	-1.43E-02	[kg]
Gallium	8.03E-09	[kg]
Gold	9.21E-06	[kg]
Indium	6.27E-06	[kg]
Iron	1.34E+01	[kg]
Lanthanides	-5.58E-16	[kg]
Lead	1.28E-02	[kg]
Magnesium	1.30E-04	[kg]
Manganese	2.45E-02	[kg]
Mercury	6.05E-14	[kg]
Molybdenum	2.84E-02	[kg]
Neodymium	-1.52E-15	[kg]
Nickel	5.61E-01	[kg]
Palladium	7.26E-07	[kg]
Phosphorus	2.27E+00	[kg]
Platinum	6.22E-08	[kg]
Praseodymium	-1.01E-16	[kg]
Rhenium	4.36E-09	[kg]
Rhodium	1.81E-08	[kg]
Samarium	-4.37E-17	[kg]
Silver	1.13E-01	[kg]
Sulphur	1.37E-01	[kg]
Tantalum	9.49E-06	[kg]
Tellurium	1.31E-06	[kg]
Tin	5.14E-04	[kg]
Zinc	-4.86E-03	[kg]
Zirconium	1.24E-05	[kg]
Non renewable resources	**1.06E+03**	[kg]
Antimonite	1.27E-03	[kg]
Barium sulphate	4.38E-01	[kg]
Basalt	7.23E-02	[kg]
Bauxite	5.11E-04	[kg]
Bentonite	2.54E-01	[kg]
Borax	4.48E-07	[kg]

Calcium chloride	1.63E-12	[kg]
Carbon, in organic matter, in soil	1.57E-01	[kg]
Chalk (Calciumcarbonate)	7.02E-35	[kg]
Chromium ore (39%)	9.48E-06	[kg]
Chrysotile	5.59E-04	[kg]
Cinnabar	4.92E-05	[kg]
Clay	6.53E+00	[kg]
Colemanite ore	9.06E-02	[kg]
Copper - Gold - Silver - ore (1,0% Cu; 0,4 g/t Au; 66 g/t Ag)	1.68E-06	[kg]
Copper - Gold - Silver - ore (1,1% Cu; 0,01 g/t Au; 2,86 g/t Ag)	1.02E-06	[kg]
Copper - Gold - Silver - ore (1,16% Cu; 0,002 g/t Au; 1,06 g/t Ag)	5.77E-07	[kg]
Copper - Molybdenum - Gold - Silver - ore (1,13% Cu; 0,02% Mo; 0,01 g	1.41E-06	[kg]
Copper ore (0.14%)	3.37E-04	[kg]
Copper ore (1.2%)	1.74E-07	[kg]
Copper ore (4%)	2.01E-14	[kg]
Copper ore (sulphidic, 1.1%)	2.38E-11	[kg]
Diatomite	1.22E-02	[kg]
Dolomite	5.01E-02	[kg]
Europium, 0.06% in bastnasite, 0.006%	-2.25E-18	[kg]
Feldspar (aluminum silicates)	2.48E-05	[kg]
Ferro manganese	5.70E-09	[kg]
Fluorspar (calcium fluoride; fluorite)	-4.17E-01	[kg]
Gadolinium, 0.15% in bastnasite, 0.015%	-3.58E-17	[kg]
Granite	2.45E-05	[kg]
Gypsum (natural gypsum)	3.12E-03	[kg]
Heavy spar (BaSO4)	1.33E-01	[kg]
Inert rock	9.98E+00	[kg]
Iron ore (56,86%)	4.16E-02	[kg]
Iron ore (65%)	6.95E-06	[kg]
Kaolin ore	2.43E-06	[kg]
Kaolinite (24% in ore as mined)	2.25E+02	[kg]
Kieserite (25% in ore as mined)	3.25E+00	[kg]
Lead - zinc ore (4.6%-0.6%)	1.08E-02	[kg]
Limestone (calcium carbonate)	2.08E+02	[kg]
Magnesit (Magnesium carbonate)	1.49E-01	[kg]
Magnesium chloride leach (40%)	3.21E-03	[kg]
Manganese ore	1.82E-06	[kg]
Manganese ore (R.O.M.)	4.20E-04	[kg]
Metamorphic stone, containing graphite	4.88E-03	[kg]
Molybdenite (Mo 0,24%)	8.65E-07	[kg]
Natural Aggregate	5.70E+02	[kg]
Nickel ore (1,5%)	3.77E-09	[kg]
Nickel ore (1.6%)	1.49E-03	[kg]
Olivine	3.07E-04	[kg]
Peat	1.78E+00	[kg]
Phosphate ore	8.04E-07	[kg]
Phosphorus minerals	4.20E-08	[kg]
Phosphorus ore (29% P2O5)	4.50E-08	[kg]
Potassium chloride	2.11E-08	[kg]
Precious metal ore (R.O.M)	1.74E-06	[kg]
Quartz sand (silica sand; silicon dioxide)	4.25E-02	[kg]
Raw pumice	2.36E-07	[kg]
Rutile (titanium ore)	1.42E-13	[kg]
sand	1.15E-01	[kg]
Slate	2.55E-03	[kg]

Sodium chloride (rock salt)	3.75E+01	[kg]
Sodium nitrate	3.39E-09	[kg]
Sodium sulphate	-1.20E-01	[kg]
Soil	2.09E-02	[kg]
Sulphur (bonded)	1.87E-09	[kg]
Sylvite (25% in Sylvinite)	4.80E-01	[kg]
Talc	-4.35E+00	[kg]
Tin ore	1.38E-15	[kg]
TiO2, 54% in ilmenite, 2.6%	-1.74E-01	[kg]
TiO2, 95% in rutile, 0.40%	2.48E-05	[kg]
Titanium dioxide	5.52E-07	[kg]
Titanium ore	1.45E-04	[kg]
Ulexite	2.87E-04	[kg]
Vermiculite	2.40E-04	[kg]
Zinc - copper ore (4.07%-2.59%)	1.83E-03	[kg]
Zinc - lead - copper ore (12%-3%-2%)	7.58E-04	[kg]
Zinc - lead ore (4.21%-4.96%)	6.85E-15	[kg]
Zinc ore (sulphidic, 4%)	2.34E-13	[kg]
Renewable resources	**1.55E+05**	[kg]
Water	***1.51E+05***	[kg]
Water	1.55E+05	[kg]
Water (feed water)	1.12E-04	[kg]
Water (ground water)	-7.66E+03	[kg]
Water (lake water)	2.52E+02	[kg]
Water (river water)	3.71E+03	[kg]
Water (sea water)	1.78E+02	[kg]
Water (surface water)	2.41E+01	[kg]
Water (well water)	2.94E-08	[kg]
Water (with river silt)	2.60E-11	[kg]
Water, salt, sole	4.60E-02	[kg]
Water,turbine use, unspecified natural origin	5.23E+02	[kg]
Air	1.19E+01	[kg]
Carbon dioxide	3.71E+03	[kg]
Nitrogen	4.87E-07	[kg]
Oxygen	-1.34E-04	[kg]
2-diazo-1(2H)-naphthalinone derivate	**6.24E-04**	[kg]
Chloracetamide	**2.13E-03**	[kg]
Citric acid	**1.50E-03**	[kg]
Other additives	**6.24E-04**	[kg]
Plate making	**3.93E+01**	[kg]
Repro process	**1.19E+01**	[kg]

Table 8.3: Inventory list – Emissions to air.

			[unit]
EMISSIONS TO AIR		**3.88E+03**	[kg]
	Heavy metals to air	**4.22E-02**	[kg]
	Antimony	5.89E-05	[kg]
	Arsenic (+V)	1.92E-04	[kg]
	Arsenic trioxide	7.39E-12	[kg]
	Cadmium (+II)	5.31E-05	[kg]
	Chromium (+III)	1.56E-09	[kg]
	Chromium (+VI)	1.99E-05	[kg]
	Chromium (unspecified)	8.77E-04	[kg]
	Cobalt	1.09E-04	[kg]
	Copper (+II)	8.30E-04	[kg]
	Heavy metals to air (unspecified)	5.94E-10	[kg]
	Hydrogen arsenic (arsine)	6.15E-10	[kg]
	Iron	2.85E-02	[kg]
	Lanthanides	1.35E-11	[kg]
	Lead (+II)	9.73E-04	[kg]
	Manganese (+II)	2.64E-03	[kg]
	Mercury (+II)	1.15E-04	[kg]
	Molybdenum	1.02E-04	[kg]
	Nickel (+II)	6.58E-04	[kg]
	Palladium	4.51E-17	[kg]
	Platinum	2.13E-10	[kg]
	Rhodium	4.36E-17	[kg]
	Selenium	2.03E-04	[kg]
	Silver	1.68E-07	[kg]
	Tellurium	2.08E-10	[kg]
	Thallium	1.71E-06	[kg]
	Tin (+IV)	1.78E-05	[kg]
	Titanium	7.23E-04	[kg]
	Vanadium (+III)	1.09E-03	[kg]
	Zinc (+II)	5.04E-03	[kg]
	Inorganic emissions to air	**3.86E+03**	[kg]
	Ammonia	1.53E-01	[kg]
	Ammonium	3.56E-11	[kg]
	Ammonium carbonate	3.34E-07	[kg]
	Ammonium nitrate	1.05E-11	[kg]
	Barium	7.43E-04	[kg]
	Beryllium	5.97E-06	[kg]
	Boron	3.16E-02	[kg]
	Boron compounds (unspecified)	3.48E-06	[kg]
	Boron trifluoride	1.25E-14	[kg]
	Bromine	1.42E-03	[kg]

Carbon dioxide	1.41E+03	[kg]
Carbon dioxide (biotic)	2.43E+03	[kg]
Carbon dioxide (biotic)	1.72E-02	[kg]
Carbon dioxide, land transformation	1.73E+00	[kg]
Carbon disulphide	1.49E-03	[kg]
Carbon monoxide	9.43E+00	[kg]
Carbon monoxide (biotic)	1.19E+00	[kg]
Chloride (unspecified)	2.59E-05	[kg]
Chlorine	4.66E-03	[kg]
Cyanide (unspecified)	2.21E-03	[kg]
Fluoride	1.32E-05	[kg]
Fluorine	7.77E-04	[kg]
Helium	2.34E-04	[kg]
Hexaflourosilicates	1.30E-04	[kg]
Hydrogen	9.65E-01	[kg]
Hydrogen bromine (hydrobromic acid)	6.33E-09	[kg]
Hydrogen chloride	6.12E-02	[kg]
Hydrogen cyanide (prussic acid)	1.23E-09	[kg]
Hydrogen fluoride	1.21E-02	[kg]
Hydrogen iodide	6.09E-12	[kg]
Hydrogen phosphorous	1.25E-10	[kg]
Hydrogen sulphide	9.31E-03	[kg]
Iodine	3.66E-04	[kg]
Isocyanide acid	1.25E-05	[kg]
Lead dioxide	5.06E-13	[kg]
Magnesium	6.31E-11	[kg]
Nitrate	5.17E-06	[kg]
Nitrogen (atmospheric nitrogen)	2.76E-03	[kg]
Nitrogen dioxide	7.34E-04	[kg]
Nitrogen monoxide	3.79E-10	[kg]
Nitrogen oxides	5.00E+00	[kg]
Nitrous oxide (laughing gas)	9.70E-02	[kg]
Oxygen	3.98E-03	[kg]
Ozone	6.20E-04	[kg]
Phosphorus	4.75E-03	[kg]
Scandium	1.74E-06	[kg]
Silicium tetrafluoride	-4.44E-07	[kg]
Sodium chlorate	4.24E-04	[kg]
Sodium dichromate	-2.78E-06	[kg]
Sodium formate	-1.70E-04	[kg]
Sodium hydro	1.45E-06	[kg]
Steam	5.03E+00	[kg]
Strontium	6.39E-04	[kg]
Sulphate	3.83E-09	[kg]
Sulphur dioxide	3.16E+00	[kg]
Sulphur hexafluoride	2.42E-05	[kg]
Sulphuric acid	3.46E-07	[kg]
Tin oxide	4.40E-14	[kg]
Zinc oxide	8.81E-14	[kg]
Zinc sulphate	1.55E-08	[kg]

Organic emissions to air (group VOC)	**5.24E+00**	[kg]
Group NMVOC to air	**1.26E+00**	[kg]
Group PAH to air	**7.20E-04**	[kg]
Anthracene	2.36E-09	[kg]
Benzo{a}anthracene	1.19E-09	[kg]
Benzo{a}pyrene	7.26E-05	[kg]
Benzo{ghi}perylene	1.06E-09	[kg]
Benzofluoranthene	2.12E-09	[kg]
Chrysene	2.92E-09	[kg]
Dibenz(a)anthracene	6.60E-10	[kg]
Indeno[1,2,3-cd]pyrene	7.88E-10	[kg]
Naphthalene	2.48E-07	[kg]
Phenanthrene	7.78E-08	[kg]
Polycyclic aromatic hydrocarbons (PAH)	6.47E-04	[kg]
Halogenated organic emissions to air	**1.34E-03**	[kg]
1-Butanol	9.48E-12	[kg]
Acentaphthene	1.36E-09	[kg]
Acetaldehyde (Ethanal)	2.10E-03	[kg]
Acetic acid	7.39E-03	[kg]
Acetone (dimethylcetone)	6.69E-04	[kg]
Acetonitrile	1.06E-04	[kg]
Acrolein	2.90E-07	[kg]
Acrylic acid	1.44E-07	[kg]
Aldehyde (unspecified)	3.03E-05	[kg]
Alkane (unspecified)	3.64E-02	[kg]
Alkene (unspecified)	5.74E-02	[kg]
Aromatic hydrocarbons (unspecified)	1.08E-02	[kg]
Benzaldehyde	7.88E-08	[kg]
Benzene	2.82E-02	[kg]
Butadiene	1.82E-09	[kg]
Butane	1.04E-02	[kg]
Butane (n-butane)	5.36E-06	[kg]
Butanone (methyl ethyl ketone)	2.62E-04	[kg]
Butene	8.33E-05	[kg]
Butylene glycol (butane diol)	3.06E-09	[kg]
butyrolactone	8.85E-10	[kg]
Chlorosilane, trimethyl-	2.59E-09	[kg]
Cumene (isopropylbenzene)	3.47E-04	[kg]
Cycloalkanes (unspec.)	8.04E-05	[kg]
Cyclohexane (hexahydro benzene)	4.50E-10	[kg]
Diethylamine	8.90E-16	[kg]
Ethane	6.19E-02	[kg]
Ethanol	2.32E-04	[kg]
Ethene (ethylene)	6.21E-02	[kg]
Ethine (acetylene)	1.02E-02	[kg]
Ethyl benzene	5.40E-04	[kg]
Ethylene acetate (ethyl acetate)	2.62E-04	[kg]
Ethylene oxide	4.40E-05	[kg]

Ethylenediamine	5.26E-06	[kg]
Fluoranthene	7.68E-09	[kg]
Fluorene	2.44E-08	[kg]
Formaldehyde (methanal)	5.32E-03	[kg]
Formic acid (methane acid)	7.11E-04	[kg]
Furan	2.02E-04	[kg]
Heptane (isomers)	9.00E-04	[kg]
Hexamethylene diamine (HMDA)	1.90E-12	[kg]
Hexane (isomers)	9.64E-03	[kg]
Hydrocarbons, aromatic	9.09E-04	[kg]
Isoprene	9.37E-06	[kg]
Mercaptan (unspecified)	3.68E-06	[kg]
Methacrylate	1.64E-07	[kg]
Methanol	4.08E-03	[kg]
Methyl amine	3.19E-10	[kg]
Methyl borate	5.52E-14	[kg]
Methyl formate	6.34E-10	[kg]
Methyl tert-butylether	1.47E-05	[kg]
Monoethanolamine	2.50E-02	[kg]
NMVOC (unspecified)	8.31E-01	[kg]
Octane	3.14E-05	[kg]
Pentane (n-pentane)	1.10E-02	[kg]
Phenol (hydroxy benzene)	1.18E-03	[kg]
Propane	4.14E-02	[kg]
Propanol (iso-propanol; isopropanol)	5.57E-05	[kg]
Propene (propylene)	1.70E-02	[kg]
Propionaldehyde	9.75E-08	[kg]
Propionic acid (propane acid)	6.60E-05	[kg]
Propylene oxide	1.33E-05	[kg]
Styrene	1.78E-06	[kg]
Terpenes	8.86E-05	[kg]
Toluene (methyl benzene)	8.34E-03	[kg]
Trimethylbenzene	4.29E-13	[kg]
Xylene (dimethyl benzene)	1.22E-02	[kg]
Xylene (meta-Xylene; 1,3-Dimethylbenzene)	1.79E-03	[kg]
Hydrocarbons (unspecified)	8.78E-04	[kg]
Methane	3.52E+00	[kg]
Methane (biotic)	4.61E-01	[kg]
VOC (unspecified)	2.04E-05	[kg]
Particles to air	**3.45E+00**	[kg]
Aluminum	1.52E-01	[kg]
Dust (> PM10)	2.01E+00	[kg]
Dust (PM10)	4.28E-04	[kg]
Dust (PM2,5 - PM10)	2.84E-01	[kg]
Dust (PM2.5)	9.96E-01	[kg]
Dust (unspecified)	3.71E-03	[kg]
Ethyl cellulose	5.23E-07	[kg]
Metals (unspecified)	2.82E-06	[kg]
Wood (dust)	1.63E-11	[kg]

Table 8.4: Inventory list – Emissions to freshwater.

		[unit]
EMISSIONS TO FRESHWATER	8.32E+00	[kg]
Ecoinvent long-term to fresh water	**8.20E+00**	[kg]
Aluminum (+III)	4.95E+00	[kg]
Ammonium / ammonia	1.34E-02	[kg]
Antimony	1.24E-03	[kg]
Arsenic (+V)	3.59E-04	[kg]
Barium	7.14E-02	[kg]
Beryllium	4.74E-04	[kg]
Bromine	5.34E-04	[kg]
Cadmium (+II)	-1.13E-04	[kg]
Calcium (+II)	-2.35E+00	[kg]
Chromium (+VI)	3.58E-03	[kg]
Cobalt	1.36E-03	[kg]
Copper (+II)	5.95E-02	[kg]
Fluoride	4.55E-02	[kg]
Hydrogen sulphide	-1.64E-02	[kg]
Iron	1.07E+00	[kg]
Lead (+II)	1.55E-02	[kg]
Magnesium (+III)	1.64E+00	[kg]
Manganese (+II)	-5.15E-01	[kg]
Mercury (+II)	4.61E-05	[kg]
Molybdenum	1.67E-03	[kg]
Nickel (+II)	1.13E-02	[kg]
Nitrate	6.83E-02	[kg]
Nitrite	7.29E-04	[kg]
Nitrogen organic bounded	2.18E-02	[kg]
Phosphate	3.46E-02	[kg]
Potassium	-8.43E-01	[kg]
Selenium	9.30E-04	[kg]
Silver	3.74E-05	[kg]
Strontium	4.19E-02	[kg]
Sulphate	3.87E+00	[kg]
Thallium	4.78E-04	[kg]
Tin (+IV)	2.47E-03	[kg]
Vanadium (+III)	3.45E-03	[kg]
Zinc (+II)	-4.25E-03	[kg]
2-Methyl-4-isothiazolin-3-one (MI)	2.93E-04	[kg]
5-Chloro-2-methyl-4-isothiazolin-3-one (CMI)	8.77E-04	[kg]
Hydroquinone	1.21E-03	[kg]
Sodium-dodecyl-diphenyloxide-disulphonate	3.00E-05	[kg]
Water	1.14E-01	[kg]
Emissions to sea water	7.82E+00	[kg]

Table 8.5: Inventory list – Emissions to sea water.

		[unit
EMISSIONS TO SEA WATER	**7.82E+00**	[kg]
Analytical measures to sea water	**5.98E+00**	[kg]
Adsorbable organic halogen compounds (AOX)	4.71E-07	[kg]
Biological oxygen demand (BOD)	2.24E+00	[kg]
Chemical oxygen demand (COD)	1.32E-01	[kg]
Total dissolved organic bounded carbon	4.22E-02	[kg]
Total organic bounded carbon	3.57E+00	[kg]
Heavy metals to sea water	**3.22E-02**	[kg]
Arsenic (+V)	2.07E-05	[kg]
Cadmium (+II)	6.57E-05	[kg]
Cesium	1.11E-06	[kg]
Chromium (unspecified)	2.44E-06	[kg]
Cobalt	4.02E-06	[kg]
Copper (+II)	4.95E-03	[kg]
Iron	1.09E-04	[kg]
Lead (+II)	2.66E-05	[kg]
Manganese (+II)	5.34E-05	[kg]
Mercury (+II)	8.67E-07	[kg]
Molybdenum	2.48E-07	[kg]
Nickel (+II)	8.55E-04	[kg]
Selenium	3.71E-07	[kg]
Silver	6.66E-07	[kg]
Strontium	2.01E-03	[kg]
Tin (+IV)	3.18E-09	[kg]
Titanium	1.44E-07	[kg]
Vanadium (+III)	3.49E-06	[kg]
Zinc (+II)	2.41E-02	[kg]
Inorganic emissions to sea water	**1.64E+00**	[kg]
Aluminum (+III)	5.81E-04	[kg]
Ammonia	3.10E-07	[kg]
Ammonium / ammonia	1.28E-04	[kg]
Barium	1.11E-03	[kg]
Barytes	2.94E-02	[kg]
Beryllium	2.29E-07	[kg]
Boron	1.01E-05	[kg]
Bromine	7.74E-04	[kg]
Calcium (+II)	9.12E-03	[kg]
Carbonate	9.26E-03	[kg]
Chloride	1.29E+00	[kg]
Cyanide	8.19E-03	[kg]
Fluoride	-1.39E-04	[kg]
Hypochlorite	1.12E-04	[kg]
Iodide	1.11E-04	[kg]
Magnesium	6.15E-03	[kg]
Nitrate	4.57E-04	[kg]
Nitrite	5.03E-06	[kg]
Nitrogen	7.48E-06	[kg]
Nitrogen organic bounded	2.41E-04	[kg]
Phosphate	-1.11E-03	[kg]
Phosphorus	9.65E-06	[kg]
Potassium	4.70E-03	[kg]

Sodium (+I)	3.39E-01	[kg]
Sulphate	-5.25E-02	[kg]
Sulphide	1.68E-03	[kg]
Sulphite	-2.54E-19	[kg]
Sulphur	2.39E-05	[kg]
Organic emissions to sea water	**5.07E-02**	[kg]
Halogenated organic emissions to sea water	**4.30E-12**	[kg]
Hydrocarbons to sea water	**5.07E-02**	[kg]
Acenaphthene	2.63E-07	[kg]
Acenaphthylene	9.77E-08	[kg]
Acetic acid	6.82E-07	[kg]
Alkane (unspecified)	1.44E-04	[kg]
Alkene (unspecified)	1.33E-05	[kg]
Anthracene	5.93E-08	[kg]
Aromatic hydrocarbons (unspecified)	6.35E-04	[kg]
Benzene	1.24E-04	[kg]
Benzo{a}anthracene	5.79E-08	[kg]
Benzofluoranthene	6.49E-08	[kg]
Chrysene	3.28E-07	[kg]
Cresol (methyl phenol)	2.34E-09	[kg]
Ethyl benzene	3.01E-05	[kg]
Fatty acids (calculated as total carbon)	6.44E-03	[kg]
Fluoranthene	6.76E-08	[kg]
Glutaraldehyde	3.63E-06	[kg]
Hexane (isomers)	2.55E-10	[kg]
Hydrocarbons (unspecified)	5.49E-04	[kg]
Methanol	6.96E-05	[kg]
Methyl tert-butylether	7.83E-06	[kg]
Oil (unspecified)	4.16E-02	[kg]
Phenol (hydroxy benzene)	2.16E-04	[kg]
Polycyclic aromatic hydrocarbons (PAH, unspec.)	8.83E-06	[kg]
Toluene (methyl benzene)	1.84E-04	[kg]
Triethylene glycol	5.77E-05	[kg]
VOC (unspecified)	3.87E-04	[kg]
Xylene (isomers; dimethyl benzene)	1.48E-04	[kg]
Naphthalene	7.88E-06	[kg]
Other emissions to sea water	**1.03E-05**	[kg]
Pesticides to sea water	**1.03E-05**	[kg]
Tributyltinoxide	1.03E-05	[kg]
Particles to sea water	**1.12E-01**	[kg]
Solids (suspended)	1.12E-01	[kg]

Table 8.6: Inventory list – Emissions to agricultural soil.

		[unit]
EMISSIONS TO AGRICULTURAL SOIL	**3.02E-01**	[kg]
Heavy metals to agricultural soil	**3.76E-03**	[kg]
Antimony	5.70E-10	[kg]
Arsenic (+V)	4.03E-07	[kg]
Cadmium (+II)	4.23E-06	[kg]
Chromium (unspecified)	2.85E-05	[kg]
Cobalt	6.09E-07	[kg]
Copper (+II)	8.34E-05	[kg]
Iron	1.81E-03	[kg]
Lead (+II)	2.38E-05	[kg]
Manganese (+II)	6.05E-04	[kg]
Mercury (+II)	1.56E-06	[kg]
Molybdenum	1.51E-07	[kg]
Nickel (+II)	2.38E-05	[kg]
Silver	1.15E-12	[kg]
Strontium	1.29E-07	[kg]
Tin (+IV)	1.62E-07	[kg]
Titanium	4.16E-05	[kg]
Vanadium (+III)	1.19E-06	[kg]
Zinc (+II)	1.14E-03	[kg]
Inorganic emissions to agricultural soil	**1.55E-03**	[kg]
Aluminum	7.51E-04	[kg]
Barium	4.60E-08	[kg]
Chlorine	9.64E-05	[kg]
Phosphorus	2.95E-04	[kg]
Sulphur	4.06E-04	[kg]
Sulphuric acid	1.87E-10	[kg]
Organic emissions to agricultural soil	**2.65E-01**	[kg]
Carbon (unspecified)	9.49E-03	[kg]
Metaldehyde	3.73E-06	[kg]
Oil (unspecified)	2.55E-01	[kg]
Sodium-dodecyl-diphenyloxide-disulphonate	4.95E-04	[kg]
Other emissions to agricultural soil	**3.15E-02**	[kg]
Pesticides to agricultural soil	**1.71E-02**	[kg]
2,4-Dichlorophenoxyacetic acid (2,4-D)	3.58E-05	[kg]
Aclonifen	3.78E-05	[kg]
Aldrin	2.28E-06	[kg]
Atrazine	5.99E-07	[kg]
Benomyl	2.27E-07	[kg]

Bentazone	1.93E-05	[kg]
Carbendazim	1.51E-06	[kg]
Carbetamide	1.24E-05	[kg]
Carbofuran	1.25E-04	[kg]
Chlormequat	1.57E-05	[kg]
Chlorothalonil	5.33E-03	[kg]
Clomazone	1.32E-07	[kg]
Cyfluthrin	3.77E-07	[kg]
Cypermethrin	2.81E-05	[kg]
Deltamethrin	2.24E-07	[kg]
Dimethachlor	6.22E-06	[kg]
Dinoseb	2.25E-12	[kg]
Fenpiclonil	2.11E-04	[kg]
Fluazifop-p-butyl	1.35E-06	[kg]
Glyphosate	2.54E-04	[kg]
Iprodione	5.22E-10	[kg]
Lambda-cyhalothrin	1.56E-07	[kg]
Linuron	2.91E-04	[kg]
Mancozeb	6.93E-03	[kg]
Metazachlor	5.78E-05	[kg]
Metconazole	2.11E-06	[kg]
Metolachlor	2.11E-03	[kg]
Metribuzin	2.44E-04	[kg]
Napropamide	1.09E-05	[kg]
Orbencarb	1.32E-03	[kg]
Pirimicarb	1.82E-06	[kg]
Prochloraz	5.81E-07	[kg]
Propaquizafop	3.13E-06	[kg]
Quinmerac	7.22E-06	[kg]
Quizalofop-P	2.78E-07	[kg]
Tau-fluvalinate	2.27E-07	[kg]
Tebuconazole	6.77E-06	[kg]
Tebutam	1.56E-05	[kg]
Teflubenzuron	1.63E-05	[kg]
Thiophanat-methyl	2.27E-06	[kg]
Thiram	4.03E-07	[kg]
Trifluralin	9.93E-06	[kg]
Trinexapac-ethyl	7.79E-08	[kg]
Vinclozolin	2.11E-06	[kg]
Different pollutants	4.35E-09	[kg]
Different pollutants	1.44E-02	[kg]

Table 8.7: Inventory list – Emissions to agricultural soil.

		[unit]
EMISSIONS TO INDUSTRIAL SOIL	**4.19E+01**	[kg]
Emissions to fresh water	**4.16E+01**	[kg]
Analytical measures to fresh water	**2.53E+01**	[kg]
Adsorbable organic halogen compounds (AOX)	1.38E-01	[kg]
Biological oxygen demand (BOD)	-3.00E-01	[kg]
Chemical oxygen demand (COD)	2.17E+01	[kg]
Solids (dissolved)	4.24E+00	[kg]
Total dissolved organic bounded carbon	5.63E-01	[kg]
Total organic bounded carbon	-1.00E+00	[kg]
Heavy metals to fresh water	**1.01E+00**	[kg]
Antimony	7.37E-04	[kg]
Arsenic (+V)	1.28E-03	[kg]
Cadmium (+II)	1.14E-04	[kg]
Cesium	2.68E-06	[kg]
Chromium (+III)	3.53E-08	[kg]
Chromium (+VI)	1.92E-03	[kg]
Chromium (unspecified)	1.28E-05	[kg]
Cobalt	2.95E-06	[kg]
Copper (+II)	4.56E-03	[kg]
Heavy metals to water (unspecified)	5.68E-09	[kg]
Iron	9.70E-01	[kg]
Lead (+II)	1.30E-04	[kg]
Manganese (+II)	-1.64E-02	[kg]
Mercury (+II)	2.91E-05	[kg]
Molybdenum	8.43E-04	[kg]
Nickel (+II)	1.52E-03	[kg]
Selenium	4.67E-04	[kg]
Silver	4.14E-04	[kg]
Strontium	5.71E-03	[kg]
Thallium	1.94E-06	[kg]
Tin (+IV)	4.72E-06	[kg]
Titanium	7.46E-05	[kg]
Tungsten	8.23E-05	[kg]
Vanadium (+III)	4.98E-05	[kg]
Zinc (+II)	3.80E-02	[kg]
Inorganic emissions to fresh water	**1.43E+01**	[kg]
Acid (calculated as H+)	5.12E-03	[kg]
Aluminum (+III)	1.32E-02	[kg]
Ammonia	4.56E-07	[kg]
Ammonium / ammonia	3.59E-02	[kg]
Barium	3.27E-03	[kg]
Beryllium	4.64E-07	[kg]
Boron	2.13E-03	[kg]
Bromate	2.85E-03	[kg]
Bromine	3.40E-03	[kg]

Calcium (+II)	1.59E-01	[kg]
Carbonate	1.16E-02	[kg]
Chlorate	4.25E-02	[kg]
Chloride	7.98E+00	[kg]
Chlorine (dissolved)	1.98E-04	[kg]
Cyanide	8.05E-03	[kg]
Dichromate	2.73E-06	[kg]
Fluoride	4.61E-03	[kg]
Fluorine	8.55E-08	[kg]
Hexaflourosilicates	2.34E-04	[kg]
Hydrogen chloride	1.64E-09	[kg]
Hydrogen fluoride (hydrofluoric acid)	1.13E-08	[kg]
Hydrogen peroxide	-8.83E-04	[kg]
Hydrogen sulphide	1.72E-05	[kg]
Hydroxide	1.17E-05	[kg]
Hypochlorite	1.63E-04	[kg]
Inorganic salts and acids (unspecified)	7.00E-04	[kg]
Iodide	3.15E-04	[kg]
Lithium	3.27E-06	[kg]
Magnesium (+III)	2.09E-02	[kg]
Magnesium chloride	1.23E-11	[kg]
Metal ions (unspecific)	1.00E-10	[kg]
Neutral salts	7.07E-08	[kg]
Nitrate	1.09E+00	[kg]
Nitrite	4.34E-04	[kg]
Nitrogen	1.92E-01	[kg]
Nitrogen organic bounded	7.04E-04	[kg]
Phosphate	9.12E-03	[kg]
Phosphorus	1.51E-02	[kg]
Potassium	1.65E-01	[kg]
Rubidium	3.81E-05	[kg]
Scandium	4.13E-05	[kg]
Silicate particles	3.40E-10	[kg]
Sodium (+I)	1.61E+00	[kg]
Sodium chloride (rock salt)	3.37E-11	[kg]
Sodium hypochlorite	1.82E-07	[kg]
Sulphate	2.96E+00	[kg]
Sulphide	3.01E-03	[kg]
Sulphite	8.65E-04	[kg]
Sulphur	3.75E-03	[kg]
Sulphuric acid	2.11E-07	[kg]
Organic emissions to fresh water	**2.49E-01**	[kg]
Halogenated organic emissions to fresh water	1.62E-04	[kg]
Hydrocarbons to fresh water	2.47E-01	[kg]
1-Butanol	1.08E-06	[kg]
Acetaldehyde (Ethanal)	1.94E-06	[kg]
Acetone (dimethylcetone)	3.04E-11	[kg]
Acrylic acid	3.41E-07	[kg]
Carbon, organically bound	1.68E-04	[kg]
Cumene (isopropylbenzene)	8.35E-04	[kg]
Ethylenediamine	1.28E-05	[kg]

Methyl acrylate	3.20E-06	[kg]
Methyl amine	7.66E-10	[kg]
Methyl isobutyl ketone	1.28E-11	[kg]
Methylformat	2.53E-10	[kg]
Naphthalene	4.00E-07	[kg]
n-Butyl acetate	1.41E-06	[kg]
Organic chlorine compounds (unspecified)	5.78E-12	[kg]
Organic compounds (dissolved)	3.13E-06	[kg]
Organic compounds (unspecified)	1.26E-11	[kg]
Particles to fresh water	**7.38E-01**	[kg]
Metals (unspecified)	4.27E-04	[kg]
Soil loss by erosion into water	2.17E-07	[kg]
Solids (suspended)	7.37E-01	[kg]
Suspended solids, unspecified	-5.78E-18	[kg]
Heavy metals to industrial soil	**5.42E-02**	[kg]
Arsenic (+V)	8.40E-07	[kg]
Cadmium (+II)	1.59E-07	[kg]
Chromium (+III)	1.47E-11	[kg]
Chromium (+VI)	8.45E-05	[kg]
Chromium (unspecified)	1.60E-05	[kg]
Cobalt	8.74E-08	[kg]
Copper (+II)	6.13E-05	[kg]
Iron	5.19E-02	[kg]
Lead (+II)	5.79E-06	[kg]
Manganese (+II)	8.49E-05	[kg]
Mercury (+II)	9.91E-11	[kg]
Nickel (+II)	3.23E-06	[kg]
Strontium	1.61E-03	[kg]
Zinc (+II)	4.29E-04	[kg]
Inorganic emissions to industrial soil	**1.83E-01**	[kg]
Aluminum	2.10E-03	[kg]
Aluminum (+III)	5.50E-06	[kg]
Ammonia	2.52E-03	[kg]
Barium	1.05E-03	[kg]
Bromide	7.49E-07	[kg]
Calcium (+II)	8.38E-03	[kg]
Chloride	8.74E-04	[kg]
Chlorine	1.55E-01	[kg]
Fluoride	1.87E-04	[kg]
Magnesium (+III)	1.68E-03	[kg]
Phosphorus	3.64E-04	[kg]
Potassium (+I)	1.37E-03	[kg]
Sodium (+I)	8.07E-03	[kg]
Sulphate	7.98E-05	[kg]
Sulphide	4.79E-04	[kg]
Sulphur	1.26E-03	[kg]
Organic emissions to industrial soil	**7.19E-03**	[kg]
Carbon (unspecified)	6.29E-03	[kg]
Oil (unspecified)	9.07E-04	[kg]
Other emissions to industrial soil	**2.71E-04**	[kg]
Pesticides to industrial soil	**2.51E-05**	[kg]
Glyphosate	2.51E-05	[kg]
Different pollutants	4.88E-07	[kg]
Different pollutants	2.45E-04	[kg]