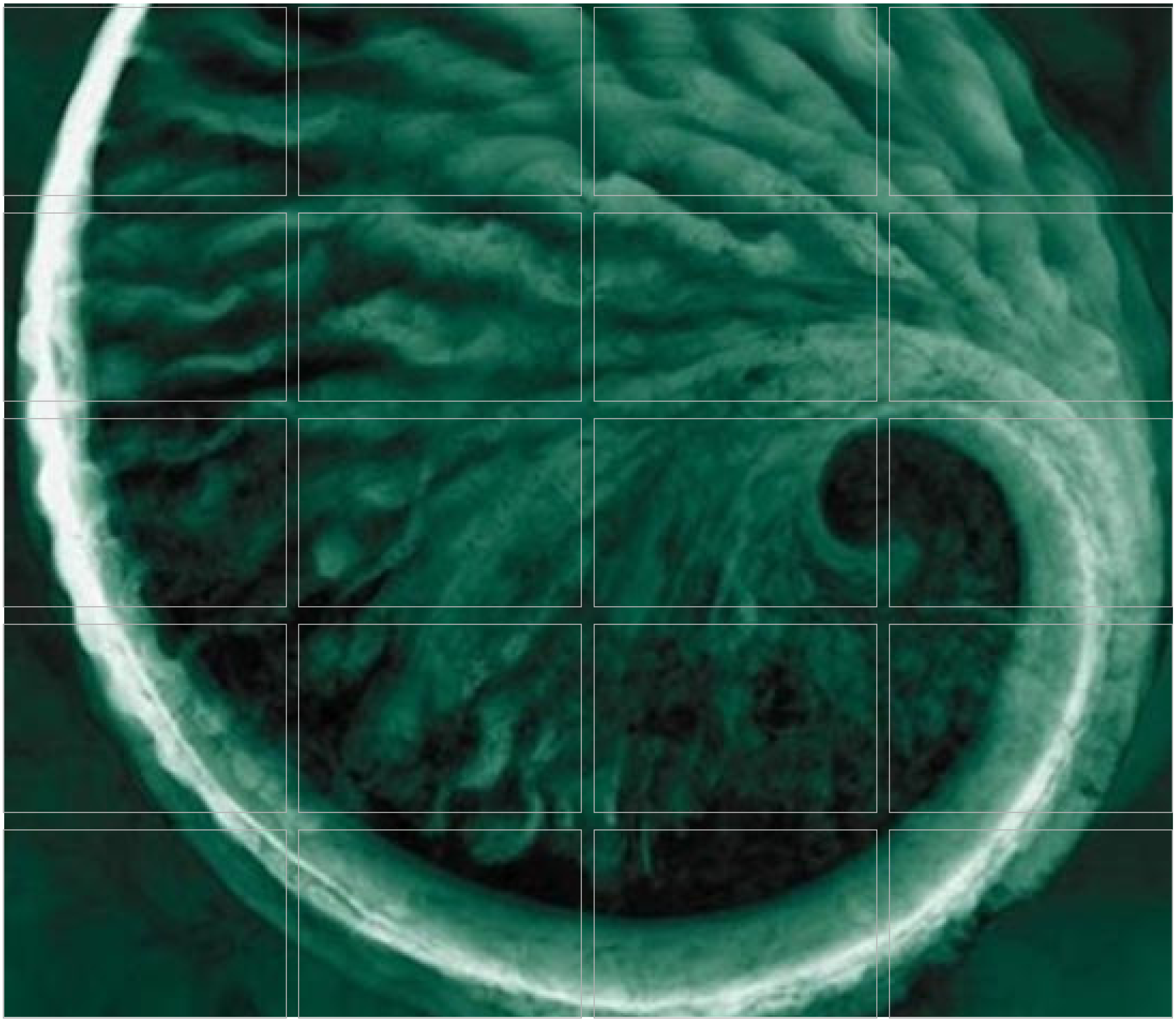

Life Cycle Assessment of Tissue Products

Final Report

December 2007

Delivering sustainable solutions in a more competitive world

ERM

Kimberly Clark

Life Cycle Assessment of Tissue Products

Final Report

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Prepared by Jacob Madsen

For and on behalf of Environmental Resources Management
Approved by: Simon Aumonier ___________
Signed: ______________________________
Position: Partner ________________________
Date: 7th December 2007__________________

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1 INTRODUCTION

1.1 PROJECT BACKGROUND

Kimberly-Clark (K-C) is a leading global health and hygiene company with operations in 37 countries, products sold in more than 150 countries and over 56,000 employees worldwide. K-C tissue products help to ensure health, hygiene, and well-being at home (e.g. facial tissues, bathroom tissue and paper towel) and away from home (e.g. hand towels, wipers and washroom products. These tissue products contain virgin wood fibre, fibres derived from paper recycling operations or a combination of the two. The use of recycled material in K-C products is driven by a long standing commitment to make the best use of all available resources that balance the sometimes competing business requirements of responding to customer and consumer mandates, expectations and perceptions that recycled materials offer environmental benefits, meeting product performance requirements in a highly competitive market and controlling raw material costs to maintain profit margins. When not using recycled fibre, K-C's stated goal is to purchase all of its fibre from suppliers certified to one of five forest certification schemes with preference for wood fibre certified under the Forest Stewardship Council (FSC) standard where FSC fibre is available and meets product performance requirements and competitive market solutions. Again, this goal is designed to deliver the best use of available resources and respond to perceived environmental benefits. As part of its continuing fibre purchasing and policy evaluations, K-C is interested in developing a more complete understanding of the environmental performance of tissue products containing responsibly managed virgin and recycled fibres.

This project is a continuation of K-C's historic leadership in the application of sound environmental science in decision making. Development and demonstration of Life Cycle Assessment (LCA) methods at K-C began in the early 1990s with Scott Paper representatives attending initial SETAC meetings on the codification of LCA and conducting a series of demonstration projects. Currently, K-C LCA efforts are focused on integrating environmental information into the product development process as part of the Vision 2010 Design for Environment programme.

This study will maintain the highest scientific standards for the practice of LCA (as established in the ISO 14040 series documents) consistent with delivering to internal decision makers reliable product insights while providing for the possible external communication of results. Therefore, Environmental Resource Management Limited (ERM) has been retained by K-C to perform the study and independent critical review by a panel of experts will take place throughout the project.

1.2 *LIFE CYCLE ASSESSMENT*

The international standard for Life Cycle Assessment, ISO14040 (ISO, 1997), states that: "*LCA is a technique for assessing the environmental aspects and potential impacts associated with a product by:*

- *compiling an inventory of relevant inputs and outputs of a product system;*
- *evaluating the potential environmental impacts associated with those inputs and outputs; and*
- *interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study*."

LCA studies the environmental aspects and potential impacts throughout a product's life (ie from cradle to grave), from raw material acquisition through production, use and disposal. The general impacts needing consideration include resource use, human health, and ecological consequences.

The key elements of an LCA are:
- goal and scope;
- life cycle inventory analysis;
- life cycle impact assessment;
- life cycle interpretation;
- reporting; and
- critical review.

2 GOAL AND SCOPE

2.1 GOAL DEFINITION

The goal of this study was to determine the environmental performance of tissue products manufactured by K-C and the environmental trade-offs associated with the use of virgin fibres and recycled fibres in tissue products. A differentiation between markets (home and business), as well as between North America and Europe, provides for a greater variation in the use of recycled fibres. The inclusion of both consumer and away from home products, as well as the European and North American markets provides variation in product market conditions, product designs (and design goals), recycling infrastructure and utility infrastructure. Overall, we believe this scope will result in a more complete understanding of the trade-off in fibre selections.

The results of the studies of European (EU 25) and the North American products were reported separately. *Table 2.1* details the tissue products under study and their geographical distribution. A presentation of the products and their functions is detailed in *section 2.2.2.*

Table 2.1 Geographical distribution of the tissue paper under study

	North America (NA)	Europe (EUR)
Bathroom tissue	√	
Washroom towel	√	
Facial tissue	√	
Kitchen towel	√	
Folded toilet tissue		√
Roll toilet tissue		√
Commercial wipers		√

Standard product names are used to refer to the products listed in *Table 2.1*. These names reflect the cultural norms and practices in the country of sales. In North America, rolled tissue products for use in perineal wiping are commonly referred to as bathroom tissue. In Europe, these products are called toilet tissue. The European toilet tissue market also includes folded sheet products.

As the study will be used externally, it will undergo critical review by an external review panel in accordance with the ISO standard on LCA.

2.2 SCOPE OF THE STUDY

2.2.1 *Functions of the product system*

When assessing different products, it is important that the functions of the different product systems are equivalent, in order to allow clear interpretation of the results. The function of tissue paper is manifold and normally separated into primary and secondary functions.

Primary functions include:

- hygiene;
- absorbency;
- strength; and
- softness.

Secondary functions include:

- image;
- luxury;
- quality; and
- consumer satisfaction.

The product systems selected for the study are based on their relative interest to KC businesses. All products are either currently produced, or sufficient data are available on recent production, such that data collection requirements can be supported from manufacturing experience.

2.2.2 Functional units

The functional units defined below capture the primary functions of the tissue paper types by referring to a specific type of product.

In the study, secondary functions as listed above were taken into consideration in the selection of products under study. Whenever possible, the products studied were selected based on their ability to provide comparable performance against both the primary and secondary functions.

Table 2.2 Functional Units

	Functional Unit	Reference flow	Additional information
NA Bathroom tissue	One year of bathroom use for a large, pragmatic US household with multiple children ages 6-17.	40,000 sheets of regular/economy bathroom tissue	K-C market research suggests that large US households, especially those with multiple children between the ages of 6 and 17, tend to purchase bathroom tissue from categories considered 'economy' or 'regular'. These households also tend to be heavy purchasers of bathroom tissue (defined as more than 40,000 sheets per year). Households in the heavy buyer category account for 66% of all bathroom tissue purchases nationally.
NA Washroom towel	One year of hand drying for 50 workers in a typical US commercial office washroom.	72,000 linear feet (app. 22 km) of 8 inch (approximately 20 cm) wide hard roll towel	US office buildings frequently supply hard roll towels for use in hand drying. K-C market research suggests that typical office workers visit the washroom three times per day using 1.5 towels (~1.2 ft^2 (0.11 m^2)) per visit. Over a 260 day year, this results in an average of 965 ft^2 (89.8 m^2) of towel use per employee.
NA Facial tissue	One year of boxed facial tissue use in a large, affluent household in the Eastern US.	5,600 sheets of premium facial tissue	K-C market research suggests large households in the Eastern US tend to fall into the super heavy purchasing category, with more than 5,600 sheets of facial tissue per year (likely due to the high occurrence of cold and flu symptoms). Purchasers in this category consume 77% of all tissue sold. Affluent households tend to purchase more heavily from the premium and higher product tiers.
NA Kitchen towel	One year of surface cleaning and health and hygiene tasks in a pragmatic US household with three or more total members.	2,100 sheets of regular kitchen towel	K-C market research suggests that households with three or more members are more likely to show heavy consumption of paper towel (more than 2,100 sheets per year). These households represent 79% of all paper towel sales volume. These consumers are likely to carefully weigh their purchasing decisions to arrive at choices that balance performance and price.

	Functional Unit	Reference flow	Additional information
EUR Folded toilet tissue	One year of office washroom use by 50 men and 50 women in an image conscious UK business	73,000 ft (22,250 m) of premium folded toilet tissue	For an image conscious establishment, the use of high quality toilet tissues is consistent with conveying important business messages. This type of business is likely to purchase premium or super-premium toilet tissue. K-C research suggests men and women tend to use washrooms at varying rates. On average, male office employees visit the washroom 2 times per day while females visit 4.3 times per day. Average toilet tissue use per visit is 0.97 ft (app 0.3 m) per visit across both genders. Consistent with UK business practices, a work year is considered 240 days.
EUR Roll toilet tissue	One year of bathroom use in an average Dutch household	160 rolls of common toilet tissue (~26,000 sheets)	K-C market research suggests that Dutch households have a very pragmatic and rational approach to toilet tissue purchases. Dutch households also tend to purchase higher volumes of toilet tissues, buying an average of 160 rolls per year compared to a Northern European average of 140.
EUR Commercial wipers	1000 kg of absorbed kitchen spills (750 kg water, 250 kg oil), over the course of one year in a hygiene conscious European chain restaurant operation.	68,000 product A centre fed roll wiper sheets, or 82,000 Product B centre fed roll wiper sheets	As is the case for kitchen towels, wipers are used for cleaning under both wet and dry conditions. Strength when wet and dry, along with absorbency rate and capacity, are all important factors in determining the quality of wiper products. Some customers require 100% virgin fibres for use in food service cleaning while others do not. Users of 100% virgin products are expected to experience greater absorbency for both oil and water than users of 100% recycled fibre products. The difference in absorbency causes the two different reference flows.

2.2.3 *System boundaries*

The tissue paper systems investigated included all life cycle stages. All energy and materials used were traced back to the extraction of resources. Emissions from each life cycle stage were quantified. Waste management processes were included, and landfilling, incineration, composting and recycling were assessed.

The tissue paper systems assessed in the study is representative of those available on the European (EU 25) and US market. To ensure representative product systems, detailed questionnaires were sent to K-C's suppliers and a detailed data collection procedure was undertaken by K-C to collate data for the paper production in their own mills. Where specific production, processing and disposal data for a tissue paper system was not available, generic data was used, together with estimates based on the data gathered for the other tissue paper systems and from the literature.

Manufacture, maintenance and decommissioning of capital equipment

The manufacture, maintenance and decommissioning of capital equipment, such as buildings or machines, were not included in the investigated system. The reason for excluding capital equipment, besides the practical aspects, was that the environmental impact related to the functional unit is negligible.

Litter

Some of the tissue paper products in the current study will be used and discarded while the consumer is outside resulting in littering. The environmental impact associated with this is difficult to quantify (visual impact, aesthetics etc) and was not included in the study

Renewable/biogenic CO_2

In this study, renewable CO_2 was reported separately to fossil CO_2 and the focus is placed on fossil carbon balances and fossil CO_2 emissions.

When using natural resources such as wood for virgin fibres, it is important to define whether CO_2 uptake by trees should be included in the definition of the system boundaries. To leave this CO_2 uptake out, and to ignore renewable CO_2 emissions from global warming impact calculations, is sometimes described as a 'carbon neutral' approach.

In order to demonstrate carbon neutrality or otherwise, biogenic and fossil carbon should be measured, and sinks understood. All assumptions need to be recorded to ensure that we understand the nature and scale of uptake and release over time.

Geographic boundaries

The systems investigated represent the situation on either the US market or the European market (EU 25).

Technological boundaries

The systems investigated represent state of the art technologies. In the cases where this is different (eg the processing of Kraft pulp), it was reported.

Time boundaries

The systems investigated should represent the situation on these markets in 2007.

For landfill, the decomposition of biomass is assumed to take place within the time boundaries of the study (100 years). The gas generation phase associated with waste in landfill is considered to be complete within this timeframe. Due to uncertainties and lack of knowledge surrounding the proportion of the biogenic carbon in the tissue paper that will be degraded, we will assume, initially, that 100% of the biogenic carbon within the tissue is degraded to CO_2 and CH_4 within this timeframe. This assumption was tested through sensitivity analysis as a result of published research undertaken into the degradation of paper under anaerobic conditions.

Allocation procedures

Allocation is needed when a process has multiple outputs. This is carried out by dividing the total environmental impact of the process between the product outputs.

According to the ISO standard, allocation should preferably be avoided, which can be achieved through system expansion. System expansion is further described below.

When an allocation situation arises and system expansion is not applicable, it is suggested that allocation on the basis of mass is used. This is a practical approach which is often used in LCA.

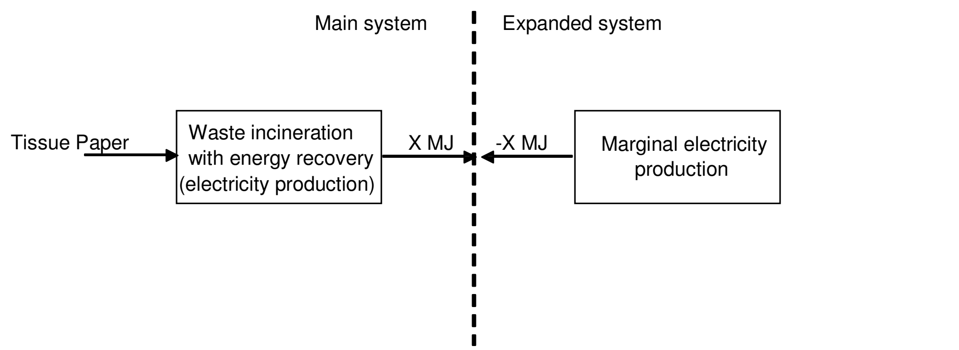
System expansion for recovered products

System expansion should be applied in the study when materials and energy generated in a product's life cycle are recovered, through recycling or energy recovery, for use in other product systems. The system boundaries should be expanded in order to include the benefits created from the recovery process.

If tissue paper is being incinerated after use, and electricity is generated, 'avoided' production of electricity should be included in the system. 'Avoided' electricity refers to electricity not having to be generated from other sources, since the energy content in the paper is used instead. A negative contribution is accounted for, thus improving the environmental profile of the tissue paper system. *Figure 2.1* illustrates system expansion for waste incineration of tissue paper with electricity production.

A marginal approach was taken for the replacement of energy, see the *Marginal approach* section below.

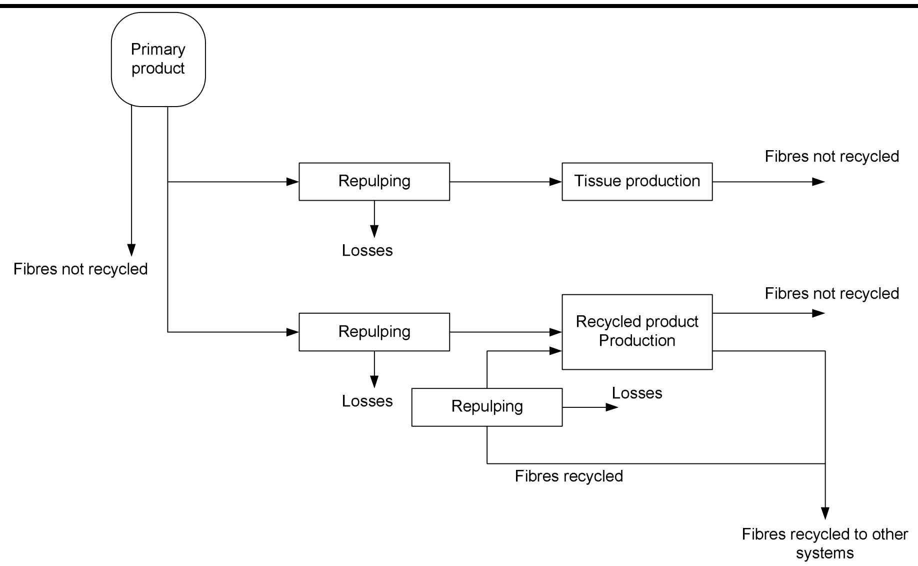
Figure 2.1 ***System expansion including energy recovered from incinerated tissue paper material***



Open loop recycling of waste paper into tissue

This systems expansion approach does not apply to the recovery and recycling of materials into tissue production as the study is comparing virgin production systems with recycled production systems. However, tissue production from waste paper presents an interesting case, as the recycling of waste paper into tissue, which by its very nature is disposed after use, results in the loss of that recycled fibre from future recycling. *Figure 2.2* presents the model for paper recycling as described in ISO14049.

Figure 2.2 Model for paper recycling



The modelling of open loop recycling of paper products to tissue paper is complex, since used tissue paper is discarded where recycled paper can be recycled, recovered and recycled a number of times. Therefore, it is considered that some account of the environmental impact associated with the loss of a fibre resource from other recycling systems should be made.

There is no widely accepted method for accounting for the reduction of fibre availability due to its loss through tissue manufacture. ISO14049 presents a solution through the partial allocation of the environmental impact of the waste paper's first life to the waste paper that is collected for tissue production. The allocation depends on the number of uses for which the fibre is recycled and the recovery rate for waste paper for recycling.

Metafore[1] concluded in their Fibre Cycle project that a fibre can be reused four to eight times notwithstanding that most paper is not recycled at all. The number of reuses is determined by the characteristics of the collecting system that recover paper, losses from the de-inking process and the decline in fibre strength. Fibre losses from using recovered fibres vary between 10% and 30% depending on the grade of paper that is produced.

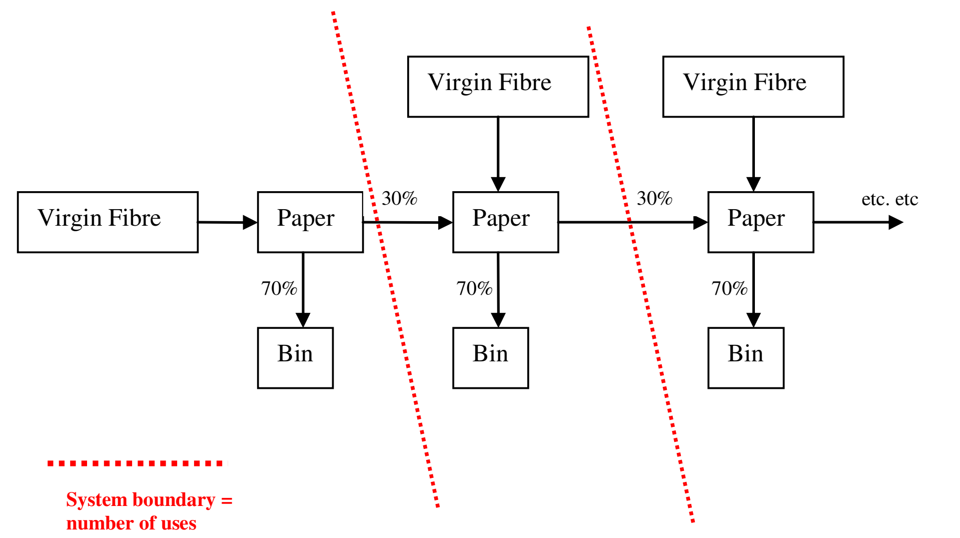
In the current study we have assessed two scenarios:

1. using the ISO14049 principles for allocating first life and assuming 6 uses (5 prior to tissue production); and
2. no allocation of first life (ie at point of collection waste paper is free of burden).

(1) [1] http://www.metafore.org/downloads/generic_cycle.pdf

If we apply a 30% recycling rate of paper this means that 70% is not recycled. After the first use, 9% (30% of 30%) is allocated to the previous life of the paper, thereafter 2.7% (9% of 30%) and so on, with the result that after 6 uses the allocation to previous lives will be minimal. This is detailed in *Figure 2.3.*

Figure 2.3 ***Paper recycling system***



The impact on the result from the different number of uses was assessed in the sensitivity analysis.

This approach provided a comprehensive overview of the environmental consequences/benefits related to the use of recycled fibres for tissue production.

Marginal approach

A marginal approach was taken for the replacement of recovered energy and recycled materials at end of life, using marginal production processes reflecting either the US or the EUR system in 2007.

Data coverage

The primary data collected from the KC suppliers and from KC's own mills represent the situation in the financial year 2006/07. Secondary data from public databases etc is not as up to date and wherever this data is used, it was justified according to other data quality indicators such as:

- reliability;
- temporal correlation;
- technological correlation;
- geographical correlation; and
- completeness.

2.2.4 *Product systems studied*

The study investigated the following tissue paper products to fulfil the goal of the study and identified as being of interest to the client.

NA bathroom tissue

	Code 1A	**Code 1B**
Manufacturing site	Mill NA-1	Mill NA-2
Furnish	100% Virgin	40% Recycled fibre
Technology	Technology A	Technology A
Ply	1	2
Basis weight (g/m^2)	17	30
Panel softness (fuzzy), up/down‡	5.9/4.7	6.1/5.6
Panel softness (gritty), up/down‡	3.6/6.0	4.7/6.3
Tensile strength (dry GMT), g/3"	830	1100

‡ More fuzziness and less grittiness are both associated with softness

No single quality parameter is strongly correlated with consumer preference for bathroom tissue. However, both softness and strength are considered important attributes. The bathroom tissue products included in this analysis have been designed to provide similar softness, while meeting the strength requirements of consumers. When these products were evaluated by a trained testing panel, they were determined to be roughly equivalent in overall softness. Although they show a significant difference in strength, both products provide sufficient strength for users in this product tier.

NA washroom towel

	Code 2A	**Code 2B**
Manufacturing site	Mill NA-1	Mill NA-3
Furnish	100% Virgin	45% Recycled fibre
Technology	Technology B	Technology B
Ply	1	1
Basis weight (g/m^2)	27	27
Absorbency (capacity), g/g	1.1	1.1
Tensile strength (dry GMT), g/3"¥	4200	4200

¥GMT = geometric mean tensile, g/3" is the standard unit of measure in the US, to convert from g/3" to N/m multiply by 0.1287

Strength and absorbency are important to purchasers and users of washroom towels. The product codes selected for study offer similar absorbent capacity (differing by <10%) and tensile strength. The minor differences in attributes for these products are not expected to influence user perception of performance.

NA facial tissue

	Code 3A	Code 3B
Manufacturing site	Mill NA-4	Mill NA-4
Furnish	100% Virgin	20% Recycled fibre
Technology	Technology C	Technology C
Ply	2	2
Basis weight (g/m^2)	29	29
Panel softness on Face‡	32.7	21.2
Panel Stiffness ‡	0.6	0.7

‡ Percentage of selections as the product officering the strongest performance against the attribute out of six tested.

Softness is an important attribute of premium facial tissue products. Consumers are known to be able to detect relatively small differences in softness between products. Although the products selected for analysis exhibit a trend of decreasing softness and increasing stiffness with increasing recycled fibre (RF) content, at a 20% RF level, the differences in softness on face observed by a trained testing panel were not considered significant. Similarly, the panel did not observe a significant difference in stiffness.

NA kitchen towel

	Code 4A	Code 4B
Manufacturing site	Mill NA-5	Mill NA-3
Furnish	100% Virgin fibre	40% Recycled fibre
Technology	Technology B	Technology B
Ply	1	1
Basis weight (g/m^2)	31	33
Absorbency (capacity), g/g	2.0	1.6
Tensile strength (dry GMT), g/3"	2 200	2 800
Tensile strength (wet CD), g/3"	750	660

Since paper towels are frequently used for cleaning in both wet and dry states, strength when wet and dry, as well as absorbency, are key attributes for users. The products selected for this analysis differ across these attributes with no one product offering superior performance across all parameters. Overall, the two products are judged, based on K-C experience, to provide comparable performance.

EUR folded toilet tissue

	Code 5A	Code 5B
Manufacturing site	Mill EU-1	Mill EU-1
Furnish	60% Recycled fibre	100% Recycled fibre
Technology	Technology A	Technology A
Ply	2	2
Basis weight (g/m^2)	36	32
Sheet length (mm)	190	190
Sheet width (mm)	120	120
Tensile strength (dry GMT), N/m	150	170

Both folded toilet tissue products selected for study provide quality and performance attributes consistent with premium tissue. Product Code 5A is designed to give image conscious customers a brighter white toilet tissue (generally associated with a more luxurious tissue). In order to provide a high brightness tissue, 40% virgin fibre is used in production. As a consequence of the use of virgin fibre, absorbency and softness are also expected to improve relative to Code 5B.

EUR roll toilet tissue

	Code 6A	**Code 6B**
Manufacturing site	Mill EU-2	Mill EU-2
Furnish	100% Virgin	20% Recycled fibre‡
Technology	Technology B	Technology B
Ply	1	1
Basis weight (g/m²)	34	34
Tensile strength (dry GMT), N/m	140	140

‡Up to 20% RF

The bathroom tissue products included in this analysis represent a standard product and a situational variation accepted under product quality tolerances. As a strategy to manage production costs and supply constraints, up to 20% alternative fibre (either recycled, hardwood, or newsprint) were added on occasion to the standard product. The occasional substitution of recycled fibre is shown here as a separate product for purposes of this study. Previous research on 1 ply, Technology B products has shown that most people do not notice a difference in tissue quality at 20% RF inclusion. The study of a situational product is considered the best approach available at this time for examining consumer products of comparable quality in Europe.

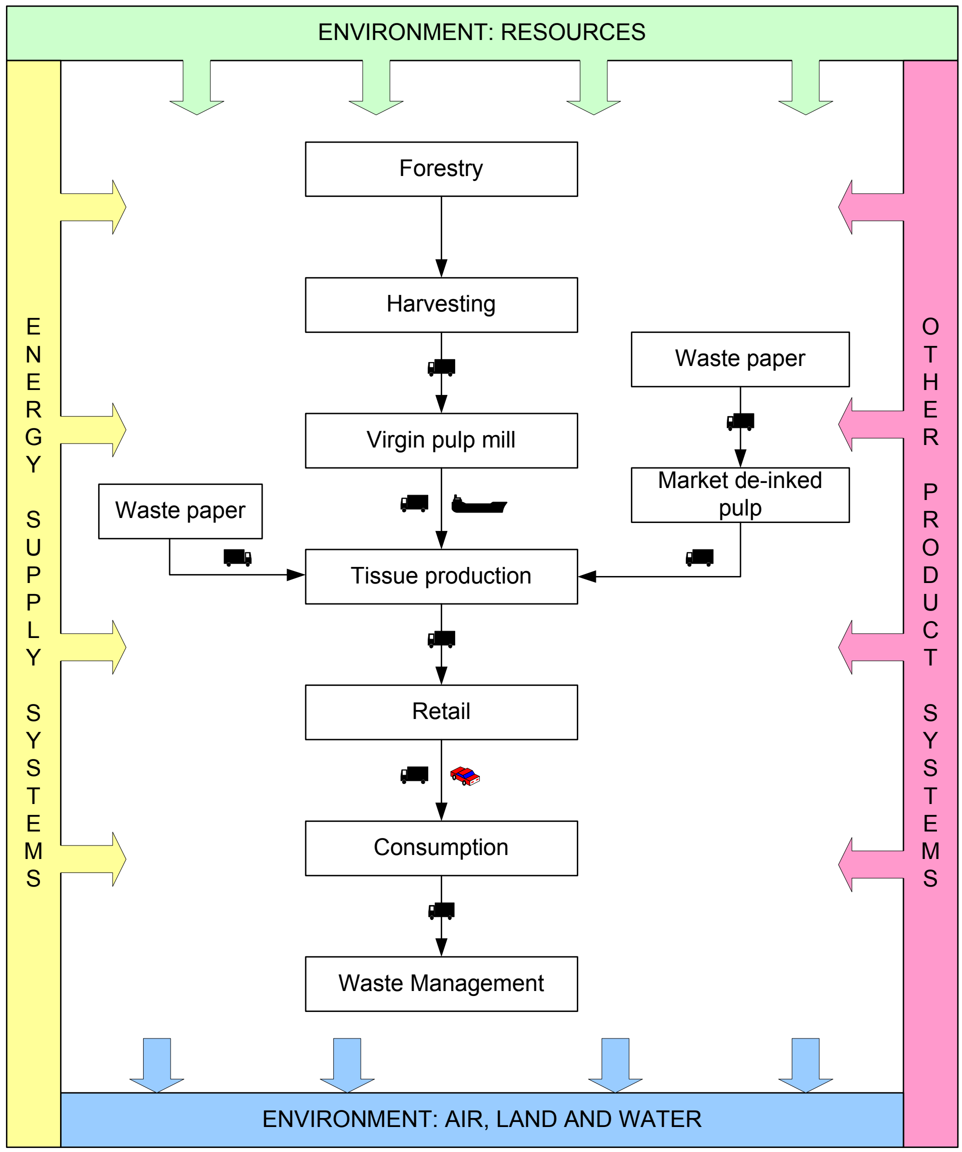
EUR commercial wipers

	Code 7A	**Code 7B**
Manufacturing site	Mill EU-3	Mill EU-3
Furnish	100% Virgin	100% Recycled fibre
Technology	Technology B	Technology B
Ply	1	1
Basis weight (g/m²)	35	35
Absorbency (water capacity), g/m²	180	140
Absorbency (oil capacity), g/m²	140	130
Tensile strength (dry GMT), g/3"	360	360
Tensile strength (wet CD), g/3"	85	85

As is the case for kitchen towels, wipers are used for cleaning under both wet and dry conditions. Strength when wet and dry along with absorbency rate and capacity are all important factors in determining the quality of wiper products. Some customers require 100% virgin fibres for use in food service cleaning while others do not. Users of 100% virgin products are expected to experience greater absorbency for both oil and water than users of 100% recycled fibre products.

Figure 2.4 details the main life cycle stages that were included in the life cycle of the tissue paper product systems specified above. In the sections below, these stages are described further.

Figure 2.4 ***System boundaries for tissue paper products***



Forestry (raw materials production)

The production of raw materials such as hardwood and softwood were included in the study. The materials and energy used for nursery and timber growth were included, as well as the emissions of substances and waste from this (see page 24).

Harvesting

The use of fuel and subsequent emissions for harvesting equipment were included in the study. Furthermore, the landscape and biodiversity impacts of infrastructure eg, roads to and from the forests, were included. If it is not possible to quantify the impacts, they were described qualitatively in the report. In some cases, pulp is produced from wood chips ie a by-product from lumber production. Here the environmental burden was allocated between the different product outputs.

Transport of wood logs

The transport of the raw material, wood logs to the mill, was included. If it was not possible to define the specific distance, a justifiable estimate was used.

Virgin pulp production

The production of pulp from either hardwood or softwood was included. The energy, water and materials/chemicals used for the production of pulp, as well as emissions, solid waste and waste water, were included in the study. The LCA included the production of selected virgin fibres using both Kraft and BCTMP (bleached chemithermomechanical pulp) processing plants located in Brazil, Canada and Scandinavia.

Waste paper

The collection, sorting and transport of office and other waste paper were included in the study.

Production of market de-inked pulp (MDIP)

The energy, water and materials/chemicals used for the production of MDIP as well as emissions, solid waste and waste water were included in the study.

Tissue production

K-C tissue is made from a combination of northern and southern softwood Kraft pulp, mechanical pulp, eucalyptus pulp, other hardwood pulp, post industrial (internal and external) pulp and post consumer (market and integrated) pulp. K-C purchases waste paper from paper merchants to use in its integrated tissue mills. The tissue paper production steps are hydropulping, de-inking, refining, drying and rolling. The inputs and outputs of raw materials, energy, water etc to these production steps differ for each of the seven product systems under study. For each product system under study, data for energy and materials used as well as emissions, solid waste and waste water treatment were included.

Transport of tissue products, retail, consumption and waste management

The environmental impacts from these activities are the same in the compared product systems so they will not show up in a comparison.
They were included in order to model a full cradle to grave analysis. The data used were generic data and proxies for the US and European market (EU 25).

2.2.5 *Modelling of what-if scenarios*

In the study, a certain number of 'what-if'-scenarios were included, in order to investigate parameters of special interest.

The following parameters were investigated:

- a specific scenario involving the EUR Commercial wipers. Currently the reference flows are based on product absorbency, resulting in two different reference flows for the same function. In the sensitivity analysis, we included a scenario where the reference flow is equivalent for both products.
- different numbers of uses for office paper before it is recycled into tissue paper;
- the use of natural gas for drying of recycled pulp; and
- the use of different impact assessment methods.

Additional parameters were expected to be identified during the project, for which a limited amount of sensitivity analysis was conducted eg the inclusion of biogenic CO_2.

2.2.6 *Data categories*

The following data categories were included in the study:

- raw materials;
- chemicals, fertilisers, pesticides;
- energy;
- other physical inputs, such as water;
- emissions to air, water and soil;
- products and co-products;
- solid waste; and
- waste water.

2.2.7 *Cut-off criteria for initial inclusion of inputs and outputs*

Ideally, cut-off criteria are based on environmental relevance. However, it might be impractical to define cut-off criteria based on environmental impact, since data for a process need to be collected in order to understand the environmental impact of that process or the entire life cycle. So if data are collected to prove this, they might as well be included in the calculations. A more practical approach is to base cut-off criteria on mass or energy.

In the study, mass flows that on aggregate contribute less than 2% of inputs to a life cycle stage were omitted from the inventory analysis.

It is ERM's belief that the cut-off criteria defined above did not affect the final results. However, care was taken when excluding processes from the inventory; especially processes or substances with a 'bad environmental reputation' such as pesticides or certain chemicals, where inputs under the 2% mass threshold could have a significant environmental impact. For example, chemicals (eg Hercobond, Kymene and Rezesol) that are used in the manufacturing of tissue paper contribute with less than 2% to the life cycle stage but have been included in the study.

2.2.8 Data requirements

Data requirements in order to perform a detailed LCA are listed below. Specific data are generally needed for the main materials, such as virgin pulp and MDIP. For the production of chemicals, packaging etc, generic data are suggested, since the mass flow in relation to the functional unit is limited.

Specific data are required for:

- production of raw materials (wood logs and wood chips);
- production of primary paper input materials (virgin and recycled fibres);
- type of waste management in the respective markets;
- waste management operations (especially waste water from mills);
- transport distances and types of transport; and
- the electricity mix, ie the split between different electricity generation methods such as hydro power, coal power, wind power, etc.

Specific emissions, resource use, solid waste and waste water data from the production and processing of wood logs, wood chips and fibres were collected from K-C's suppliers using questionnaires. Specific data on electricity mix and type of waste management in the geographical area where the product is produced, used and disposed were sourced from published data.

Generic data were used for:

- production of raw materials (when generic data are of sufficient quality, or specific data not available);
- waste management operations (when generic data are of sufficient quality, or specific data not available);
- electricity generation methods;

- emission data from transports; and
- production of fuels.

2.2.9 *Data quality requirements*

Data quality requirements are defined in *Table 2.3* below, based on the ISO standard on goal and scope definition and inventory analysis.

Table 2.3 Data quality requirements

Parameter	**Description**	**Requirement**
Time-related coverage	Desired age of data and the minimum length of time over data should be collected.	Data should represent the situation in 2006. General data and database data should represent the situation in 2006, and not be more than 10 years old.
Geographical coverage	Area from which data for unit processes should be collected.	Data should be representative of the situation in the respective markets.
Technology coverage	Technology mix	Data should be representative of the situation in the respective markets.
Precision	Measure of the variability of the data values for each data category expressed.	N/A
Completeness	Assessment of whether all relevant input and output data are included for a certain data set.	Specific datasets were compared with literature data and databases.
Representativeness	Degree to which the data represents the identified time-related, geographical and technological scope.	The data should fulfil the defined time-related, geographical and technological scope.
Consistency	How consistent the study method has been applied to different components of the analysis	The study method was applied to all the components of the analysis.
Reproducibility	Assessment of the method and data, and whether an independent practitioner was able to reproduce the results.	The information about the method and the data values should allow an independent practitioner to reproduce the results reported in the study.
Sources of the data	Assessment of data sources used.	Data were derived from credible sources and databases.
Source: EN ISO 14044:2006		

2.2.10 *Inventory analysis*

Inventory analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. For each of the tissue product systems, inventories of significant environmental flows to and from the environment, and internal material and energy flows, were produced.

The inventories that were generated will provide data on hundreds of internal and elemental flows for each tissue paper system and it is not applicable to report them all in the inventory analysis. Therefore the following inventory data are presented in detail, for each of the tissue paper systems:

- water use;
- coal, oil and natural gas use;
- PAH emissions;
- NOx;
- SOx;
- COD, BOD;
- suspended solids;
- particulates;
- solid waste;
- raw material use for the tissue mills;
- energy use (as 'cumulative energy demand');
- non-renewable CO_2 emissions;
- renewable CO_2 emissions; and
- CH_4 emissions.

Water use has been included due to environmental and political concern relating to water use globally and the perception that the paper industry consumes significant amounts of water.

Inventory data for raw material use, energy use, CO_2 and CH_4 emissions have been included due to their relevance to wood-based products. The inventory distinguished between biogenic and fossil CO_2 emissions.

Energy use is presented as the 'cumulative energy demand', using factors as presented in the SimaPro LCA software. These factors distinguish between renewable and non-renewable sources. This is relevant for the energy used in the pulp mills.

2.2.11 Impact assessment method

The contributions of each system were assessed for the impact indicators listed below. The listed impact categories address a breadth of environmental issues, and thorough methods have been developed for these categories.

The study employs the problem-oriented approach for the impact assessment, which focuses on:

- Climate change;
- ozone depletion;
- photo-oxidant formation;
- depletion of abiotic resources;
- eutrophication;
- acidification;
- human toxicity;
- fossil energy consumption;
- solid waste; and
- water use.

The contribution that solid waste management and fossil energy consumption make to global warming; resource depletion; acidification; toxicity; ozone depletion; photo chemical oxidant formation (smog); and eutrophication were calculated for each system.

The impact categories listed above are further described in *Annex A*.

For some impact categories, particularly human toxicity and eco-toxicity, a number of simplifying assumptions are made in the modelling used to derive characterisation factors. As a result, their adequacy in representing impacts is still the subject of some scientific discussion. Recently the International Council for mining and minerals (ICMM), UNEP and SETAC held a workshop[1] with leading LCA scientists to review existing methods to assess life cycle impacts. The workshop affirmed the inadequacy of current methods to model eco-toxicity and especially eco-toxicity of metals. They recommended a revision of current methods and that no business or policy decisions should be made based on the current methods. In that context, eco-toxicity has been left out of this study.

The impact assessment reflects potential, not actual, impacts and it takes no account of the local receiving environment.

The method that we will use is that developed and advocated by CML (Centre for Environmental Science, Leiden University) and which is incorporated into the SimaPro LCA software tool. The version contained in the software is based on the CML spreadsheet version 2.02 (September 2001) as published on the CML web site.

The method used for each impact category for classification and characterisation are further described in *Annex A*.

[1]http://www.unep.fr/pc/sustain/reports/lcini/Declaration%20of%20Apeldoorn_final_2c.pdf

2.2.12 *Interpretation*

The results of seven studies were interpreted individually and conclusions were drawn on the difference in environmental impact. Another objective of the interpretation was to identify improvement potentials in the individual life cycle stages of the products.

However, general observations and learning from all 21 product systems were presented and discussed. This included elements such as comparisons of the recycling technologies used and the environmental impacts of the different tissue products, eg North American bathroom tissue with European roll toilet tissue.

2.2.13 *Reporting*

According to the ISO standard, when the results of an LCA are to be communicated to any third party, a third-party report shall be prepared. The third party report shall be made available to any third party to whom the communication is made. For LCA studies supporting comparative assertions intended to be disclosed to the public, additional reporting requirements apply.

Although no third party disclosure is currently planned, K-C would like to leave this possibility open. Therefore, this report fulfils the demands according to the ISO standard for a third party report, supporting comparative assertions intended to be disclosed to the public.

2.2.14 *Critical review considerations*

In accordance with the ISO standard on LCA, the study was reviewed by an external review panel consisting of three experts. The review was carried out as an interactive review as recommended by the SETAC Code of Practice. The review panel's report, and ERM's responses, are included in the present report.

The reviewers addressed the issues below.

- For the goal and scope:
  - ensure that the scope of the study is consistent with the goal of the study, and that both are consistent with the ISO standard; and
  - include this in a review statement.
- For the inventory:
  - review the inventory for transparency and consistency with the goal and scope and with the ISO standard;
  - check data validation and that the data used are consistent with the system boundaries. It is unreasonable to expect the review panel to check data and calculations beyond a small sample but all data are available on request; and
  - include this in a review statement.

- For the impact assessment:
    - review the impact assessment for appropriateness and conformity to the ISO standard; and
    - include this in a review statement.
- For the interpretation:
    - review the conclusions of the study for appropriateness and conformity with the goal and scope of the study; and
    - include this in a review statement.
- for the draft final report:
    - review the draft final report for consistency with reporting guidelines in the ISO standard and check that recommendations made in previous review statements have been addressed adequately; and
    - prepare a review statement including consistency of the study and international standards, scientific and technical validity, transparency and relation between interpretation, limitations and goal.

Critical reviewers

The critical review panel was chaired by Professor Walter Klöpffer, who is the editor of the International Journal of LCA and has extensive experience in the area of LCA. The other two members of the review panel are Dr Jim Bowyer and Mary Ann Curran.

Dr Jim Bowyer is a retired professor from the College of Natural Resources at the University of Minnesota and is a known expert on LCA and forestry. Mary Ann Curran directs the US EPA System Analysis Branch´s Life Cycle Assessment (LCA) research program. This program includes the development of LCA methodology, the presentation of life-cycle case studies, life-cycle workshops and conferences, and the development of a life cycle data directory website. Mary Ann Curran is an LCA expert of international renown.

2.2.15 Modifications to the initial scope

LCA is an iterative process and modifications to the initial scope were needed. Where this was the case, it was discussed and agreed with K-C and documented in the report eg inclusion of an additional scenario (BB).

3 INVENTORY ANALYSIS

3.1 INVENTORY ANALYSIS

3.1.1 Introduction

The following inventory analysis serves two purposes:

1 an assessment of the appropriateness and completeness of the data collected; and
2 a quantitative assessment of the data collected.

The appropriateness and completeness of the data are assessed using the data quality measurements presented in *Table 2.3*.

Furthermore, this chapter describes the tissue life cycle system assessed and the data collection procedure undertaken to generate a complete life cycle inventory.

Each product is represented by a code. They are:

1. NA bathroom tissue;
2. NA washroom towel;
3. NA facial tissue;
4. NA kitchen towel;
5. EUR folded toilet tissue;
6. EUR roll toilet tissue; and
7. EUR commercial wipers.

The life cycle environmental impact of each code is calculated using three scenarios per product code. They comprise:

Scenario A. Product containing the most virgin fibres;

Scenario B. Product containing the most recycled fibres and where environmental burden is assigned to the previous life of the paper before it turns into waste paper; and

Scenario BB. Product containing the most recycled fibres and where no environmental burden is assigned to the waste paper up until it is collected.

The data collation using questionnaires were checked using mass balances and other cross checks such as the relation between energy use and CO_2 emissions. Any irregularities were reported to the supplier and clarifications were obtained.

The inventory analysis will not contain any specific data due to confidentiality. However the data are available to the reviewer upon request.

3.1.2 *Forestry*

Forestry comprises the operations of seedling production, silviculture, logging and haulage to the forest industries. The key environmental issues of concern for the forestry sector are generally considered to be the protection of biodiversity in the context of forestry practices and achieving increased energy efficiency of forestry operations.

The main environmental impacts from forestry processes originate from energy use in silviculture and logging processes as well as haulage. Emissions are generally either fuel-related or engine-related.

Wood data, including the forestry processes, for this study were required for:

1. Northern American softwood;
2. Southern American softwood;
3. Brazilian hardwood (Eucalyptus); and
4. Scandinavian softwood.

Data were sought through the use of questionnaires. Returned questionnaires were obtained for Brazilian hardwood and Northern American softwood. The primary data have been collected for the Brazilian eucalyptus wood. However, the North American softwood questionnaire was incomplete.

Due to difficulties in obtaining data and the incompleteness of data, secondary data from the ecoinvent database have been used for Northern American, Southern American and Scandinavian softwood. *Table 3.1* below describes the data quality of the Brazilian hardwood data.

Table 3.1 Data quality description for primary forestry data

	Brazilian hardwood (Eucalyptus)
Time-related coverage	Calendar year 2006.
Geographical coverage	Forests in the Brazilian regional areas of Aracruz, São Mateus and Bahia, all owned or leased by the Aracruz Celulose S.A. Occasional purchases of wood on the market.
Technology coverage	Current technology used in 2006.
Representativeness	Data represents the wood used at the mill in question, ie is fully representative.
Consistency	The method used for the data collection (eg allocation and data inclusion) is consistent with the overall study methodology.
Reproducibility	The data is very specific to this study and has been collected using questionnaires and cannot be reproduced by an independent practitioner
Sources of the data	Aracruz Celulose S.A., Brazil.
Completeness for the study	Data is from a state of the art eucalyptus wood producer using advanced forestry management such as soil surveys and a network of weather stations to minimise the environmental impacts associated with the production of wood. The data are complete for the objectives of this study.

Aracruz Celulose owns or leases the forestry areas where the majority of wood used for the products is grown. This allows the company to fully control the processes from cradle-to-gate. The main processes are summarised below.

1 Seedlings are grown in the company's own plant nursery where around 95% of the seedlings are produced by plant propagation (cloning) and 5% are produced from seeds produced in the company's seed orchards.

2 Silviculture activities, either through coppice from recently harvested areas or the implementation of new plantations, include control of Leaf-Cutter Ants, pre-planting chemical weeding, soil preparation and pre-planting phospating, planting / irrigation, fertilisation, control of competing weeds and clearing operations.

3 Forest harvesting is generally mechanised, using harvesters for logging and processing (debarking and sawing). In areas where logging is not possible, stands may be logged manually with the use of chainsaws. In areas cultivated for solid wood products, pruning (selective logging of trees) is undertaken.

4 The logged and processed wood is removed by forwarder forest tractors and stacked at the side of the road and/or firebreaks. The wood is transported to the pulp mill or sawmill by flatbed trucks or train. Wood produced in the south of Bahia is shipped using ocean barges.

The inventory model for Brazilian hardwood has been developed using materials and processes from the ecoinvent database. The data sources used is shown in *Table 3.2* below. The ecoinvent data used for the fertilizer and developed 2,4 D [1] are commonly used chemicals in agriculture and silviculture. The data for 2,4 D are actually based on North American data., where as the ammonium nitrate phosphate is based on European data. The datasets used for the formicide and raticide are herbicide data used as proxies for these particular biocides. ERM assumes that, even though the wood production is in South America, the production of fertiliser and all the biocides data are representative on a global level and are therefore considered adequate for this study.

Table 3.2 Ecoinvent datasets used to model Brazilian hardwood

Material / process reported by Aracruz Celulose S.A.	Ecoinvent data used
Fertiliser	Ammonium nitrate phosphate
Herbicide	2,4-D
Formicide	Diuron
Porta Iscas (or raticide)	Cyanazine
Diesel	Diesel, burned in chopper
Heavy fuel oil	Heat, heavy fuel oil, at industrial furnace
Truck (50 tonnes)	Transport, lorry 40t
Freight train	Transport, freight, rail
Barge	Transport, barge

As mentioned above, data were difficult to obtain. For data representing Northern American, Southern American and Scandinavian softwood production we used data from the ecoinvent database on Scandinavian softwood production. Before using the Scandinavian data, we compared the data from softwood production in the US using data from CORRIM[2]. CORRIM is the source for forestry data for NREL/US LCI data. In the CORRIM/NREL data it was not possible to distinguish the forestry component from the forest products data (timber, woodchips, bark etc). Woodchips are predominantly used in K-C's pulp mills and specific data for wood chips are available in ecoinvent. Therefore Scandinavian woodchips data were used for US woodchips production. *Table 3.3* below describes the data quality of the used data.

[1] 2,4-dichlorophenoxyacetic acid

[2] Consortium for Research on Renewable Industrial Materials

Table 3.3 Data quality description for secondary forestry data

	Northern and Southern American softwood	**Scandinavian softwood**
Dataset used	Chips, Scandinavian softwood (plant-debarked), u = 70%	Chips, Scandinavian softwood (plant-debarked), u = 70%
Time-related coverage	Year 2000	Year 2000
Geographical coverage	Sweden and Finland.	Sweden and Finland.
Technology coverage	State of the art technology currently used in Finland and Sweden.	State of the art technology currently used in Finland and Sweden.
Precision	No measurement of precision was carried out.	No measurement of precision was carried out.
Representativeness	Average data from nine different sawmills, located in Sweden and Finland, belonging to the Stora Enso group. Even though the data is for Scandinavia, ERM assumes that the climate and technology conditions are very similar and, as such, the data used is appropriate for use in this study.	Average data from nine different sawmills, located in Sweden and Finland, belonging to the Stora Enso group.
Consistency	Allocation of the wood outputs based on their economic value: sawn timber (0.96), wood chips (0.03), and sawdust (0.01).	Allocation of the wood outputs based on their economic value: sawn timber (0.96), wood chips (0.03), and sawdust (0.01).
Reproducibility	The ecoinvent data are from a licensed database, so an independent practitioner is not allowed to reproduce the results using the data (unless a licence is purchased).	The ecoinvent data are from a licensed database, so an independent practitioner is not allowed to reproduce the results using the data (unless a licence is purchased).
Sources of data	Ecoinvent dataset	Ecoinvent dataset
Completeness for the study	The Northern and Southern Softwood Pulp producers predominantly use wood chips as raw material for their process. The ecoinvent data include the entire life cycle of tree from tree nursing and stand establishment to cutting. This is the most up to date and comprehensive dataset available and we consider it complete for this study.	The Northern and Southern Softwood Pulp producers predominantly use wood chips as raw material for their process. The ecoinvent data include the entire life cycle of tree from tree nursing and stand establishment to cutting. This is the most up to date and comprehensive dataset available and we consider it complete for this study.

3.1.3 Virgin pulp production

The pulp and paper industry has historically been considered a major user of natural resources (wood, water) and energy (fossil fuels, electricity), and a significant contributor to air and water emissions. However, due to cost and environmental pressures, both internal and external, the emissions have been significantly reduced over the last two decades. Despite these measures the pulp and paper industry remains a high energy and water consuming industry.

The main environmental impacts from the pulping process originate from the production of the energy required for the process and the emissions to air and water from the pulping and bleaching processes.

Virgin pulp data for this study were required for:

1. bleached chemo-thermomechanical pulp (BCTMP) from a Canadian supplier;
2. bleached softwood kraft pulp from a Canadian and Swedish/Norwegian supplier;
3. hardwood (eucalyptus) pulp from Aracruz Celulose, Brazil; and
4. softwood sulfite pulp from Kimberly–Clark .

Data were sought through the use of questionnaires. Returned questionnaires were obtained for all the pulp types assessed in this study.

Thus, primary data have been collected for the BCTMP, NBSK (North America), Eucalyptus pulp, SW Sulfite pulp, and bleached kraft pulp (Europe). *Table 3.4* below describes the data quality of pulp data. The products containing 100% virgin pulp (and 40% virgin pulp in product 5) were modelled as Product A.

Table 3.4 Data quality description for primary pulp data

Pulp	BCTMP	NBSK	Eucalyptus pulp	SW Sulfite slush pulp	Bleached kraft pulp
Time-related coverage	2006.	2006.	2006.	2006	2006.
Geographical coverage	Alberta, Canada.	Nova Scotia, Canada.	Aracruz, ES, Brazil.	USA	Norway.
Technology coverage	Mill dates from 1988. Highly automated. Consistently upgraded.	40 year old mill. Conventional equipment. Many upgrades over the years.	Mill A from 1978, B from 1991, and C from 2002. Mill A and B modernised in 1997. All mills modernised and capacity increased in 2007.	Old technology	Best available technology (BAT). Primary treatment of effluent. No external biological treatment.
Precision	No measurement of precision was carried out	No measurement of precision was carried out	No measurement of precision was carried out	No measurement of precision was carried out	No measurement of precision was carried out
Completeness	All relevant inputs and outputs have been included in the data sets. They fit within acceptable ranges of literature data.	All relevant inputs and outputs have been included in the data sets. They fit within acceptable ranges of literature data.	All relevant inputs and outputs have been included in the data sets. They fit within acceptable ranges of literature data.	All relevant inputs and outputs have been included in the data sets. They fit within acceptable ranges of literature data.	All relevant inputs and outputs have been included in the data sets. They fit within acceptable ranges of literature data.
Representativeness	The data represents the pulp produced in question and is therefore fully representative.	The data represents the pulp produced in question and is therefore fully representative.	The data represents the pulp produced in question and is therefore fully representative.	The data represents the pulp produced in question and is therefore fully representative.	The data partially represents the pulp produced in question, as the use of chemicals was based on a process in North America.
Consistency	The method used for data collection, such as allocation and cut-off criteria, is consistent with the overall method	The method used for data collection, such as allocation and cut-off criteria, is consistent with the overall method	The method used for data collection, such as allocation and cut-off criteria, is consistent with the overall method	The method used for data collection, such as allocation and cut-off criteria, is consistent with the overall method	The method used for data collection, such as allocation and cut-off criteria, is consistent with the overall method
Reproducibility	The data is very specific to this study and has been collected using questionnaires and can not be reproduced by an independent practitioner	The data is very specific to this study and has been collected using questionnaires and can not be reproduced by an independent practitioner.	The data is very specific to this study and has been collected using questionnaires and can not be reproduced by an independent practitioner.	The data supplied is specific to this study, obtained internally by K-C, via questionnaires and can not be reproduced by an independent practitioner	The data is very specific to this study and has been collected using questionnaires and can not be reproduced by an independent practitioner
Sources of data	Confidential	Confidential	Aracruz Celulose S.A.	Kimberly-Clark	Confidential

Data was obtained for both North American and Scandinavian NBSK pulp. Due to the proprietary nature of the chemical use data, the data provider for the Scandinavian pulp only provided a partially completed questionnaire, omitting the chemical use data. As the NBSK pulp used in North America is very similar to that produced in Scandinavia, the chemical use data provided by the North America data provider was used and adapted the wood and water use of the Scandinavian production. ERM believes that this approach is appropriate for this study, as the technologies are very similar.

The data supplied for all the pulp types are confidential. For the entire range of chemicals used by the different processes, fuels and electricity, ecoinvent datasets were used. Most data in ecoinvent is for European production, yet ERM assumes that technology levels between the North America and Europe are very similar and therefore the use of these data are deemed appropriate for the study. In some cases, some inputs in the pulp production did not have ecoinvent dataset available. In these cases, ERM used proxy datasets from the ecoinvent database. ERM believes that these proxy data are suitable for the study, and that they will have very limited effect on the results.

3.1.4 Waste paper collection and recovery

The collection and recovery of waste paper and the conversion into recycled fibres were modelled using two scenarios:

1. environmental burden assigned to the first life of the graphic paper; and;
2. waste paper comes free of burden up until it is collected.

The first scenario was modelled as **Product B**, for products containing different amounts of recycled fibres. The second scenario for burden free recycled fibres was modelled as **Product BB**.

Ecoinvent data were used to model the impact from waste paper and graphic paper. For the US scenario's, the data have been manipulated to represent US conditions ie European electricity has been substituted with an average US electricity grid mix using data from IEA[1]. Other aspects such transport efficiency etc was not applied.

[1] International Energy Agency (www.IEA.org)

Table 3.5 Waste paper recovery

	Graphic paper	Waste paper
Time-related coverage	2000	1995
Geographical coverage	European data manipulated to represent the US	Swiss data manipulated to represent Europe and the US
Technology coverage	Average data	Average data
Precision	A measure of variability of the data values has not been applied by the database providers	A measure of variability of the data values has been applied by the database providers.
Completeness	All relevant inputs and outputs have been included in the data sets.	All relevant inputs and outputs have been included in the data sets.
Representativeness	The data represents the specific processes involved in producing paper in the specific geography	The data represents the specific processes involved in producing paper in the specific geography
Consistency	The method used for data collection, such as allocation and cut-off criteria, is consistent with the overall method.	The method used for data collection, such as allocation and cut-off criteria, is consistent with the overall method.
Reproducibility	Data is from ecoinvent and a license is needed to reproduce the data	Data is from ecoinvent and a license is needed to reproduce the data
Sources of data	Ecoinvent	Ecoinvent

Although the information is outdated for this study, it is estimated that the differences in sorting strategies have not materially impacted energy use in collection/sorting systems so the data is considered appropriate for the study.

3.1.5 *Market de-inked pulp (MDIP) production*

Recovered fibre has become an indispensable raw material for the paper manufacturing industry. This is due to the favourable price of recovered fibres in comparison with the corresponding grades of market pulp and because of the promotion of wastepaper recycling.

The production of MDIP requires waste paper, water and chemical additives, together with electricity and fossil fuels. The process produces MDIP and emissions to water and air. The air emissions result from the combustion of the fossil fuels and from the pulping process itself. The process also produces large amounts of waste and waste water.

The main environmental impacts from the pulping process originate from the production of the energy required for the process and the emissions to air and water from the pulping or bleaching processes.

The MDIP used by K-C is produced by a regular Canadian supplier based in the US. Data were sought through the use of questionnaires. In addition to the MDIP produced externally, K-C also produces its own de-inked pulp for products 5 and 7. *Table 3.6* shows the data quality assessment for the de-inked pulps.

Table 3.6 De-inked pulp

Pulp	**MDIP**	**De-inked pulp**
Time-related coverage	2006	2006
Geographical coverage	Fairmont, West Virginia (US)	UK
Technology coverage	100% air dried Recycled Bleached Kraft (RBK) pulp latest technology, best in class.	BAT
Precision	A measure of variability of the data values has not been applied.	A measure of variability of the data values has been applied.
Completeness	All relevant inputs and outputs have been included in the data sets. They fit within acceptable ranges of literature data, except for energy use, which is higher than reported in literature.	All relevant inputs and outputs have been included in the data sets. They fit within acceptable ranges of literature data.
Representativeness	The data represent the pulp produced in question and is from a supplier frequently used by K-C and is therefore fully representative.	The data represents the pulp produced in question and is therefore fully representative.
Consistency	The method used for data collection, such as allocation and cut-off criteria, is consistent with the overall method.	The method used for data collection, such as allocation and cut-off criteria, is consistent with the overall method.
Reproducibility	The data is very specific to this study and cannot be reproduced by an independent practitioner	The data is very specific to this study and cannot be reproduced by an independent practitioner
Sources of data	Confidential	Kimberly-Clark

The questionnaire provided foreground data for energy and raw materials used eg chemicals. However questionnaires were not sent out to the suppliers of chemicals so data for manufacturing of the raw materials in the MDIP manufacturing process were modelled using ecoinvent datasets. Most data in ecoinvent are for European production, yet ERM assumes that technology levels between the North America and Europe are very similar and therefore the use of these data are deemed appropriate for the study.

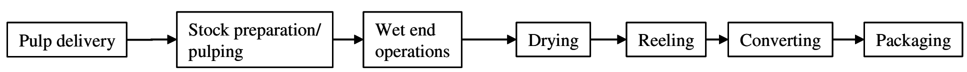
3.1.6 Tissue production

Tissue production takes place at K-C's facilities in Europe and North America. The individual tissue products are described in the *Functional units* section of the *Scope*. The data collection took place under the auspices of K-C's Corporate Sustainability team. This primary data are of great importance to the study and are fully described.

The collection of the data is consistent with the Goal and Scope of the study, identifying differentiating characteristics of the products studied. In many cases, the inputs and outputs vary significantly between different facilities as a result of local regulatory or resource availability constraints. These variations are independent of characteristics of the products. The regional and temporal variations were mitigated by calculating averages or by using operational benchmarks. This has enabled consistent treatment of all products.

The data provided for tissue production are gate-to-gate datasets, as shown in *Figure 3.1*

Figure 3.1 ***Gate-to-gate data for tissue production***



Material Inputs

When available, data were taken directly from the manufacturing bill of materials. When the bill of materials was unavailable, as was the case for product 1B and 6A, the materials were determined on the basis of existing bill of materials information and the expert knowledge of product managers of the fibre types used in the products.

Energy

The energy requirements for tissue production include:

1. Tissue machine (stock preparation to reel);
2. Converting (reel to dock);
3. HVAC (heating, ventilation, and air conditioning); and
4. Site electricity (lighting, computers, etc).

The energy use for de-inking and pulping operations of integrated mills is excluded (but is included in for the production of de-inked pulp for products 5 and 7)

The tissue machine energy consumption varies, depending on factors such as fibre characteristics, drying technology, humidity (and other environmental factors), and other operational factors. These factors lead to a certain degree of variability in energy consumption.

The energy consumption profiles for the different products have been established using technology-specific energy performance benchmarks for tissue machines based on available metering data and taking into account product characteristics such as weight and moisture content.

The energy used to convert tissue on the reel into the final product and packaging for delivery to customers is a relatively minor component of the total energy consumption. A single benchmark value was used for all products. The HVAC and other site electricity use were obtained from the facility's electricity bills and were allocated to output on a mass basis.

Table 3.7 North American Tissue Products

NA Products	**NA bathroom tissue**	**NA washroom towel**	**NA facial tissue**	**NA kitchen towel**
Time-related coverage	2006	2006	2006	2006
Geographical coverage	USA (North East and Mid West)	USA (North West and South East)	Canada (North)	USA (South East)
Technology coverage	BAT	BAT	BAT	BAT
Precision	A measure of variability of the data values has been applied.	A measure of variability of the data values has been applied.	A measure of variability of the data values has been applied.	A measure of variability of the data values has been applied.
Completeness	All relevant inputs and outputs have been included in the data sets. They fit within acceptable ranges of literature data.	All relevant inputs and outputs have been included in the data sets. They fit within acceptable ranges of literature data.	All relevant inputs and outputs have been included in the data sets. They fit within acceptable ranges of literature data.	All relevant inputs and outputs have been included in the data sets. They fit within acceptable ranges of literature data.
Representativeness	The data represents the pulp produced in question and is therefore fully representative.	The data represents the pulp produced in question and is therefore fully representative.	The data represents the pulp produced in question and is therefore fully representative.	The data represents the pulp produced in question and is therefore fully representative.
Consistency	The method used for data collection, such as allocation and cut-off criteria, is consistent with the overall method	The method used for data collection, such as allocation and cut-off criteria, is consistent with the overall method.	The method used for data collection, such as allocation and cut-off criteria, is consistent with the overall method.	The method used for data collection, such as allocation and cut-off criteria, is consistent with the overall method.
Reproducibility	The data is very specific to this study and can not be reproduced by an independent practitioner.	The data is very specific to this study and can not be reproduced by an independent practitioner.	The data is very specific to this study and can not be reproduced by an independent practitioner..	The data is very specific to this study and can not be reproduced by an independent practitioner..
Sources of data	K-C	K-C	K-C	K-C

Table 3.8 European Tissue Products

EU products	Folded toilet tissue	Roll toilet tissue	Commercial wipes
Time-related coverage	2006	2006	2006
Geographical coverage	UK	France	UK
Technology coverage	BAT	BAT	BAT
Precision	A measure of variability of the data values has been applied.	A measure of variability of the data values has been applied.	A measure of variability of the data values has been applied.
Completeness	All relevant inputs and outputs have been included in the data sets. They fit within acceptable ranges of literature data.	All relevant inputs and outputs have been included in the data sets. They fit within acceptable ranges of literature data.	All relevant inputs and outputs have been included in the data sets. They fit within acceptable ranges of literature data.
Representativeness	The data represents the pulp produced in question and is therefore fully representative.	The data represents the pulp produced in question and is therefore fully representative.	The data represents the pulp produced in question and is therefore fully representative.
Consistency	The method used for data collection, such as allocation and cut-off criteria, is consistent with the overall method.	The method used for data collection, such as allocation and cut-off criteria, is consistent with the overall method.	The method used for data collection, such as allocation and cut-off criteria, is consistent with the overall method.
Reproducibility	The data is very specific to this study and can not be reproduced by an independent practitioner.	The data is very specific to this study and can not be reproduced by an independent practitioner.	The data is very specific to this study and can not be reproduced by an independent practitioner.
Sources of data	K-C	K-C	K-C

Water use

Water consumption at K-C tissue mills can vary considerably, as local environmental conditions play an important role in water use. The product itself has practically no impact on these variations. Therefore, the water use for tissue operations was established using a benchmark water quantity, both for tissue machine and steam generation. The benchmark values reflect the expected water requirements per unit of tissue material produced.

For integrated mills, where no separate data for the pulping operations and tissue operation were available, the water use has been allocated 50% to each type of operations. This allocation is expected to have a limited influence on the total system result.

Waste water

Waste water effluent data from K-C trials suggests that different levels of recycled fibre content do not affect the environmental characteristics of the effluent. Representative mill effluent data from 2006 has been used as a source. The effluents have been allocated on a mass basis. Data for six mills have been used, where only biological oxygen demand (BOD) and total suspended solids (TSS) have been monitored consistently.

In the case of integrated mills, waste water effluents have been allocated 50% to the de-inking operations and 50% to tissue manufacture operations.

Solid waste

Waste generation data from the tissue mills were obtained as reported for the year 2006. The data reported are annual averages allocated to production output.

In the case of integrated mills, the de-inking operations contribute more than 98% of the waste water treatment sludge. In these mills, all sludge output is allocated to the de-inking operations. The sludge is used in land application, recycling, landfilled or incinerated.

Air emissions

Air emissions are estimated using engineering models of fuel combustion under current conditions present in each tissue mill, and based on usage data for chemicals employed in production processes. Fuel combustion emissions reflect the burner types present in the appropriate mills and the natural gas consumption reported for the product production.

Volatile organic compounds (VOC) emissions associated with the production process for each product were based on information on the volatile fraction of the chemicals and usage rates. European tissue mills do not monitor VOC emissions. Therefore these were estimated assuming adhesives emit 1.0E-3 kg VOC/kg of adhesive applied.

Secondary data

The K-C suppliers provided detailed foreground data on the specific inputs and outputs to their production processes. No questionnaires were sent to a supplier's supplier so any raw material used by a supplier was modelled using background data, mainly ecoinvent. K-C tissue manufacturing takes place both in Europe and in the US and technology levels were assumed to be very similar.

3.1.7 *Retail and consumption*

The retail and the consumption of the tissue products are not included in the life cycle model.

3.1.8 *Waste management*

The main sources of waste are the pulp production step and the end-of-life step, when the used tissue is disposed. The end of life scenarios fall into two categories:

1 North American bathroom tissue (product 1), European folded toilet tissue (product 5) and roll toilet tissue (product 6) are modelled as all ending up in the public waste water treatment facilities; and

2 The North America washroom towel (product 2), facial tissue (product 3) and kitchen towel (product 4), as well as the European commercial wipes (product 7) are modelled as ending up in the residual solid waste stream, with a landfill and incineration split specific to the countries in question (USA, the Netherlands and the UK).

The waste amounts generated at pulp and tissue manufacture are confidential. The sludges produced at these stages are either landfilled or incinerated. The datasets used for this were taken from the ecoinvent database and are shown *Table* 3.9.

Table 3.9 ***Pulp and waste disposal datasets for pulping****

Pulp/waste disposal route	Disposal, sludge from pulp and paper production, 25% water, to sanitary landfill	Disposal, inert waste, 5% water, to inert material landfill
Time-related coverage	2000	2000
Geographical coverage	Switzerland	Switzerland
Technology coverage	Unspecified	Unspecified
Representativeness	Unspecified	Unspecified
Sources of data	Ecoinvent	Ecoinvent

* Both waste scenarios do not include environmental benefit from energy recovery

Waste water treatment process

The waste tissues used in the bathroom are all disposed off via the sewer system and end up at a waste water treatment plant. The waste water treatment process can be summarised into the following steps:

1 preliminary (mechanical treatment);
2 primary (physical separation);
3 secondary (biological treatment); and
4 final (disinfection).

The preliminary (or coarse) screening processes removes larger articles such as rags, papers, plastics and other floating objects to prevent the blocking of downstream equipment in the sewage system. All such material is periodically collected and removed. The collected solids are disposed of through a number of routes.

After the coarse screening (6 mm), a fine screening (1.5 to 6 mm) takes place, which removes material that may create operation and maintenance problems in downstream processes, particularly in systems that lack primary treatment. In addition, comminuting and grinding devices are installed in the waste water flow channel to grind and shred material up to 6 to 19 mm in size.

Organic substances and carbon dioxide

Under aerobic conditions, many organic substances are able to breakdown to form carbon dioxide and water through the activity of micro-organisms. This activity arises from the interaction of bacteria in the waste water and oxygen. As the amount of organic material in waste water increases, the need for oxygen required to consume the matter also increases. Solid organic substances in sewerage derive from toilet paper and faeces. Dissolved organic substances are present in the form of sugars and biodegradable detergents.

The CO_2 produced during this process, is considered to be part of the renewable CO_2 cycle, as opposed to the emissions of fossil CO_2, as mentioned in the Scope.

Waste disposal routes

The end of life of Products 1, 5 and 6 is modelled as sewage sludge in the respective countries, whereas for other products this stage is modelled as disposal as household waste in the respective countries.

Sludge disposal

The UK produces more than one million tonnes of dry solids per year which are disposed of (and modelled) as follows:

1 62% to agriculture (as treated bio solids);
2 19% to incineration;
3 11% to land reclamation;
4 1% landfill; and
5 7% other (including non-food crops).

The Netherlands disposal scenarios for sludge are:

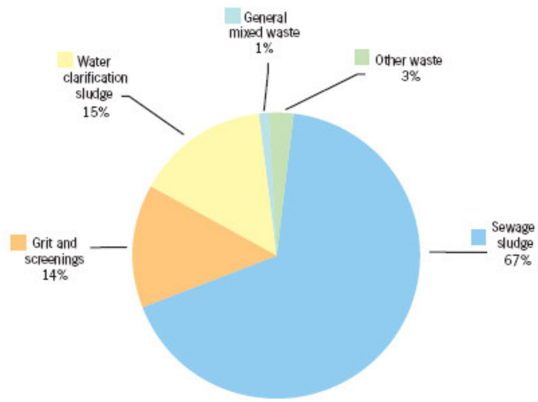
1 38% to agriculture;
2 24% to incineration; and
3 48% to sanitary landfill.

The US disposes of sludge as follows:

1 55% agricultural and forestry applications;
2 19% to landfill;
3 17% to incineration; and
4 9% other (including non-food crops).

Figure 3.2 shows the proportions of each type of waste that is generated within the treatment process. The screening process is where tissue would be stopped from entering downstream flow.

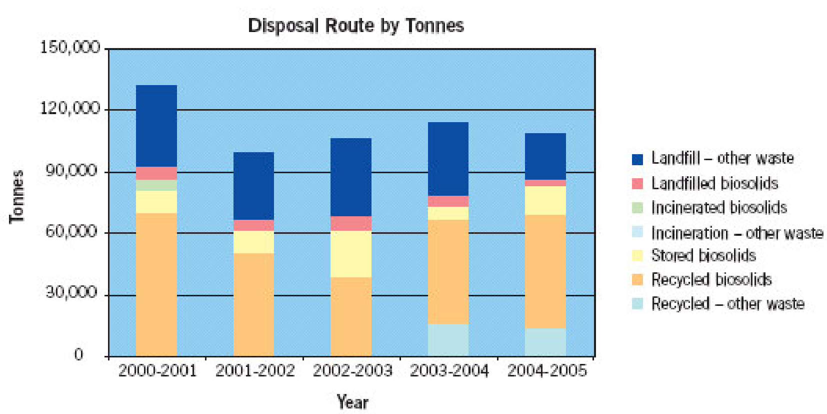
Figure 3.2 Waste water waste generation



Source: Southern water UK – Planning for a Sustainable Future, Technical Performance 2004-2005

Figure 3.3 shows the various disposal routes that the different classes of wastes can undergo.

Figure 3.3 Sludge disposal



Source: Southern water UK – Planning for a Sustainable Future, Technical Performance 2004-2005

Household waste disposal

The washroom towels, facial tissues and kitchen towel in North America and the commercial wipes in Europe, were modelled as residual solid waste in the US and in the Netherlands.

The US residual household waste disposal was modelled as follows:

1 79% landfill; and
2 21% incineration.

The Dutch residual household waste disposal was modelled as follows:

1 13% landfill; and
2 87% incineration.

Both the landfill and incineration of tissues do not include energy generation (methane and electricity production). This assumption will potentially overestimate the environmental impact from waste management of tissue paper. However, the actual number of landfill sites and incineration facilities with energy recovery in the US and the Netherlands were not available. Assuming that all incinerators and landfill sites have energy recovery facilities could potentially underestimate the impact from waste management of tissue paper. To ensure that we would not underestimate the environmental impact from waste management, we assumed no environmental benefit from energy recovery from waste treatment of tissue paper.

3.1.9 Transport

The ecoinvent datasets for European transport have been used for all transport in this study. Due to the lack of representative data, European transport data have also been used for transport in Northern and Southern America.

The transport modes considered are road, rail and sea transport.

Road (lorry) transport

The ecoinvent dataset for heavy goods vehicle transport in Europe is based on the European research project Copert III. The datasets are a function of the direct process of vehicle operation and the indirect processes of vehicle fleet operation (fleet production, maintenance and disposal) and road infrastructure. Two categories of vehicles are used as shown in *Table 3.10* below, along with the assumed average vehicle load.

Table 3.10 ***Ecoinvent HGV categories including load and fuel assumption***

Vehicle category	Gross vehicle weight	Average load assumed	Diesel consumption assumed	
	tonnes	tonnes	kg / tkm	ltr / 100 km
40 tonnes	> 16	9.7	0.0361	47.07

Based on parameters describing lorry size, load and road category, the fuel consumptions and emissions were then calculated as a function of the distance travelled.

Rail transport

The ecoinvent dataset for rail transport in Europe is based on several rail transport studies. The datasets are a function of the direct process of rail operation with a mix of diesel and electric trains, the indirect processes of rail equipment (train production, maintenance and disposal) and rail infrastructure.

Sea transport

The ecoinvent dataset for sea transport is based on a number of sea transport studies. The datasets are a function of the direct process of vessel operation and the indirect processes of vessel fleet (vessel production, maintenance and disposal) and port infrastructure. The vessels used are as shown in *Table 3.1.1* below along with the assumed average vehicle load.

Table 3.11 ***Ecoinvent transoceanic freight ship description and fuel assumptions***

Vessel category	Engine	Average load assumed	Fuel consumption assumed	
Transoceanic freight ship, dry bulk carrier	Average of slow speed engine and steam turbine propulsion	~50,000 dwt (dead weight tonnes)	2.5g/tkm	Heavy fuel oil

In order to provide robust estimates of transportation requirements for the products, the average transportation distances for tissue products in the US and Europe were calculated and supplied by K-C. The following delivery distance averages were used for each product code.

1 Code 1, 3 and 4: 600 miles;
2 Code 2: 568 miles;
3 Code 5: 1220 km;
4 Code 6: 494 km; and
5 Code 7: 1332 km.

3.1.10 Energy

Energy was used in the form of fossil fuels, such as diesel, natural gas and fuel oil, and as electricity. At all life cycle stages, energy is used: forestry; pulp production; and tissue production.

The ecoinvent datasets were used for most energy inputs in this study. European system data sets have been used directly for the European operations, and indirectly for the North American and Brazilian profiles. In some cases, North American datasets have been used, mainly the Franklin 98 database. *Table 3.12* documents the energy datasets used. Reproducibility, consistency, completeness and precision assessments have been left out of the data description as these are published datasets.

Table 3.12 Energy datasets

Fuel/Energy source	Geography	Year	Technology	Representativeness	Reference
Diesel, burned in chopper	Europe	2006	Unspecified	Unspecified	ecoinvent
Heat, heavy fuel oil, at industrial furnace 1MW	Switzerland	2000	Unspecified	Unspecified	ecoinvent
Diesel powered industrial equipment (1000 gal)	North America	1998	Average technology	Mixed data	Franklin 98
Natural gas in industrial equipment (1000 cu ft)	North America	1998	Average technology	Mixed data	Franklin 98
Diesel, at regional storage	Europe	2000	Unspecified	Unspecified	ecoinvent
DFO into industrial boilers	North America	1998	Average technology	Mixed data	Franklin 98
Heat, natural gas, at industrial furnace >100kW	Europe	2003	Unspecified	Unspecified	ecoinvent
electricity, medium voltage, production GB, at grid/kWh/GB	GB	2000	Unspecified	Unspecified	ecoinvent
electricity, medium voltage, production FR, at grid/kWh/FR	France	2000	Unspecified	Unspecified	ecoinvent
Electricity US	USA	1990-94	Average technology	Mixed data	Electricity mix based on IEA data, using UCTE profiles from ecoinvent
Electricity Canada	Canada	1990-94	Average technology	Mixed data	Electricity mix based on IEA data, using UCTE profiles from ecoinvent
Electricity Brazil	Brazil	1990-94	Average technology	Mixed data	Electricity mix based on IEA data, using UCTE profiles from ecoinvent
Electricity, hard coal, at power plant/kWh/UCTE	Europe	2000	Unspecified	Unspecified	ecoinvent
Electricity, natural gas, at power plant/kWh/UCTE	Europe	2000	Unspecified	Unspecified	ecoinvent
Electricity, lignite, at power plant/kWh/UCTE	Europe	2000	Unspecified	Unspecified	ecoinvent
Electricity, nuclear, at power plant/kWh/UCTE	Europe	2000	Unspecified	Unspecified	ecoinvent
Electricity, oil, at power plant/kWh/UCTE	Europe	2000	Unspecified	Unspecified	ecoinvent
Electricity, hydropower, at power plant/GB U	GB	2000	Unspecified	Unspecified	ecoinvent
Electricity, at wind power plant/CH S	Switzerland	2000	Unspecified	Unspecified	ecoinvent

The electricity datasets for the USA, Canada and Brazil have been generated by consulting the electricity supply mixes as provided by the IEA. They take into account the various sources of electricity power generation (coal, gas, nuclear, etc) and the transmission losses. In turn, these power mixes use mainly UCTE (union for the co-ordination and transfer of electricity) electricity datasets in the ecoinvent database, as well as British and Swiss datasets for hydropower and wind power respectively.

3.2 BURDEN ANALYSIS

For each tissue paper system, a summary inventory of environmental flows is presented for the following:

1 coal;
2 oil;
3 natural gas;
4 fossil carbon dioxide;
5 methane;
6 NOx;
7 SOx;
8 COD;
9 BOD;
10 suspended solids;
11 particulates;
12 water consumption;
13 water total [1] ;
14 PAH (air borne);
15 cumulative energy demand (CED);
16 resources; and
17 waste [2].

Table 3.13 to *Table 3.19* detail the inventory flows for the seven tissue products. For each product, the inventory flows are shown for product **A**, **B** and **BB** where:

- **A** represents the products which contain a larger share of virgin fibres than;
- **B** which represents the products containing 100% recycled fibres or a significant percentage of recycled fibres and where environmental impact has been assigned to the waste paper's first life; and
- **BB** which is the same product as B, but where the waste paper used to produce recycled fibres come without environmental burden.

Each table is followed by an inventory flow chart for fossil carbon dioxide emissions (*Figure 3.5 – 3.26*). These show where the main sources of fossil

1 Water total and water consumption present two different approaches to measuring the water used by the product systems. Water consumption measures all water used at each process step, excluding the water used for electricity generation. The water total quantity does include hydropower water use.
2 The waste consists of three components: The product and the packaging itself, the waste arisings at KC operations, and the wastes related to the productions of the pulps used by KC.

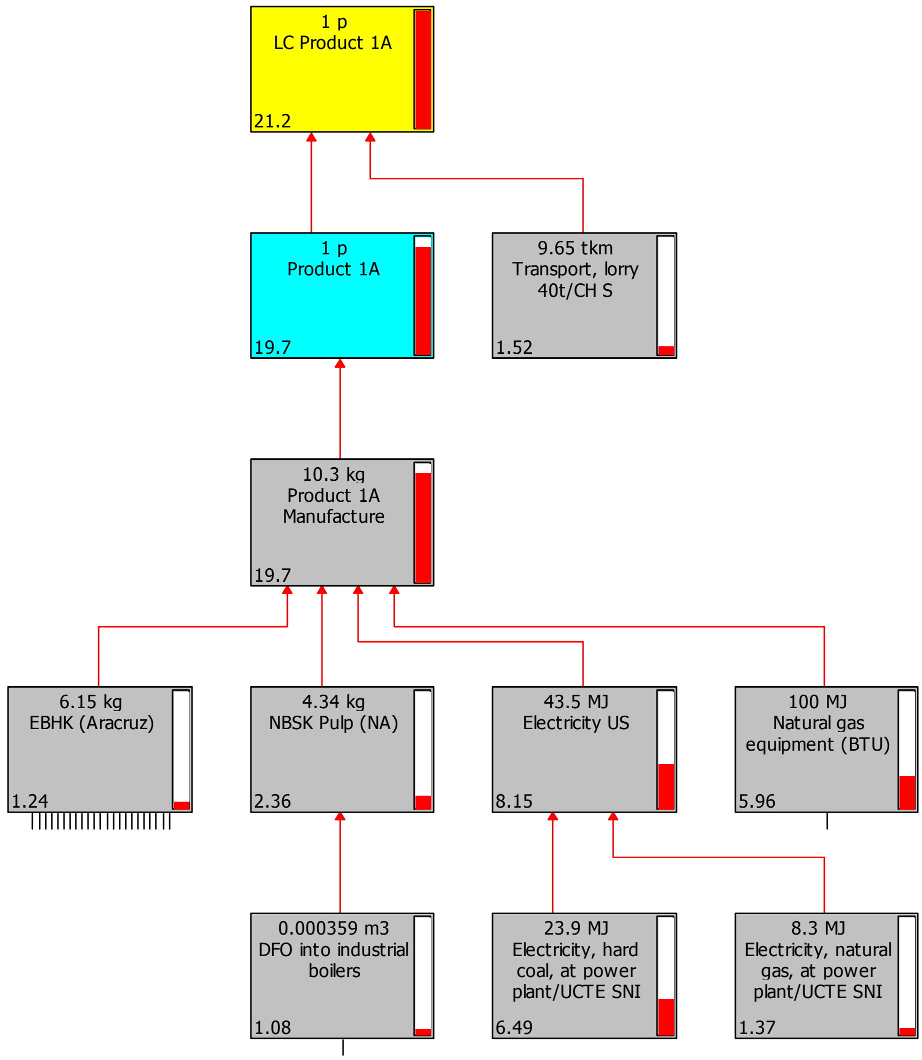
carbon emissions and water consumption occur across the life cycle of the tissue products.

Table 3.13 ***Product 1 – North American bathroom tissue***

Impact category	Unit	Product 1A	Product 1B	Product 1BB
Coal	kg Coal	4.47	10.57	9.57
Oil	kg Oil	1.71	4.01	3.24
Natural gas	m^3 Gas	4.41	10.02	9.07
Carbon Dioxide (Fossil)	kg CO_2	21.2	55.1	47.58
Methane	kg CH_4	0.14	0.41	0.40
NOx	kg NOx	0.14	0.32	0.29
SOx	kg SOx	0.13	0.30	0.27
COD	kg COD	0.69	1.42	1.34
BOD	kg BOD	0.10	0.27	0.25
Suspended Solids	kg SS	0.04	0.06	0.06
Particulates	kg PM	0.02	0.05	0.04
Water consumption (manufacturing)	m^3	1.73	3.48	2.79
Water total	m^3	69.96	225.18	135.35
PAH (air borne)	kg PAH	1.06E-04	8.55E-05	8.46E-05
CED	MJ-eq	655	1599	1195
Raw materials (manufacturing)	kg	10.91	16.99	16.99
Waste (manufacturing)	kg	0.4	0.57	0.57

Raw materials and waste are both equal for product B and BB since these only include the manufacturing stage. The difference between the two products is in the way recycled paper is allocated before the manufacturing stage and will thus not have any impact on the results presented in the inventory tables.

Figure 3.4 Product 1A fossil carbon dioxide flow chart



The grey boxes are individual processes and the coloured boxes are life cycle stages which are made up of a number of processes. The yellow box represents the whole life cycle consisting of manufacture (blue box), transport processes and waste management processes. The red 'thermometer' to the right of each process/life cycle stage represents the contribution from the processes to the emission of CO_2. The number in the left bottom corner is the actual CO_2 emission from each process. For example 1.08 kg CO_2 is emitted from burning 0.000359 m^3 natural gas in an industrial boiler. The 1.08 kg CO_2 is caused by the use of natural gas to produce NBSK pulp.

The use of 4.34 kg of NBSK pulp results in an emission of 2.36 kg CO_2 where the 1.08 kg is caused by the use of natural gas which means a difference of 1.28 kg CO_2 (2.36-1.08). The difference is due to the way these flow charts are generated. The flow chart does not include all processes in the life cycle. The life cycle of Product 1A consist of a total of 137 processes, but it is not possible to show all of them in a flow diagram. Therefore a cut off criteria is applied to narrow the number of process boxes down to 11. To narrow it down to the 11 processes presented in *Figure 3.4* , all processes that contribute less than 4% to the total CO_2 emission have been left out of flowchart but their contribution is still included in the result.

Figure 3.5 Product 1B fossil carbon dioxide flow chart

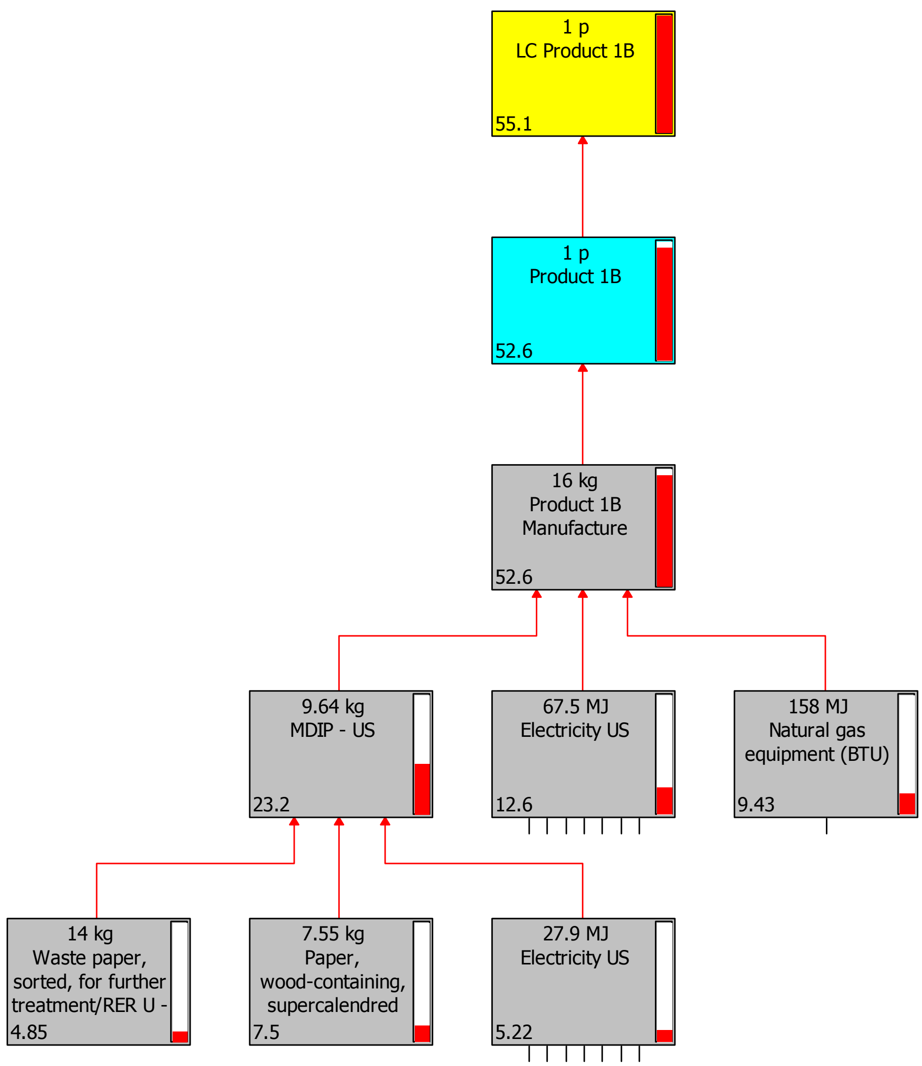


Figure 3.6 Product 1BB fossil carbon dioxide flow chart

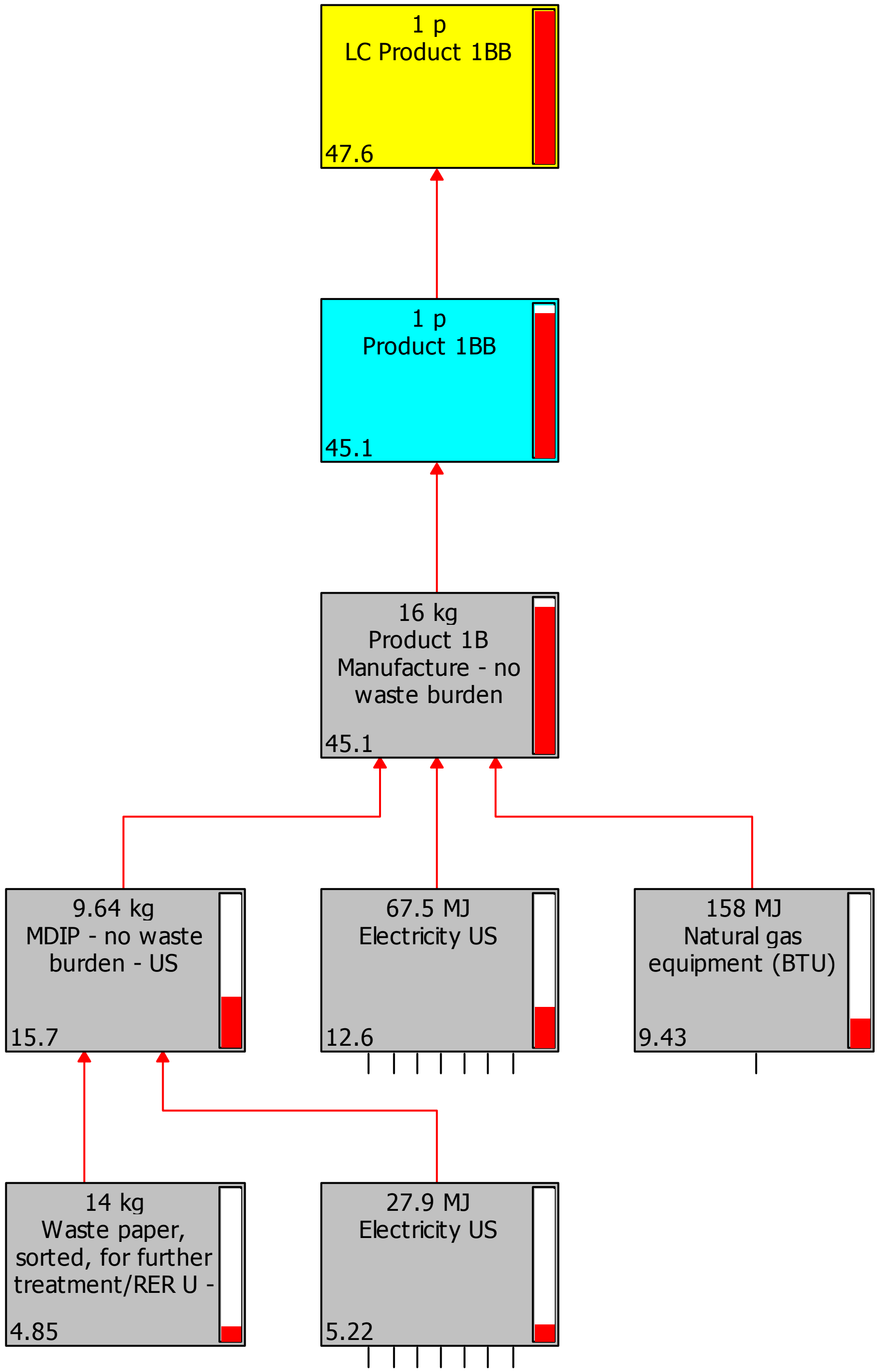


Table 3.14 Product 2 – North American Washroom towel

Impact category	Unit	Product 2A	Product 2B	Product 2BB
Coal	kg Coal	92.10	117.98	111.71
Oil	kg Oil	18.52	31.74	26.92
Natural gas	m^3 Gas	78.19	105.44	99.52
Carbon Dioxide (Fossil)	kg CO2	375.8	550.44	503.65
Methane	kg CH4	4.42	5.66	5.58
NOx	kg NOx	2.13	2.91	2.74
SOx	kg SOx	2.86	2.84	2.67
COD	kg COD	12.71	19.19	18.69
BOD	kg BOD	3.07	3.66	3.54
Suspended Solids	kg SS	0.30	0.33	0.31
Particulates	kg PM	0.30	0.45	0.37
Water consumption (manufacturing)	m^3	22.9	30.8	26.5
Water total	M^3	1171.29	2074.89	1514.74
PAH (air borne)	kg PAH	1.32E-03	7.60E-04	7.55E-04
CED	MJ-eq	10935	14788	12270
Raw materials (manufacturing)	kg	142.4	154.4	154.4
Waste (manufacturing)	kg	47.1	47.2	47.2

Figure 3.7 Product 2A fossil carbon dioxide flow chart

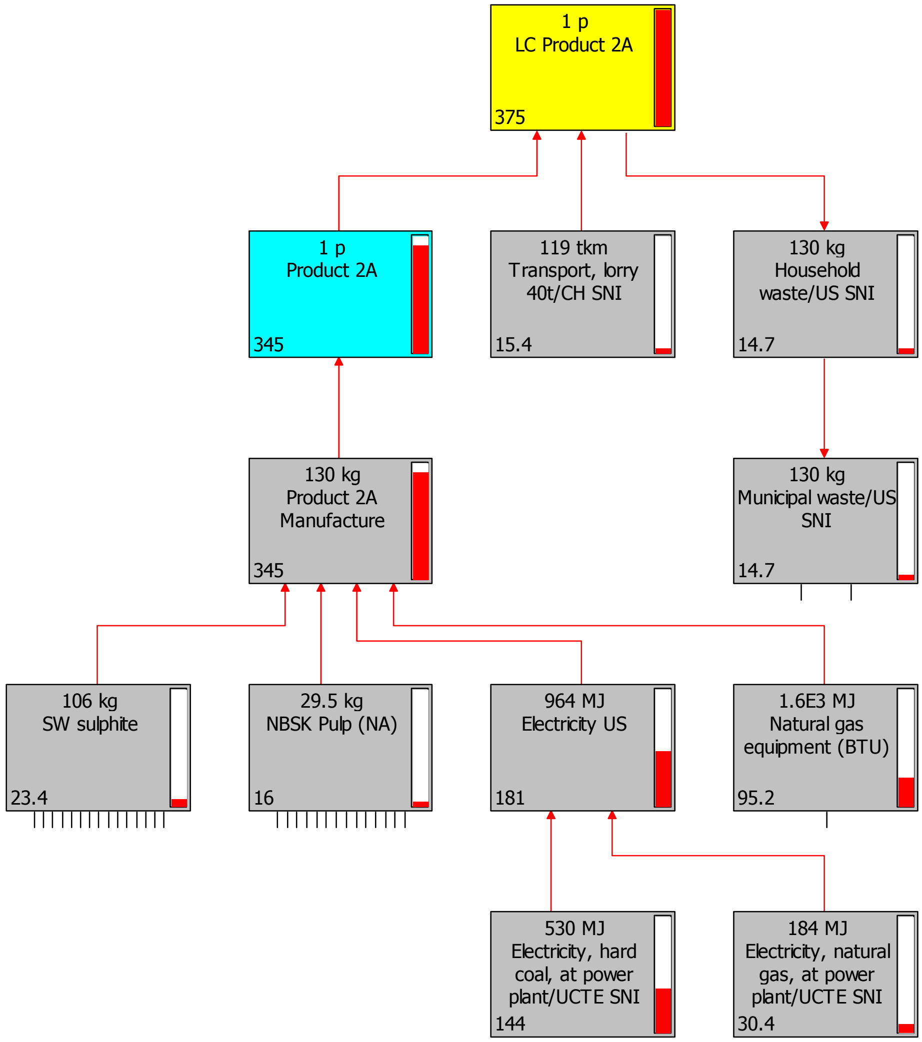


Figure 3.8 Product 2B fossil carbon dioxide flow chart

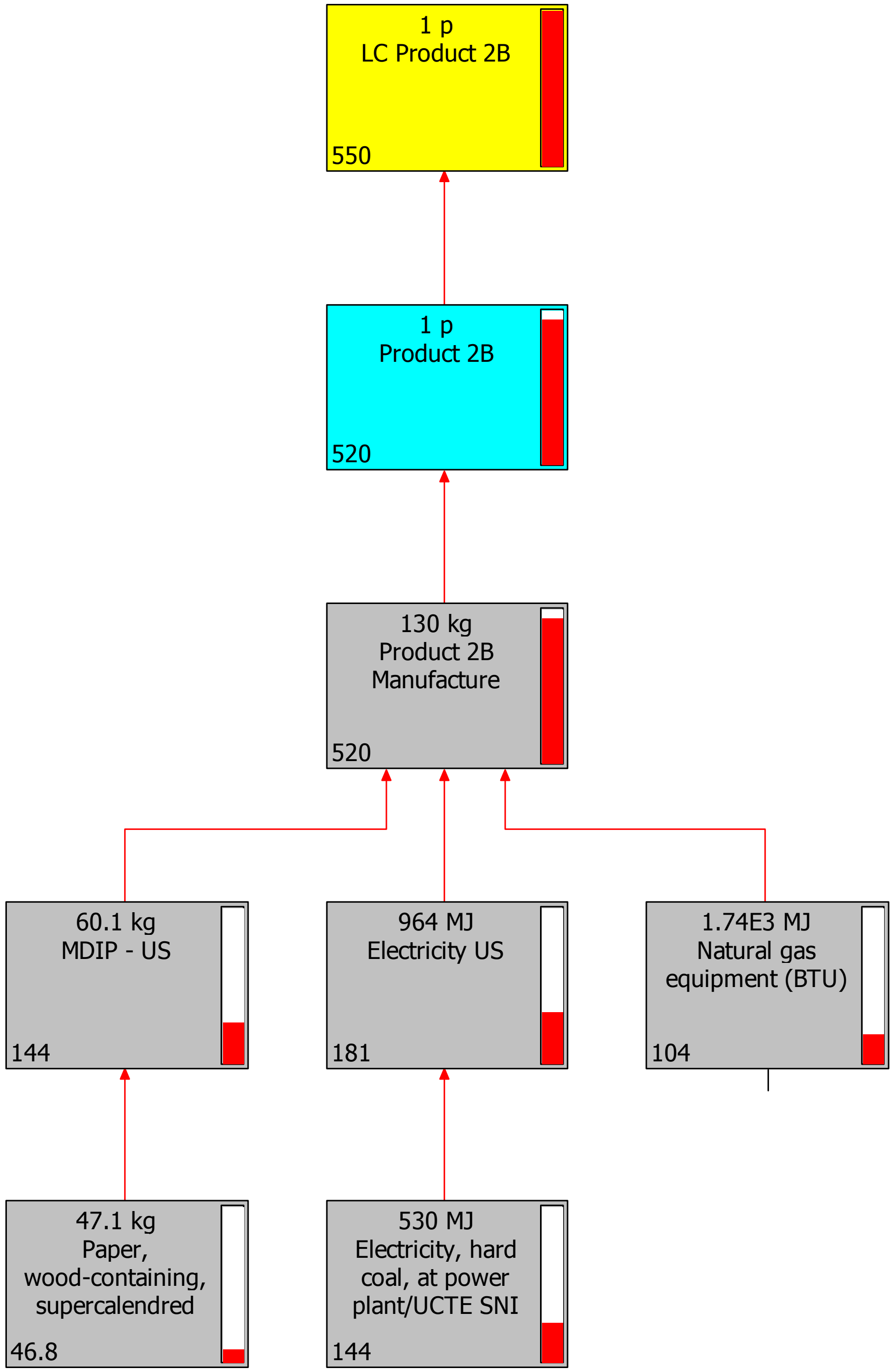


Figure 3.9 Product 2BB fossil carbon dioxide flow chart

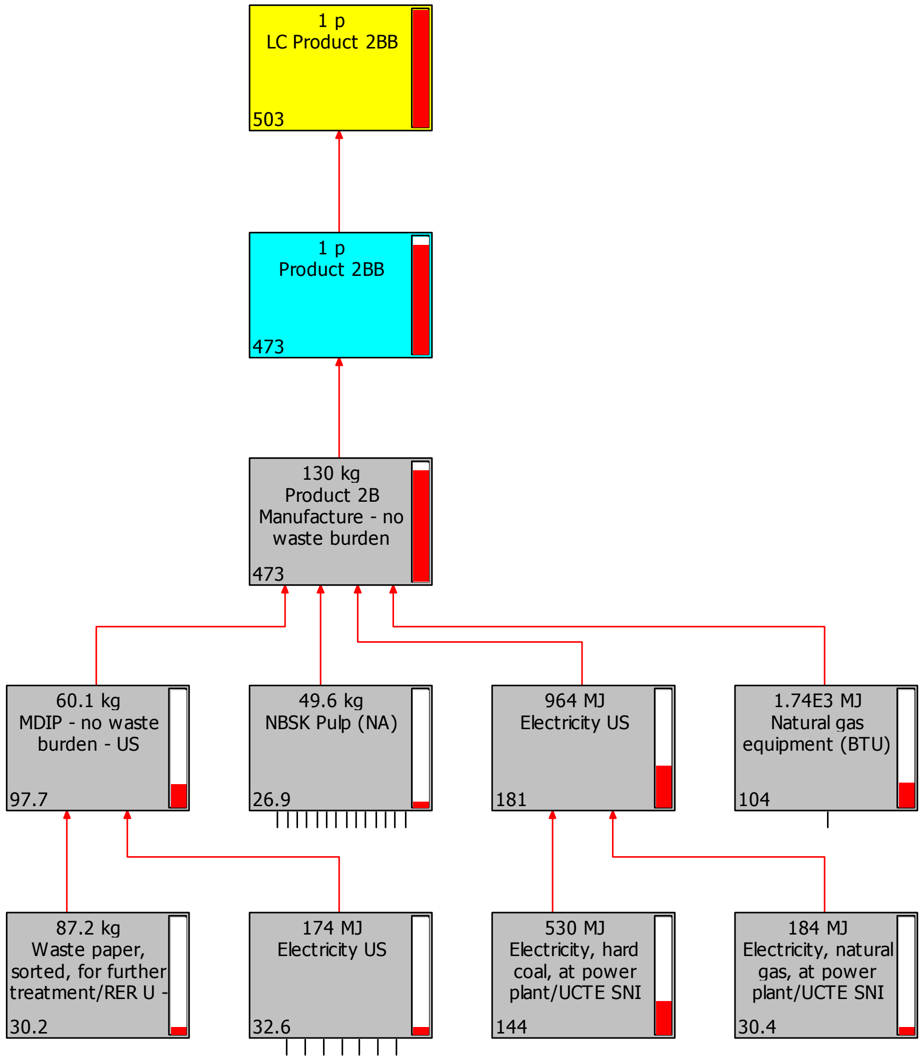


Table 3.15 Product 3 – North American Facial tissue

Impact category	**Unit**	**Product 3A**	**Product 3B**	**Product 3BB**
Coal	kg Coal	4.88	5.97	5.73
Oil	kg Oil	3.59	4.08	3.9
Natural gas	m^3 Gas	5.58	6.71	6.49
Carbon Dioxide (Fossil)	kg CO_2	31.77	38.78	37.01
Methane	kg CH_4	0.22	0.28	0.27
NOx	kg NOx	0.21	0.24	0.23
SOx	kg SOx	0.14	0.17	0.16
COD	kg COD	0.97	1.13	1.10
BOD	kg BOD	0.19	0.23	0.22
Suspended Solids	kg SS	0.018	0.018	0.017
Particulates	kg PM	0.023	0.029	0.026
Water consumption (manufacturing)	m^3	1.45	1.75	1.59
Water total	m^3	68.99	100	79
PAH (air bourne)	kg PAH	9.31E-5	7.18E-5	7.16E-5
CED	MJ-eq	698	904	809
Raw materials (manufacturing)	kg	9.76	9.89	9.89
Waste (manufacturing)	kg	0.8	0.77	0.77

Figure 3.10 Product 3A fossil carbon dioxide flow chart

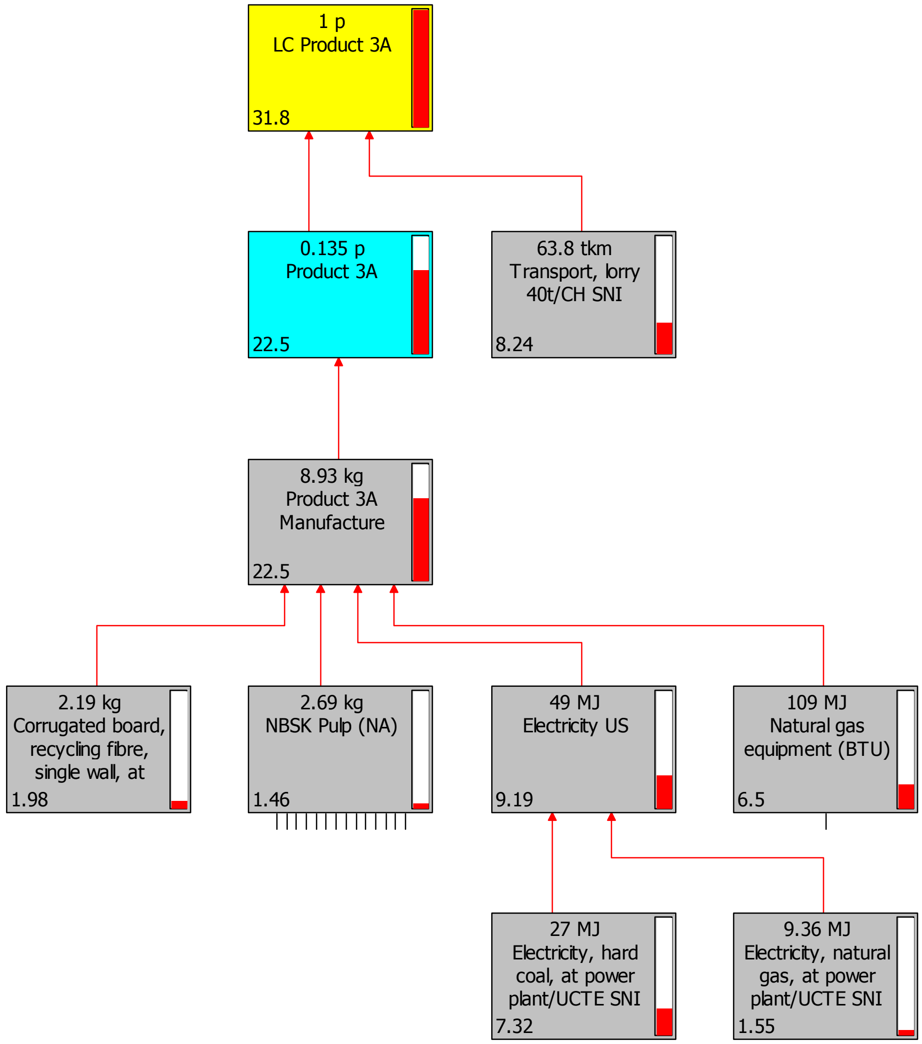


Figure 3.11 Product 3B fossil carbon dioxide flow chart

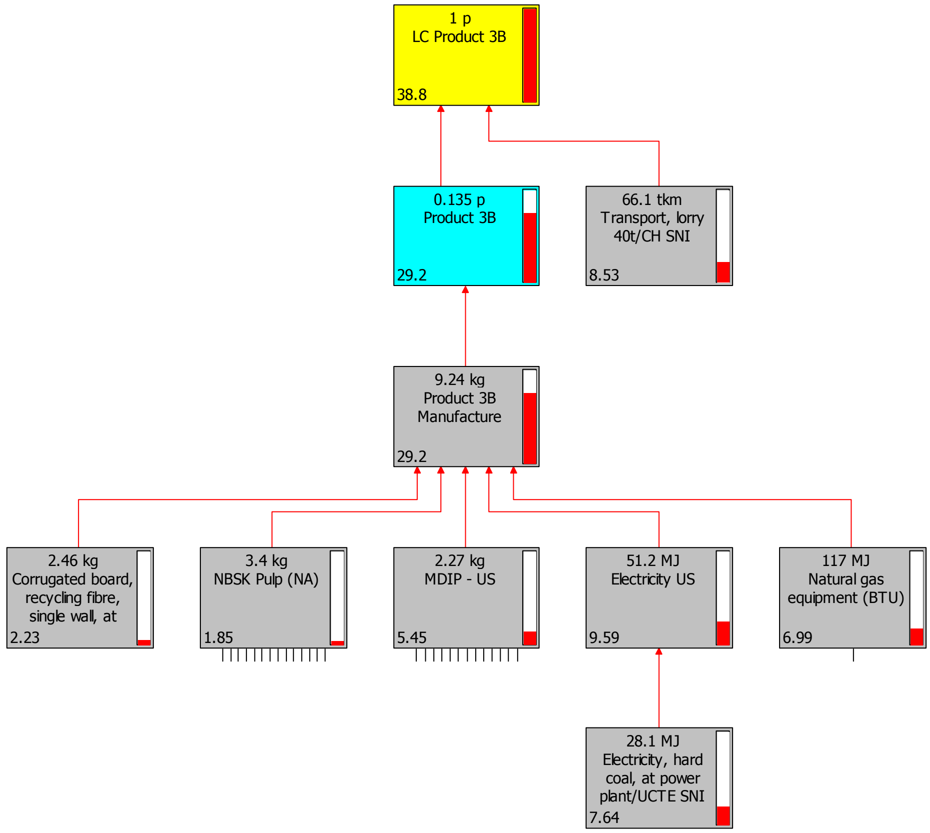


Figure 3.12 Product 3BB fossil carbon dioxide flow chart

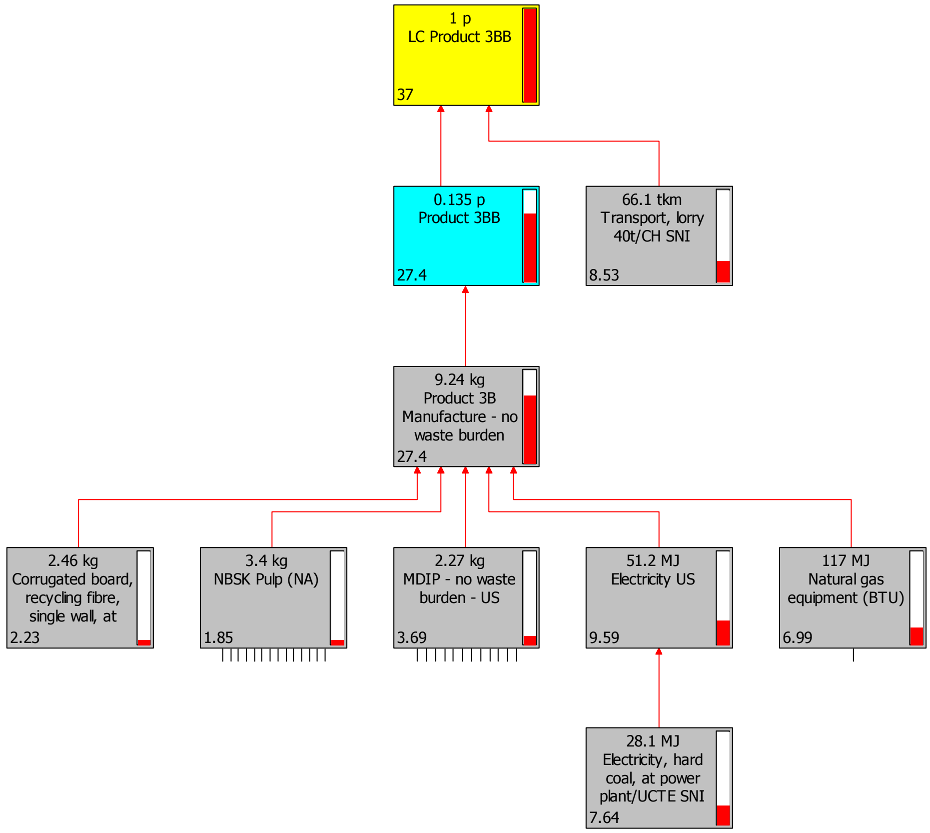


Table 3.16 Product 4 – North American Kitchen towel

Impact category	Unit	Product 4A	Product 4B	Product 4BB
Coal	kg Coal	5.12	5.74	5.42
Oil	kg Oil	1.32	1.73	1.48
Natural gas	M^3 Gas	4.53	5.28	4.98
Carbon Dioxide (Fossil)	kg CO_2	22.10	27.66	25.23
Methane	kg CH_4	0.20	0.27	0.26
NOx	kg NOx	0.12	0.15	0.14
SOx	kg SOx	0.12	0.14	0.13
COD	kg COD	0.83	0.93	0.91
BOD	kg BOD	0.15	0.18	0.18
Suspended Solids	kg SS	0.01	0.01	0.01
Particulates	kg PM	0.02	0.02	0.02
Water consumption (manufacturing)	m^3	1.35	1.15	0.93
Water total	m^3	156.80	103.56	74.53
PAH (air bourne)	kg PAH	4.72E-05	3.51E-05	3.48E-05
CED	MJ-eq	653	763	632
Raw materials (manufacturing)	kg	7.53	7.53	7.53
Waste (manufacturing)	kg	2.54	2.84	2.84

Figure 3.13 Product 4A fossil carbon dioxide flow chart

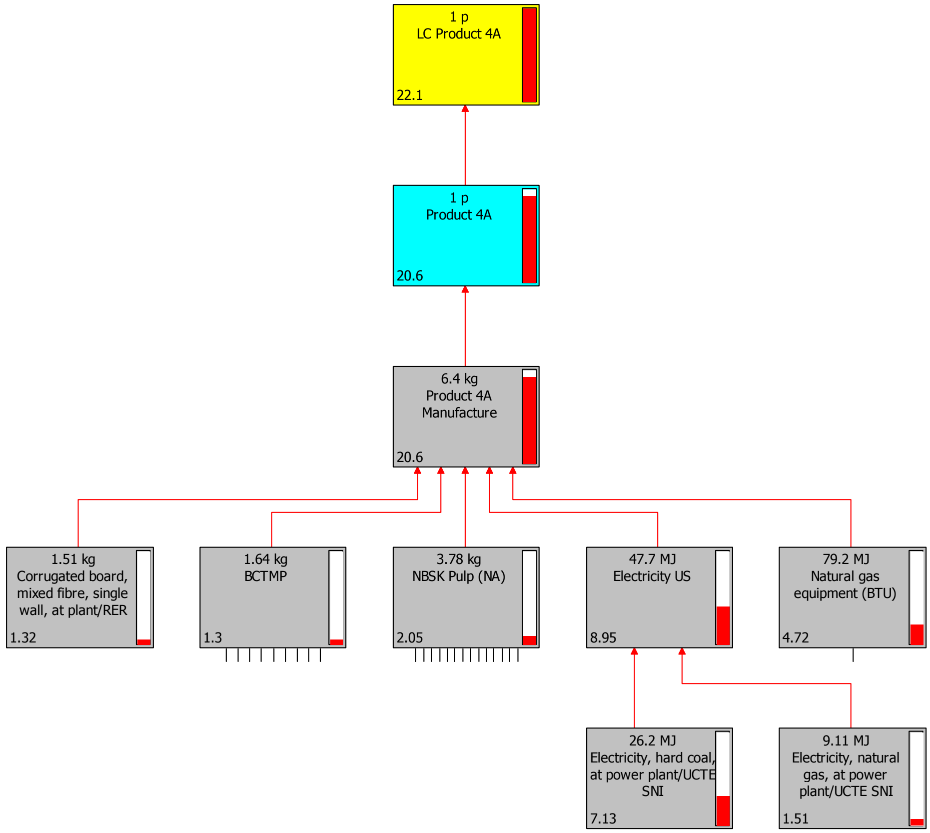


Figure 3.14 Product 4B fossil carbon dioxide flow chart

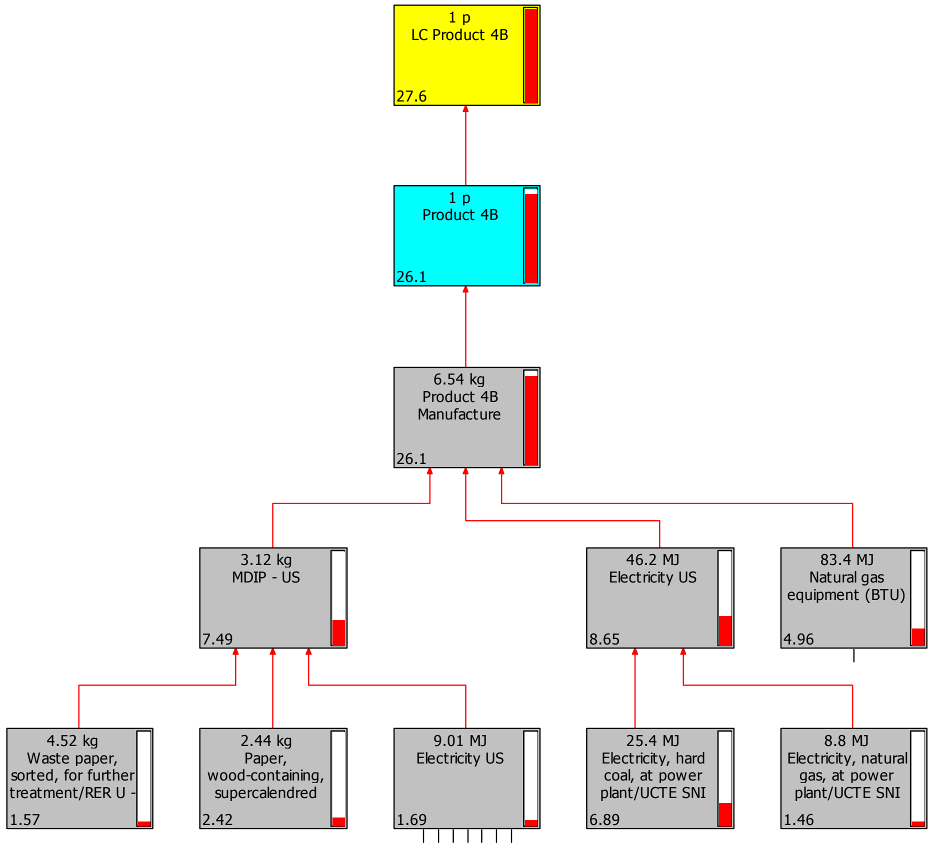


Figure 3.15 Product 4BB fossil carbon dioxide flow chart

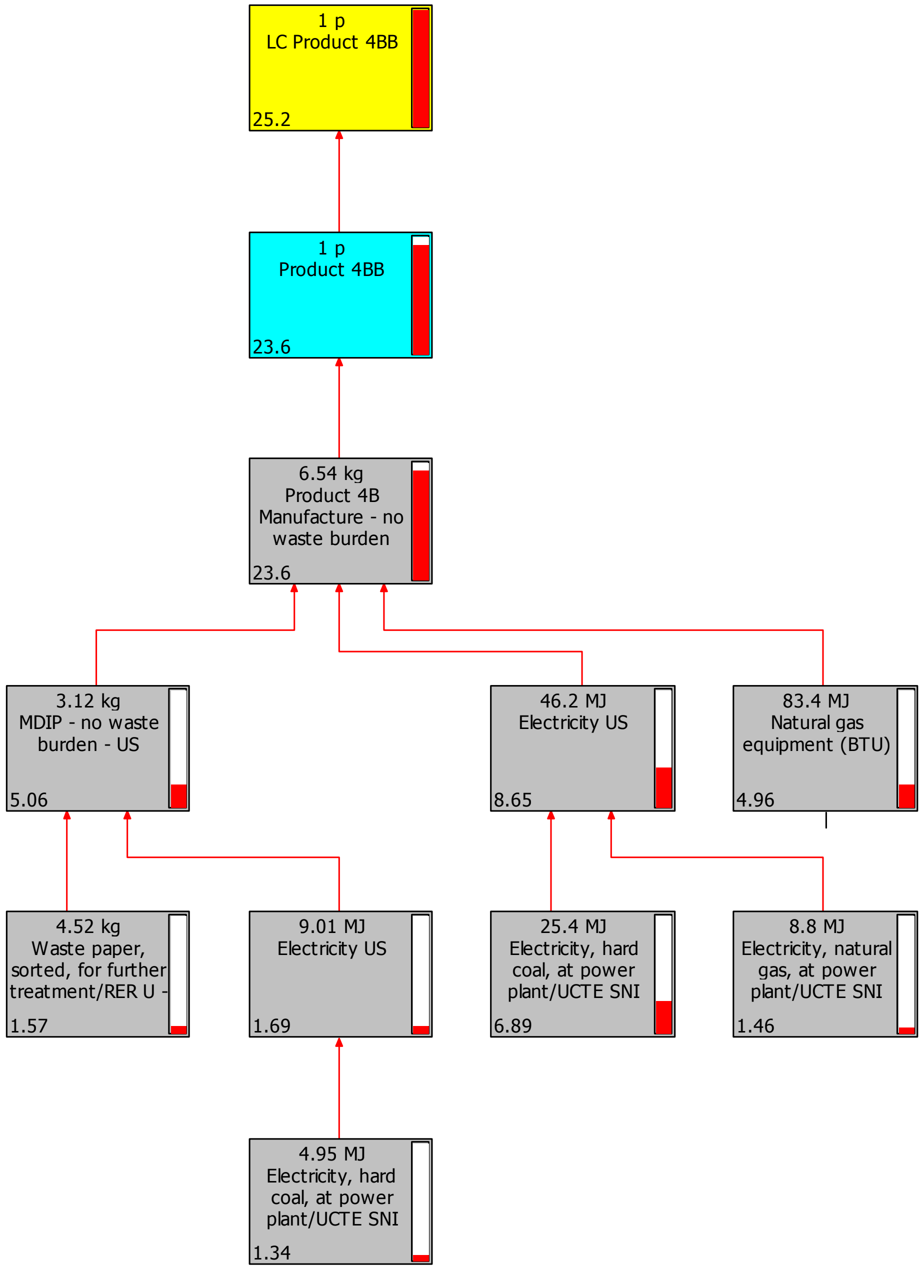


Table 3.17 Product 5 – European Folded toilet tissue

Impact category	Unit	Product 5A	Product 5B	Product 5BB	Product 5AB
Coal	kg Coal	141.4	147.7	111.5	114.4
Oil	kg Oil	66.63	64.7	43.9	51.1
Natural gas	m^3 Gas	194.36	190.3	156.2	168.9
Carbon Dioxide (Fossil)	kg CO_2	950.0	967.4	786.6	814.8
Methane	kg CH_4	9.54	11.37	10.89	9.18
NOx	kg NOx	2.46	2.63	1.84	1.87
SOx	kg SOx	2.22	2.08	1.16	1.53
COD	kg COD	15.95	12.86	10.61	14.27
BOD	kg BOD	3.37	3.59	3.19	3.07
Suspended Solids	kg SS	0.38	0.31	0.18	0.28
Particulates	kg PM	0.80	0.88	0.45	0.47
Water consumption (manufacturing)	m^3	52.17	50.48	25.36	33.7
Water total	m^3	3639	4294.70	1017.19	1189.08
PAH (air bourne)	kg PAH	1.51E-03	1.60E-04	1.30E-04	1.5E-03
CED	MJ-eq	28359	27306	12882	17578
Raw materials (manufacturing)	kg	382.3	352.4	352.4	382.3
Waste (manufacturing)	kg	21.7	19.3	19.3	21.7

Figure 3.16 Product 5A fossil carbon dioxide flow chart

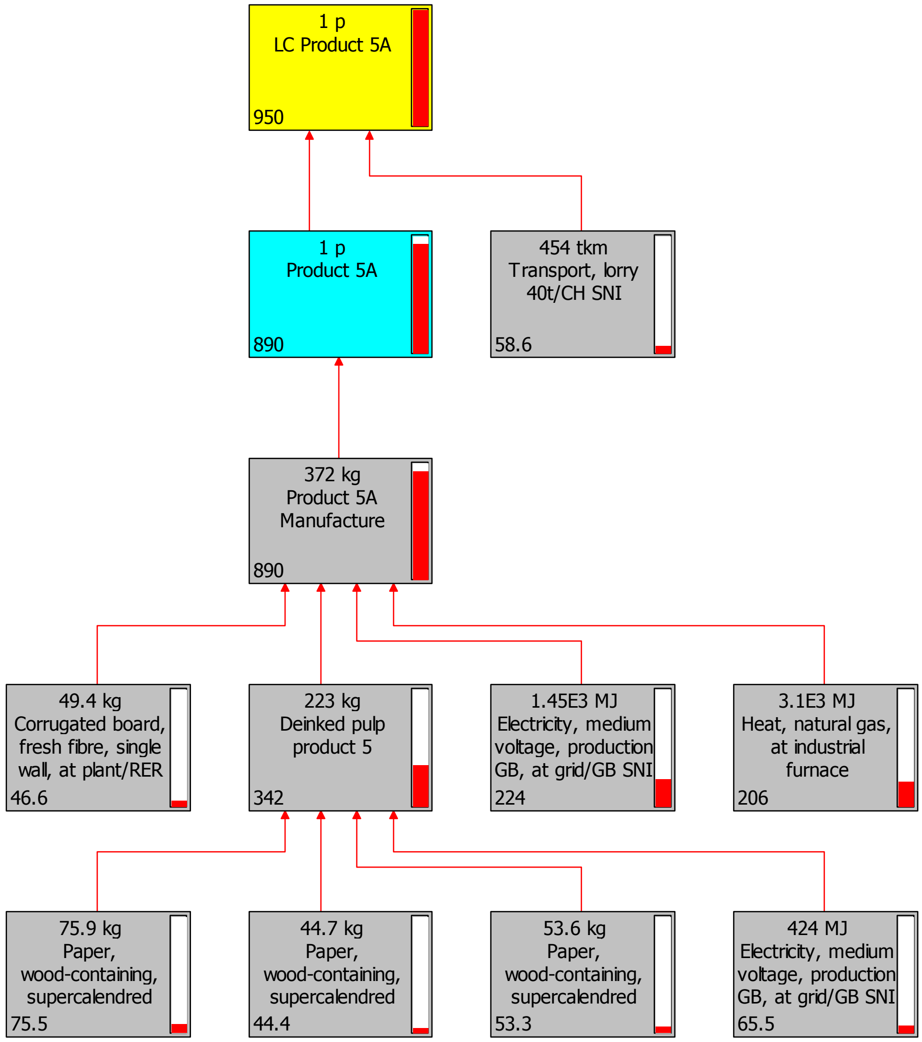


Figure 3.17 Product 5B fossil carbon dioxide flow chart

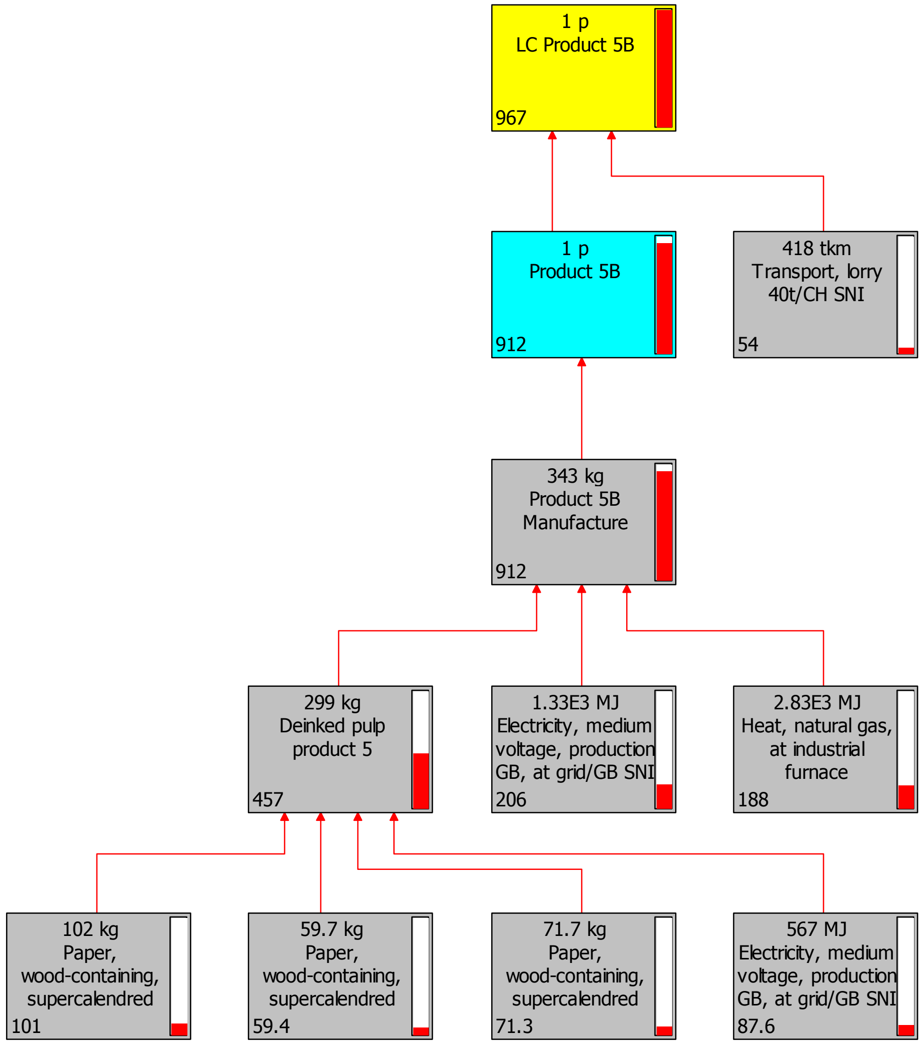


Figure 3.18 Product 5BB fossil carbon dioxide flow chart

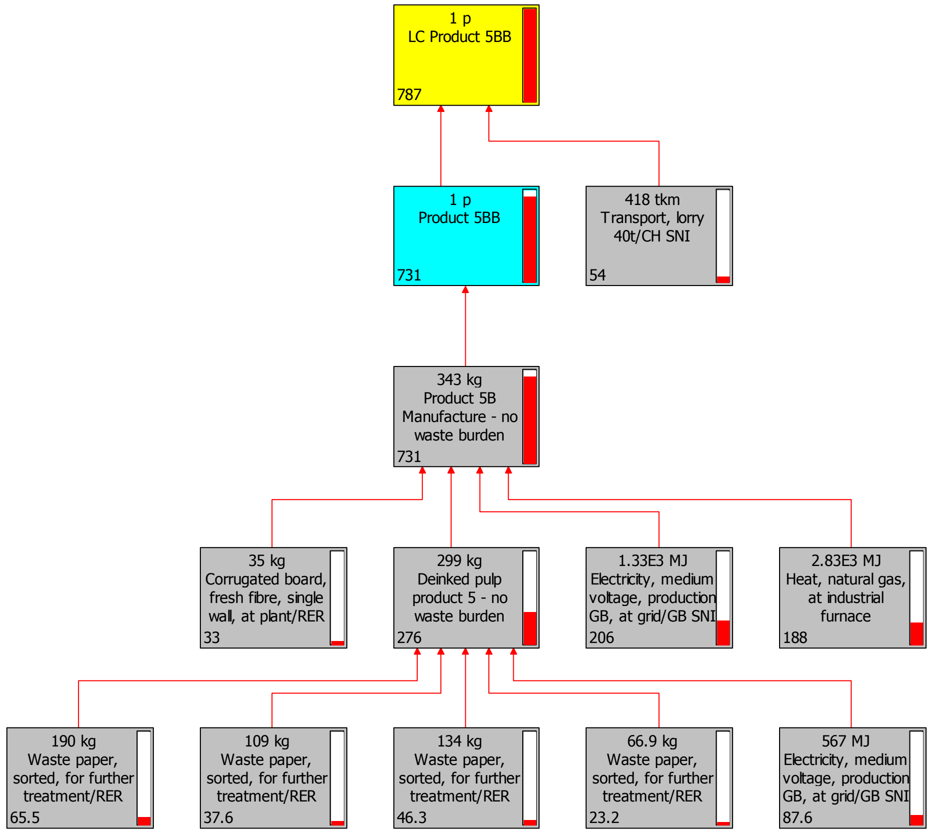


Figure 3.19 Product 5AB fossil carbon dioxide flow chart

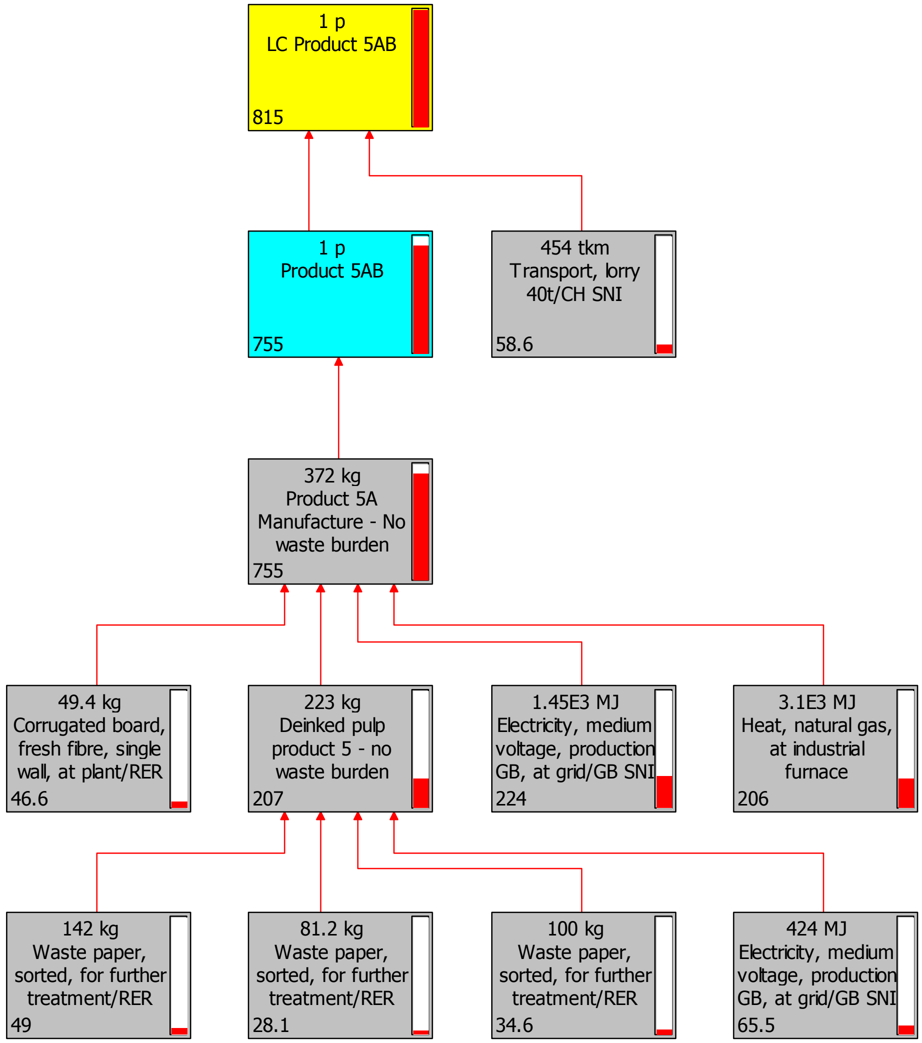


Table 3.18 Product 6 – European Roll toilet tissue

Impact category	Unit	Product 6A	Product 6B	Product 6BB
Coal	kg Coal	3.29	5.25	4.64
Oil	kg Oil	3.09	3.87	3.39
Natural gas	m^3 Gas	13.97	16.11	15.53
Carbon Dioxide (Fossil)	kg CO_2	43.11	56.02	51.42
Methane	kg CH_4	0.66	0.78	0.77
NOx	kg NOx	0.11	0.17	0.15
SOx	kg SOx	0.11	0.15	0.13
COD	kg COD	1.93	2.06	2.01
BOD	kg BOD	0.36	0.43	0.42
Suspended Solids	kg SS	0.04	0.04	0.04
Particulates	kg PM	0.02	0.03	0.03
Water consumption (manufacturing)	m^3	3.01	3.36	2.94
Water total	m^3	497.90	531.33	476.32
PAH (air bourne)	kg PAH	2.86E-04	2.21E-04	2.21E-04
CED	MJ-eq	1847	2089	1842
Raw materials (manufacturing)	kg	32.86	32.97	32.97
Waste (manufacturing)	kg	3.48	3.48	3.48

Figure 3.20 Product 6A fossil carbon dioxide flow chart

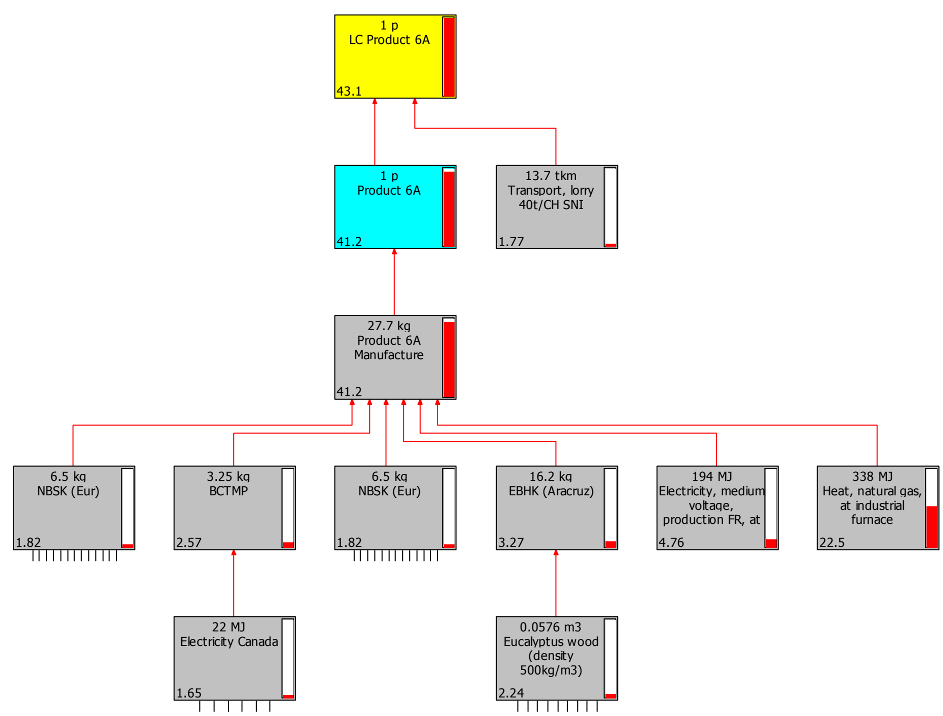


Figure 3.21 Product 6B fossil carbon dioxide flow chart

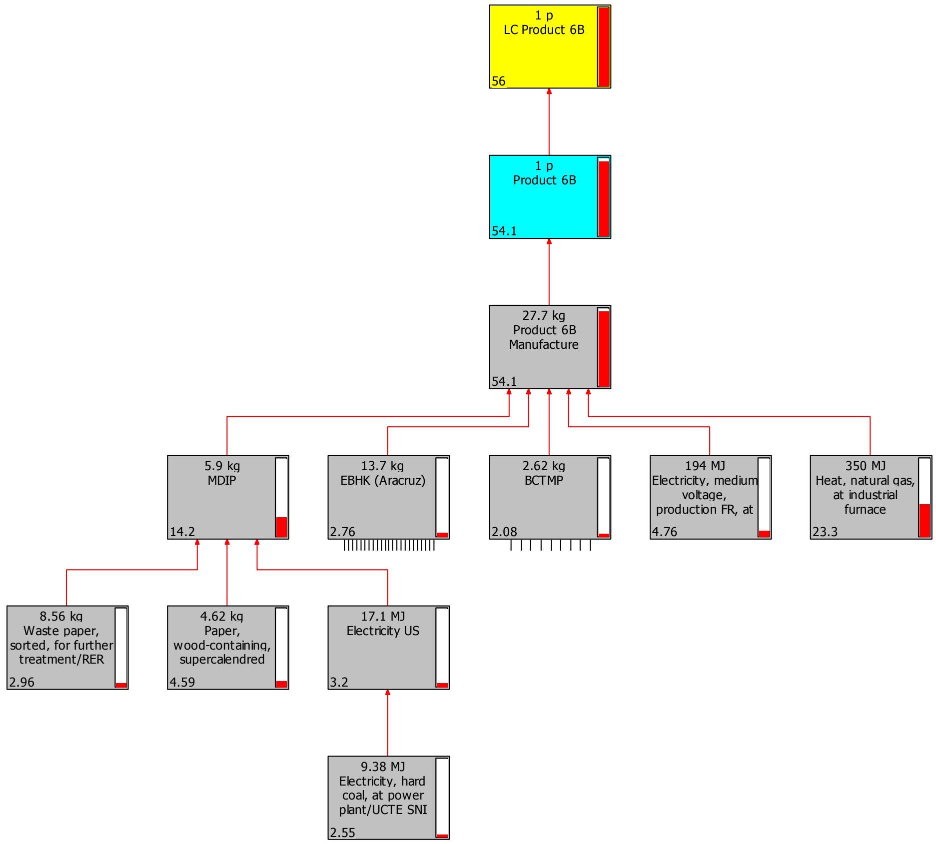


Figure 3.22 Product 6BB fossil carbon dioxide flow chart

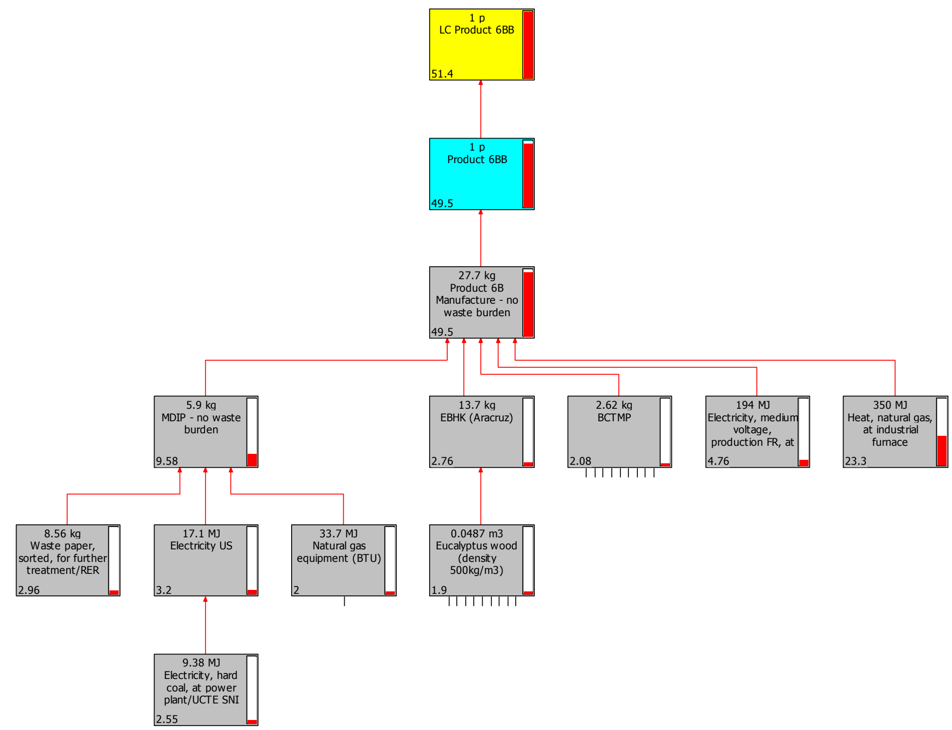


Table 3.19 Product 7 – European Commercial Wipers

Impact category	Unit	Product 7A	Product 7B	Product 7BB
Coal	kg Coal	83.8	162.6	136.7
Oil	kg Oil	31.2	50.8	35.9
Natural gas	M^3 Gas	130.3	202.9	178.4
Carbon Dioxide (Fossil)	kg CO_2	596.9	953.6	824.0
Methane	kg CH_4	1.70	12.26	11.92
NOx	kg NOx	1.13	2.23	1.66
SOx	kg SOx	1.19	1.80	1.13
COD	kg COD	12.40	23.59	21.99
BOD	kg BOD	2.15	6.12	5.83
Suspended Solids	kg SS	0.17	0.17	0.07
Particulates	kg PM	0.31	0.79	0.44
Water consumption (manufacturing)	m^3	25.9	41.45	23.45
Water total	m^3	697.4	3208.9	859.7
PAH (air bourne)	kg PAH	2.1E-03	8.8E-05	6.7E-05
CED	MJ-eq	14463.2	23914.3	13407.6
Raw materials (manufacturing)	kg	201.6	243.15	243.15
Waste (manufacturing)	kg	3.48	6.15	6.15

Figure 3.23 Product 7A fossil carbon dioxide flow chart

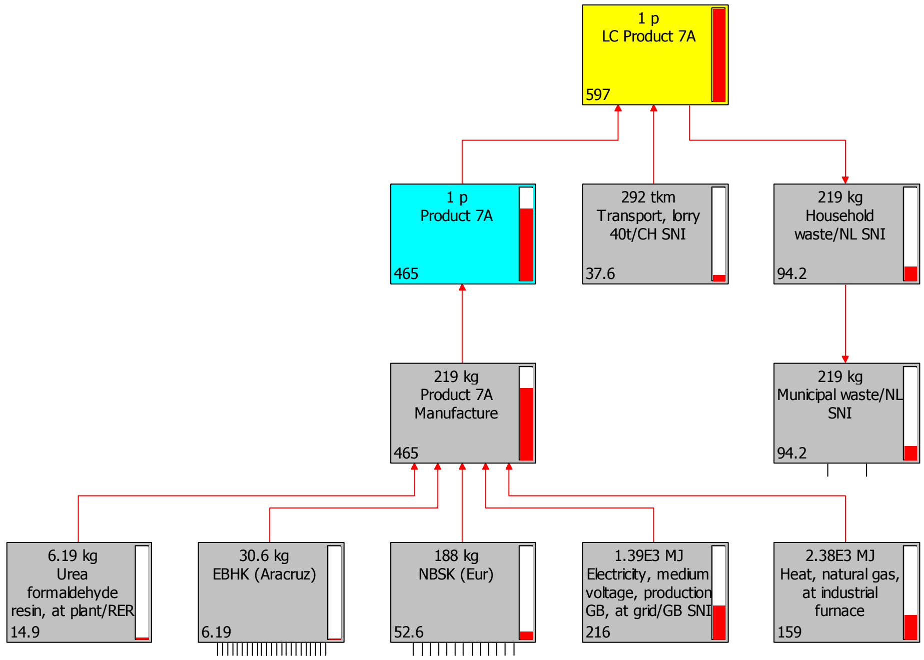


Figure 3.24 Product 7B fossil carbon dioxide flow chart

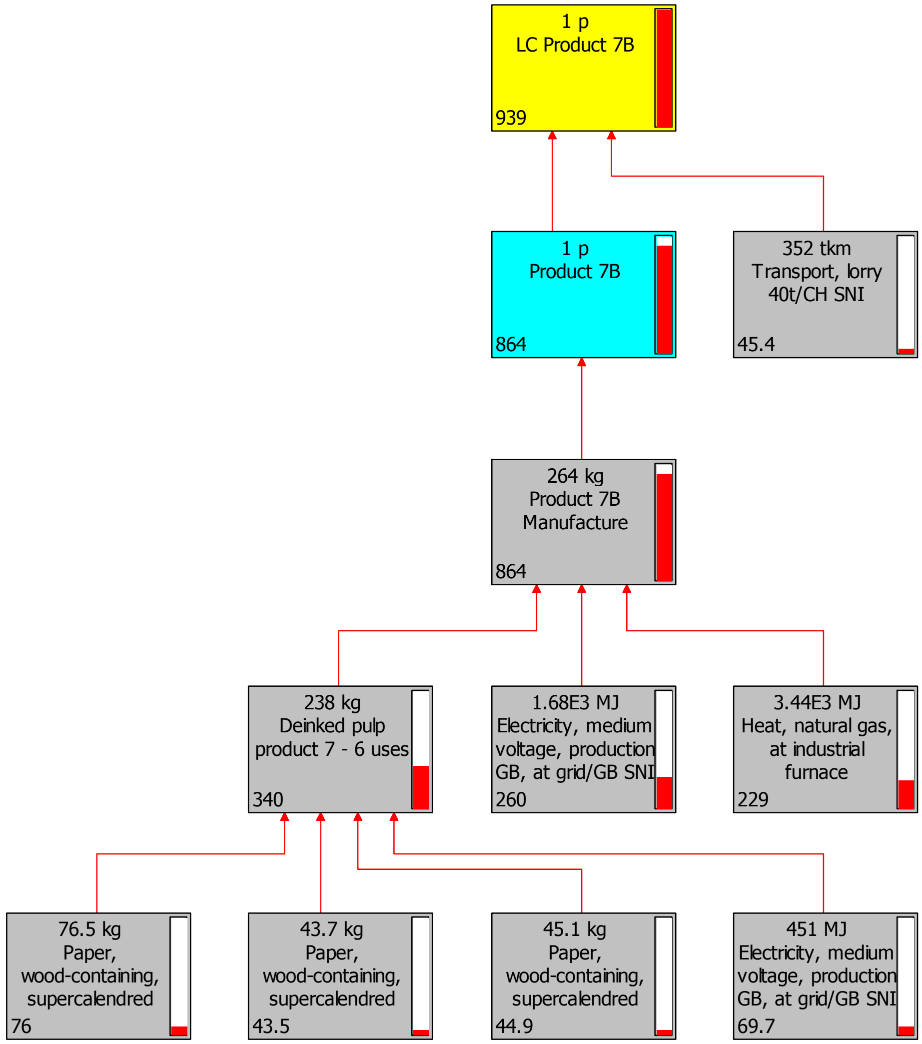
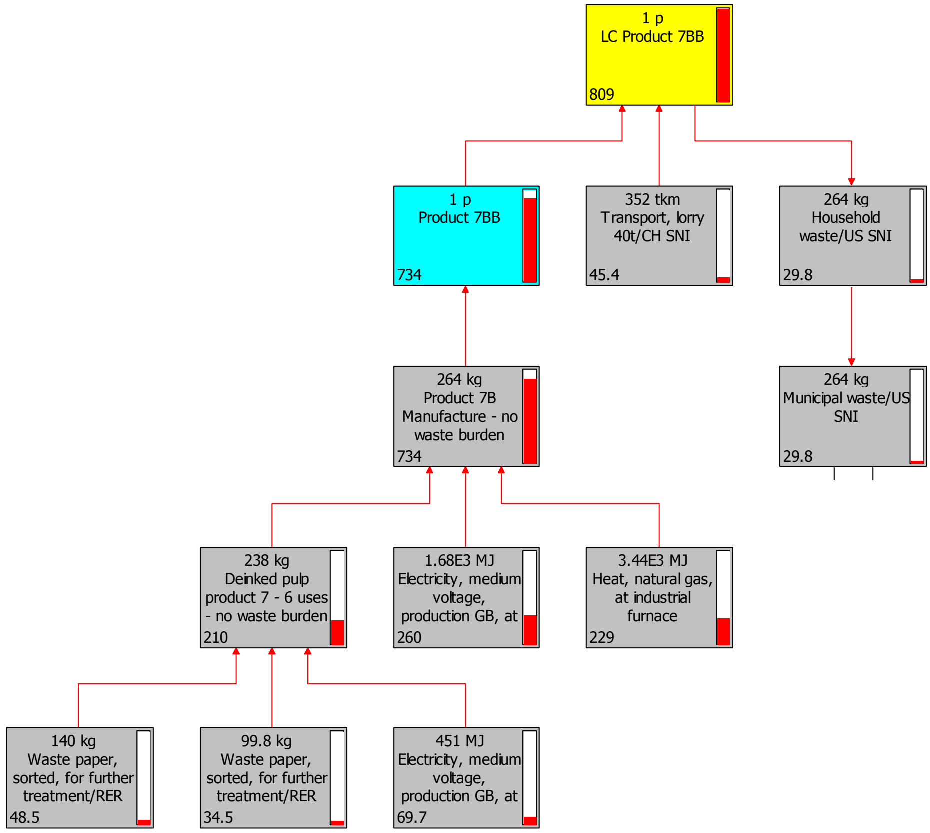


Figure 3.25 Product 7BB fossil carbon dioxide flow chart



4 *IMPACT ASSESSMENT*

In the following chapter, the data that has been collated and analysed in the life cycle inventory was further interpreted using the CML 2001 Baseline life cycle impact assessment methodology. As described in the goal and scope, we removed ecotoxicity from the CML method due to the large uncertainties of the validity of the results. To account for this, the sensitivity analysis will include an assessment using the Impact 2002+ method which includes detailed and up to date calculations of ecotoxicity.

Furthermore a comparison of energy use, water use and solid waste is presented.

The results will be shown per product type, where Product A is produced using virgin fibres and Product B contain recycled fibres in different amounts specific to the product assessed. Product BB represents the recycled fibre scenario where waste paper comes free of burden and no environmental impacts have been allocated to the paper's previous lives. In addition to the impact assessment results, the inventory results for water consumption, Cumulative Energy Demand (CED) and waste production are shown as well.

To assess the scale of the impacts, a normalisation step is carried out for a selection of the products under study.

Although a statistical treatment of the data was not possible we believe that when comparing values, only a difference of 10% or more is meaningful. In other cases the systems are considered equivalent. This is explained further in the life cycle interpretation section (C*hapter 5*)

4.1 *PRODUCT 1 – NORTH AMERICAN BATHROOM TISSUE*

Figure 4.1 and *Table 4.1* show the life cycle impacts for Product 1A, 1B and 1BB. *Figure 4.1* shows a comparison of the three life cycles illustrated by relating the contribution from the three product codes to each impact category. Note these are represented as a percentage of the impact of the product which has the greatest impact in the particular impact category.

Figure 4.1 ***Comparison of the three life cycles***

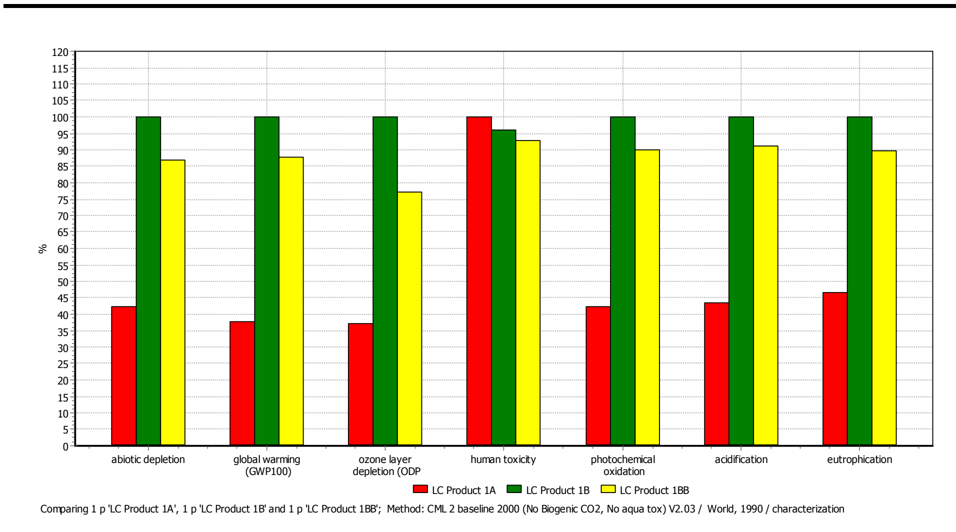


Table 4.1 details the results for each impact category.

Table 4.1 ***Impact profile for Products 1A, 1B and 1BB***

Impact category	Unit	Product 1A	Product 1B	Product 1BB
abiotic depletion	kg Sb eq	0.185	0.435	0.38
global warming	kg CO_2 eq	24.847	65.772	57.76
ozone layer depletion	kg CFC-11 eq	9.62E-07	2.60E-06	2.00E-06
human toxicity	kg 1,4-DB eq	64.743	62.118	60.04
photochemical oxidation	kg C_2H_4	0.009	0.021	0.02
acidification	kg SO_2 eq	0.225	0.520	0.47
eutrophication	kg PO_4--- eq	0.045	0.096	0.09
water consumption	m^3	1.73	3.48	2.79
CED	MJ	655	1599	1195
Waste	kg	0.4	0.57	0.57

As can be seen from *Figure 4.1* and *Table 4.1*, Product 1B has a higher environmental impact for all categories except 'human toxicity'. The main reason for the variation in environmental impact between the three product systems is the difference in weight of material to reach functional equivalence of 40, 000 sheets which is the functional unit, ie Product 1B weighs almost two times more than Product A per m^2 tissue. The higher impact on human toxicity from Product 1A is due to the emissions of PAH from burning black liquor for energy in the production of virgin pulp. In addition the results show that Product 1A consumes less water and energy, and produces less waste than Product 1B. Changing the recycling scenario does not influence the conclusions that the virgin fibre product has less impact.

Table 4.2 shows the variation in contribution per life cycle stages of the three product systems (A, B and BB). They comprise:

- raw materials and manufacturing of tissues;
- transport to storage/retail; and

- end of life.

Table 4.2 ***Variation in contribution from different life cycle stages for Products 1A, 1B and 1BB***

Impact category	Manufacture	Transport	End of life
Abiotic Depletion	94-96%	4-5%	0%
Global Warming	86-92%	4-6%	5-8%
Ozone Layer Depletion	72-84%	5-21%	0-1%
Human Toxicity	95-97%	1%	3-4%
Photochemical Oxidaton	92-94%	2-3%	4-6%
Acidification	92-97%	1-4%	0-7%
Eutrophication	83-87%	3-4%	10-14%

The manufacturing life cycle stage is dominant for all product codes. A more detailed analysis of the manufacturing phase for the three product codes is detailed in *Table 4.3* to *Table 4.5*.

Table 4.3 ***Product 1A NA Bathroom tissue: Impact profile per input to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	2.5%	45.6%	5.1%	25.8%	21.1%	< 1%
global warming	2.3%	54.2%	4.1%	22.6%	16.7%	< 1%
ozone layer depletion	3.9%	67.9%	8.5%	19.3%	< 1%	< 1%
human toxicity	< 1%	95.7%	< 1%	3.1%	< 1%	< 1%
photochemical oxidation	1.7%	46.4%	4.2%	11.3%	36.3%	< 1%
acidification	1.2%	39.1%	4.0%	11.5%	44.1%	< 1%
eutrophication	1.3%	70.8%	2.9%	4.3%	20.7%	< 1%

Table 4.4 ***Product 1B NA Bathroom tissue: Impact profile per input to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	2.5%	45.6%	5.1%	25.8%	21.1%	< 1%
global warming	2.3%	54.2%	4.1%	22.6%	16.7%	< 1%
ozone layer depletion	3.9%	67.9%	8.5%	19.3%	< 1%	< 1%
human toxicity	< 1%	95.7%	< 1%	3.1%	< 1%	< 1%
photochemical oxidation	1.7%	46.4%	4.2%	11.3%	36.3%	< 1%
acidification	1.2%	39.1%	4.0%	11.5%	44.1%	< 1%
eutrophication	1.3%	70.8%	2.9%	4.3%	20.7%	< 1%

Table 4.5 Product 1BB NA Bathroom tissue: Impact profile per input to manufacturing

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	2.9%	36.9%	5.9%	29.9%	24.4%	< 1%
global warming	2.7%	47.2%	4.8%	26.1%	19.3%	< 1%
ozone layer depletion	5.4%	55.8%	11.7%	26.5%	< 1%	< 1%
human toxicity	< 1%	95.5%	< 1%	3.2%	< 1%	< 1%
photochemical oxidation	1.9%	40.0%	4.8%	12.7%	40.6%	< 1%
acidification	1.4%	33.1%	4.4%	12.6%	48.5%	< 1%
eutrophication	1.5%	66.8%	3.3%	4.9%	23.5%	< 1%

For Products 1A, 1B and 1BB, pulp production and energy consumption during manufacturing contribute the most to each impact category.

4.2 PRODUCT 2 – NORTH AMERICAN WASHROOM TOWEL

Figure 4.2 and *Table 4.8* compare the life cycle impact of the three product types.

Figure 4.2 Comparison of the three life cycles

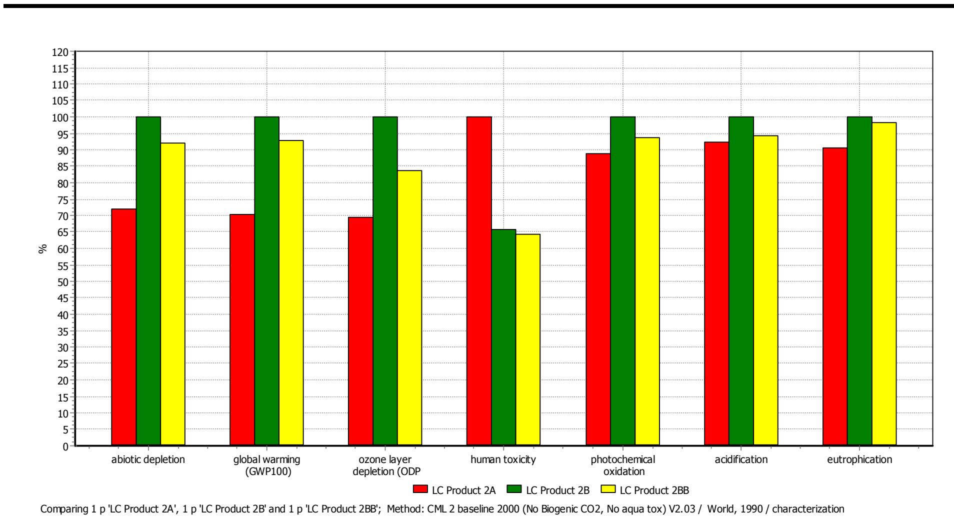


Table 4.6 ***Impact profile for Product 2A, 2B and 2BB (NA Washroom tissue)***

Impact category	Unit	Product 2A	Product 2B	Product 2BB
abiotic depletion	kg Sb eq	3.18	4.41	4.05
global warming	kg CO_2 eq	486.77	691.64	641.72
ozone layer depletion	kg CFC-11 eq	0.00	0.00	0.00
human toxicity	kg 1,4-DB eq	839.01	552.25	539.31
photochemical oxidation	kg C_2H_4	0.19	0.22	0.20
acidification	kg SO_2 eq	4.53	4.91	4.62
eutrophication	kg PO_4--- eq	3.20	3.54	3.48
water consumption	m^3	22.9	30.8	26.5
CED	MJ	10935	14788	12270
Waste	kg	47.1	47.2	47.2

As shown in *Figure 4.2* and *Table 4.6,* Product 2B has a higher environmental impact for all categories except for human toxicity. Product 2B also consumes more water and energy over its lifetime, yet produces a smaller amount of waste than Product 2A. This difference in waste production is only *circa* 5%.

Table 4.7 shows the variation in contribution per life cycle stages of the three product systems (A, B and BB).

Table 4.7 ***Variation in contribution from different life cycle stages for Products 2A, 2B and 2BB***

Impact category	Manufacture	Transport	End of life
Abiotic Depletion	97-98%	2-3%	0%
Global Warming	83-87%	2-3%	10-14%
Ozone Layer Depletion	84-87%	10-15%	1%
Human Toxicity	95-97%	0%	3-5%
Photochemical Oxidaton	92-93%	1%	6-7%
Acidification	98%	2%	0%
Eutrophication	91-97%	1-3%	0-9%

The manufacturing life cycle stage is dominant for all product codes. A more detailed analysis of the manufacturing phase for the three product codes is detailed in *Table 4.8* to *Table 4.10*.

Table 4.8 ***Product 2A NA Washroom tissue: Impact profile per input to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	8.4%	10.9%	1.7%	50.0%	28.8%	< 1%
global warming	6.8%	11.3%	1.9%	48.1%	25.1%	6.9%
ozone layer depletion	13.9%	33.8%	5.3%	44.8%	< 1%	1.6%
human toxicity	< 1%	95.5%	< 1%	3.2%	< 1%	< 1%
photochemical oxidation	3.9%	30.7%	< 1%	18.5%	42.0%	4.2%
acidification	2.4%	27.1%	< 1%	18.7%	50.8%	< 1%
eutrophication	< 1%	5.0%	< 1%	1.8%	6.0%	86.4%

Table 4.9 ***Product 2B NA Washroom tissue: Impact profile per input to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	9.0%	30.4%	1.2%	35.6%	22.4%	1.4%
global warming	6.4%	36.2%	1.3%	31.9%	18.1%	6.0%
ozone layer depletion	16.6%	46.8%	3.6%	29.3%	< 1%	3.2%
human toxicity	1.2%	92.0%	< 1%	4.9%	< 1%	1.1%
photochemical oxidation	5.5%	33.7%	< 1%	16.3%	40.1%	3.8%
acidification	3.1%	27.9%	< 1%	17.3%	50.9%	< 1%
eutrophication	< 1%	14.6%	< 1%	1.6%	5.9%	77.0%

Table 4.10 ***Product 2BB NA Washroom tissue: Impact profile per input to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	9.8%	24.1%	1.3%	38.8%	24.4%	1.6%
global warming	7.0%	30.5%	1.4%	34.8%	19.7%	6.5%
ozone layer depletion	20.2%	35.0%	4.4%	35.9%	< 1%	4.0%
human toxicity	1.2%	91.8%	< 1%	5.0%	< 1%	1.2%
photochemical oxidation	5.9%	28.9%	< 1%	17.4%	43.0%	4.1%
acidification	3.3%	23.3%	< 1%	18.3%	54.1%	< 1%
eutrophication	< 1%	12.9%	< 1%	1.6%	6.0%	78.5%

For Products 2A, 2B and 2BB, pulp production and energy consumption during manufacturing contribute the most to each impact category (except eutrophication where leachate of nutrients from solid waste treatment contributes the most). The large contribution from waste to eutrophication is not as extreme for the other product codes (eg product 1). Most pulp mills recycle their paper waste and thus the impact of this is typically included in the extra energy consumed for this recycling process and not as waste to landfill.

For both products, over 90% of the human toxicity impact is due to pulp production. Product 2A consists of 100% virgin fibre whilst, Product 2B consists of 55% virgin fibre and 45% recycled. The use of black liquor to produce the energy consumed in production of virgin fibre going in to Product 2B is thus the cause of the high human toxicity potential associated with this product.

4.3 PRODUCT 3 – NORTH AMERICAN FACIAL TISSUE

Figure 4.3 and *Table 4.11* show the environmental impacts associated with the life cycles of the three product types.

Figure 4.3 Comparison of the three life cycles

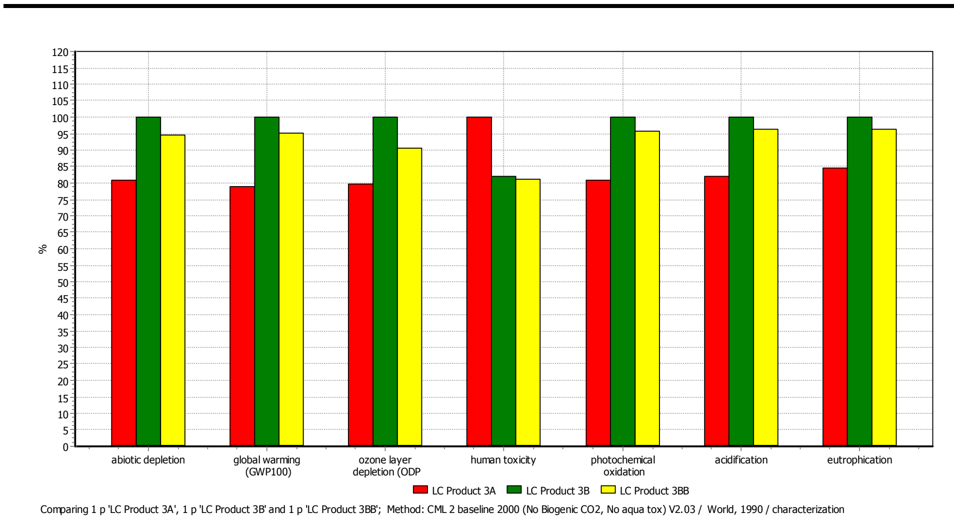


Table 4.11 Impact profile for Products 3A, 3B and 3BB (NA facial tissue)

Impact category	Unit	Product 3A	Product 3B	Product 3BB
abiotic depletion	kg Sb eq	0.25	0.30	0.29
global warming	kg CO_2 eq	37.46	45.85	43.97
ozone layer depletion	kg CFC-11 eq	2.29E-06	2.63E-06	2.49E-06
human toxicity	kg 1,4-DB eq	58.11	47.81	47.32
photochemical oxidation	kg C_2H_4	0.01	0.01	0.01
acidification	kg SO_2 eq	0.28	0.33	0.32
eutrophication	kg PO_4--- eq	0.06	0.07	0.07
water consumption	m^3	1.45	1.75	1.59
CED	MJ	4381	5880	5176
Waste	kg	0.8	0.77	0.77

As shown in *Figure 4.3* and *Table 4.11*, Product 3B has a higher environmental impact for all categories except for human toxicity. Again, this is caused by the PAH emissions from burning black liquor. The water consumption and energy use across the lifetime of Product 3A is lower than Product 3B, as is waste production.

Table 4.12 shows the variation in contribution for the life cycle stages of the product systems.

Table 4.12 Variation in contribution from different life cycle stages for Product 3A, 3B and 3BB

Impact category	Manufacture	Transport	End of life
Abiotic Depletion	96-97%	3-4%	0%
Global Warming	81-85%	3-4%	12-15%
Ozone Layer Depletion	84-87%	12-15%	1%
Human Toxicity	96-97%	0%	3-4%
Photochemical Oxidaton	89-91%	1%	8-10%
Acidification	97%	3%	0%
Eutrophication	63-67%	2%	31-35%

The manufacturing life cycle stage is dominant for all product codes. A more detailed analysis of the manufacturing phase for the three product codes is detailed in *Table 4.13* to *Table 4.15*.

Table 4.13 Product 3A NA facial tissue: Impact profile per input to manufacturing

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	5.9%	11.6%	11.7%	39.9%	30.9%	< 1%
global warming	5.1%	12.9%	13.1%	40.6%	28.4%	< 1%
ozone layer depletion	8.3%	28.8%	31.6%	30.7%	< 1%	< 1%
human toxicity	< 1%	96.1%	1.1%	2.4%	< 1%	< 1%
photochemical oxidation	3.6%	13.8%	4.8%	19.2%	58.5%	< 1%
acidification	2.1%	9.7%	3.6%	18.2%	66.4%	< 1%
eutrophication	2.0%	46.7%	8.3%	7.8%	35.2%	< 1%

Table 4.14 Product 3B NA facial tissue: Impact profile per input to manufacturing

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	5.0%	23.9%	11.0%	33.4%	26.7%	< 1%
global warming	4.0%	29.4%	11.6%	31.9%	23.0%	< 1%
ozone layer depletion	6.9%	39.4%	28.5%	24.7%	< 1%	< 1%
human toxicity	< 1%	94.8%	1.5%	3.0%	< 1%	< 1%
photochemical oxidation	3.0%	26.9%	4.5%	15.9%	49.8%	< 1%
acidification	1.8%	21.0%	3.5%	15.5%	58.2%	< 1%
eutrophication	1.7%	54.4%	7.6%	6.4%	29.8%	< 1%

Table 4.15 ***Product 3BB NA facial tissue: Impact profile per input to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	5.3%	19.4%	11.6%	35.4%	28.3%	< 1%
global warming	4.3%	25.1%	12.3%	33.9%	24.4%	< 1%
ozone layer depletion	7.7%	32.0%	32.0%	27.7%	< 1%	< 1%
human toxicity	< 1%	94.7%	1.5%	3.1%	< 1%	< 1%
photochemical oxidation	3.2%	23.3%	4.7%	16.7%	52.2%	< 1%
acidification	1.9%	17.8%	3.6%	16.1%	60.5%	< 1%
eutrophication	1.8%	51.8%	8.1%	6.8%	31.6%	< 1%

For Products 3A, 3B and 3BB, pulp production and energy consumption during manufacturing contribute most to each impact category (except eutrophication, where waste treatment contributes the most). For both products over 90% of the human toxicity impact is due to pulp production. Product 3A consists of 100% virgin fibre, whilst Product 3B consists of 80% virgin fibre and 20% recycled fibre. The use of black liquor to produce the amount of virgin fibre consumed in Product 3B is the cause of the high human toxicity potential from this product.

4.4 PRODUCT 4 – NORTH AMERICAN KITCHEN TOWEL

Figure 4.4 and *Table 4.22* detail the environmental impact associated with the three products.

Figure 4.4 ***Comparison of the three life cycles***

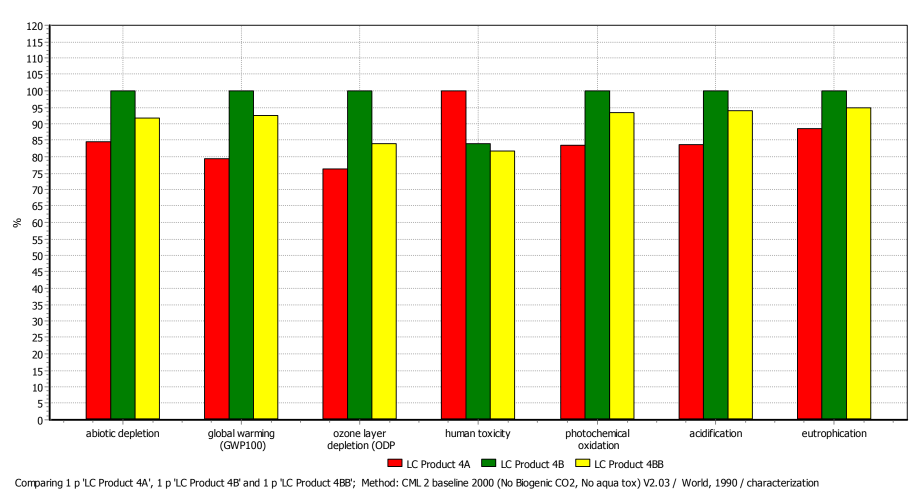


Table 4.16 ***Impact profile for Products 4A, 4B and 4BB (NA kitchen towel)***

Impact category	Unit	Product 4A	Product 4B	Product 4BB
abiotic depletion	kg Sb eq	0.19	0.22	0.20
global warming	kg CO2 eq	27.28	34.34	31.76
ozone layer depletion	kg CFC-11 eq	9.17E-07	1.20E-06	1.01E-06
human toxicity	kg 1,4-DB eq	30.72	25.80	25.13
photochemical oxidation	kg C2H4	0.01	0.01	0.01
acidification	kg SO2 eq	0.20	0.24	0.23
eutrophication	kg PO4--- eq	0.06	0.06	0.06
water consumption	m^3	1.35	1.15	0.93
CED	MJ	653	763	632
Waste	kg	2.54	2.84	2.84

As shown in *Figure 4.4* and *Table 4.16*, Product 4B has a higher environmental impact for all categories, except for human toxicity. Again, this is caused by the PAH emissions from burning black liquor. The alternative recycling scenario does not change the results significantly. The water consumption and energy use across the lifetime of Product 3A is lower than Product 3B, as is waste production.

Table 4.17 shows the variation in contribution to the different life cycle stages of the three product systems.

Table 4.17 ***Variation in contribution from different life cycle stages for Product 4A, 4B and 4BB***

Impact category	Manufacture	Transport	End of life
Abiotic Depletion	97%	3%	0%
Global Warming	85-87%	3%	10-12%
Ozone Layer Depletion	86-87%	11-14%	1%
Human Toxicity	94-95%	0%	4-5%
Photochemical Oxidaton	91-93%	1%	7-8%
Acidification	97-98%	2-3%	0%
Eutrophication	74-76%	2%	22-24%

The manufacturing life cycle stage is dominant for all product codes. A more detailed analysis of the manufacturing phase for the three product codes is detailed in *Table 4.18* to *Table 4.20*

Table 4.18 ***Product 4A NA kitchen towel: Impact profile per input material to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	8.4%	15.7%	9.8%	41.8%	24.1%	< 1%
global warming	6.7%	16.5%	9.4%	41.6%	21.7%	4.1%
ozone layer depletion	21.3%	18.8%	20.7%	37.7%	< 1%	< 1%
human toxicity	< 1%	92.9%	1.5%	4.3%	< 1%	< 1%
photochemical oxidation	6.4%	20.7%	4.3%	20.1%	45.4%	3.2%
acidification	3.2%	15.5%	4.3%	20.7%	56.1%	< 1%
eutrophication	2.1%	38.0%	5.3%	6.3%	21.1%	27.2%

Table 4.19 ***Product 4B NA kitchen towel: Impact profile per input material to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	8.1%	30.5%	5.9%	34.0%	21.4%	< 1%
global warming	6.0%	37.0%	5.4%	30.9%	17.5%	3.0%
ozone layer depletion	14.4%	45.5%	12.2%	26.8%	< 1%	< 1%
human toxicity	1.1%	92.0%	1.4%	5.1%	< 1%	< 1%
photochemical oxidation	5.2%	34.4%	2.6%	16.0%	39.3%	2.5%
acidification	3.0%	28.4%	2.5%	16.6%	49.2%	< 1%
eutrophication	2.1%	47.8%	3.4%	5.2%	19.0%	22.4%

Table 4.20 ***Product 4BB NA kitchen towel: Impact profile per input material to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	8.9%	24.0%	6.5%	37.2%	23.4%	< 1%
global warming	6.6%	31.1%	5.9%	33.8%	19.2%	3.3%
ozone layer depletion	17.6%	33.5%	14.9%	32.7%	< 1%	< 1%
human toxicity	1.1%	91.7%	1.4%	5.2%	< 1%	< 1%
photochemical oxidation	5.6%	29.4%	2.8%	17.2%	42.3%	2.7%
acidification	3.2%	23.7%	2.7%	17.7%	52.4%	< 1%
eutrophication	2.3%	44.1%	3.7%	5.5%	20.4%	24.0%

For Product 4A, 4B and 4BB, pulp production and energy consumption during manufacturing contribute the most to each impact. For both products, the contribution to human toxicity from pulp production is above 90% of the total human toxicity potential. Product 4A consists of 100% virgin fibre, whilst Product 4B consists of 60% virgin fibre and 40% recycled fibre. The use of black liquor to produce the amount of virgin fibre consumed in Product 4B is thus the cause of the high human toxicity potential from this product. The contribution from waste is caused by nitrate leachate from landfilling the paper waste.

4.5 *PRODUCT 5 – EUROPEAN FOLDED TOILET TISSUE*

When compared to the other products, Product 5 is unique in that product A contains 60% recycled fibre whereas Product B contains 100% recycled fibre. Therefore the results were supplemented with an extra scenario where the results of Product 5A were calculated where no environmental burden has been assigned to the previous life of the waste paper used to produce recycled fibres.

Figure 4.5 and *Table 4.21* detail the life cycle impacts from the four products assessed.

Figure 4.5 Comparison of the three life cycles

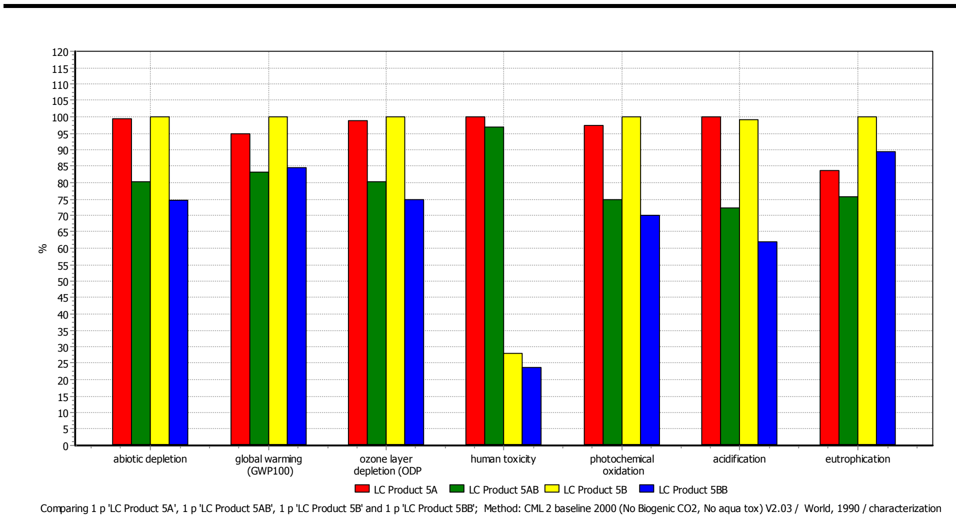


Table 4.21 Impact profile for Products 5A, 5AB, 5B and 5BB (EUR folded toilet tissue)

Impact category	Unit	Product 5A	Product 5AB	Product 5B	Product 5BB
abiotic depletion	kg Sb eq	7.48	6.05	7.53	5.61
global warming	kg CO_2 eq	1207.72	1059.92	1273.89	1076.18
ozone layer depletion	kg CFC-11 eq	7.22E-05	5.86E-05	7.30E-05	5.47E-05
human toxicity	kg 1,4-DB eq	1065.65	1030.94	298.13	251.69
photochemical oxidation	kg C_2H_4	0.24	0.18	0.24	0.17
acidification	kg SO_2 eq	4.07	2.94	4.04	2.52
eutrophication	kg PO_4--- eq	2.52	2.28	3.00	2.68
water consumption	m^3	52.17	33.7	50.48	25.36
CED	MJ	28519	17738	27521	13097
Waste	kg	21.7	21.7	19.3	19.3

Figure 4.5 and *Table 4.21* show that compared to Product 5A, Product 5B has a higher environmental impact for all categories, except for human toxicity. Again, this is caused by the PAH emissions from burning black liquor. However, modelling the waste paper used in the integrated deinking mill as free of environmental burden, and with no allocation to the paper's previous lives, has a significant impact on the life cycle results. In this case using recycled fibres has a lower environmental impact than using virgin fibres. Product 5AB has the lowest contribution to global warming when compared to the other products. For the remaining impacts (except eutrophication), Product 5BB has the lowest environmental contribution. Eutrophication is mainly caused by landfilling waste paper from the manufacturing of recycled fibre hence higher impact from products using recycled fibres.

Table 4.22 shows the variation in contribution to the different life cycle stages of the three product systems.

Table 4.22 ***Variation in contribution from different life cycle stages for Product 5A, 5AB, 5B and 5BB***

Impact category	Manufacture	Transport	End of life
Abiotic Depletion	94-95%	5-6%	<1%
Global Warming	91-92%	4-5%	3-4%
Ozone Layer Depletion	81-87%	12-15%	<1%
Human Toxicity	76-94%	0-2%	6-22%
Photochemical Oxidaton	90-93%	3-4%	5-7%
Acidification	87-92%	7-12%	1%
Eutrophication	91-93%	2-3%	5-6%

The manufacturing life cycle stage is dominant for all product codes. A more detailed analysis of the manufacturing phase for the four product codes is detailed in *Table 4.23* to *Table 4.26*.

Table 4.23 ***Product 5A EU folded toilet tissue: Impact profile per input material to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	3.5%	38.6%	4.9%	25.7%	26.4%	<1%
global warming	2.2%	50.6%	4.8%	21.6%	19.8%	<1%
ozone layer depletion	4.8%	38.3%	5.4%	8.0%	42.6%	<1%
human toxicity	1.3%	91.5%	1.7%	3.1%	2.2%	<1%
photochemical oxidation	3.0%	63.3%	12.0%	15.0%	6.6%	<1%
acidification	3.2%	64.7%	6.1%	21.9%	4.2%	<1%
eutrophication	<1%	93.5%	2.9%	2.5%	<1%	<1%

Table 4.24 ***Product 5AB EU folded toilet tissue: Impact profile per input material to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	4.4%	23.0%	6.2%	32.2%	33.0%	1.2%
global warming	2.6%	43.0%	5.5%	25.0%	22.9%	1.0%
ozone layer depletion	6.2%	21.2%	6.9%	10.2%	54.4%	1.2%
human toxicity	1.3%	91.2%	1.7%	3.2%	2.2%	<1%
photochemical oxidation	4.0%	51.0%	16.0%	20.0%	8.8%	<1%
acidification	4.6%	49.2%	8.8%	31.5%	6.0%	<1%
eutrophication	<1%	92.7%	3.2%	2.8%	<1%	<1%

Table 4.25 ***Product 5B EUR folded toilet tissue: Impact profile per input material to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	2.8%	45.6%	3.4%	23.4%	23.8%	<1%
global warming	1.7%	58.7%	3.2%	18.7%	17.0%	<1%
ozone layer depletion	3.2%	47.1%	3.7%	7.2%	38.0%	<1%
human toxicity	4.7%	69.1%	5.0%	12.0%	8.3%	<1%
photochemical oxidation	2.3%	70.2%	8.2%	13.3%	5.8%	<1%
acidification	2.6%	69.1%	4.4%	20.2%	3.8%	<1%
eutrophication	<1%	95.6%	1.7%	1.9%	<1%	<1%

Table 4.26 ***Product 5BB EUR folded toilet tissue: Impact profile per input material to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	3.9%	25.8%	4.7%	32.0%	32.5%	1.1%
global warming	2.0%	50.4%	3.8%	22.4%	20.4%	<1%
ozone layer depletion	4.4%	26.1%	5.2%	10.0%	53.1%	1.1%
human toxicity	5.8%	61.7%	6.2%	14.9%	10.3%	1.1%
photochemical oxidation	3.4%	55.9%	12.1%	19.7%	8.6%	<1%
acidification	4.4%	47.9%	7.4%	34.1%	6.4%	<1%
eutrophication	<1%	95.1%	1.9%	2.1%	<1%	<1%

For Product 5A, 5AB, 5B and 5BB, pulp production and energy consumption during manufacturing contribute most to each impact. For Product 5A, over 90% of the human toxicity impact is due to pulp production. Product 5A consists of 40% virgin fibres and 60% recycled fibre, whilst Product 5B consists of 100% recycled fibre. The use of black liquor to produce the energy for generating virgin fibres consumed in Product 5A is thus the cause of the high human toxicity potential from this product.

4.6 *PRODUCT 6 – EUROPEAN ROLL TOILET TISSUE*

Figure 4.6 and *Table 4.27* detail the impact from the life cycles of the three products.

Figure 4.6 Comparison of the three life cycles

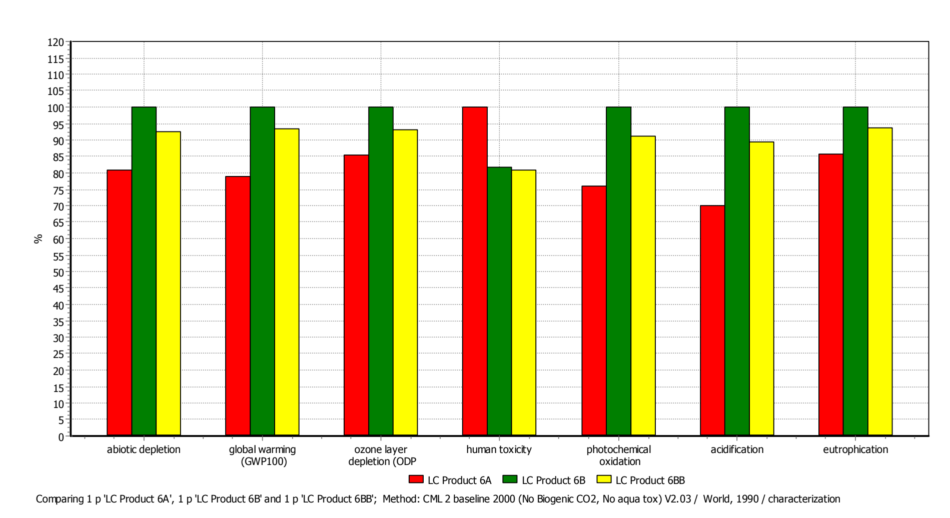


Table 4.27 Impact profile for Products 6A, 6B and 6BB (EUR roll toilet tissue)

Impact category	Unit	Product 6A	Product 6B	Product 6BB
abiotic depletion	kg Sb eq	0.38	0.47	0.43
global warming	kg CO_2 eq	59.03	74.95	70.05
ozone layer depletion	kg CFC-11 eq	0.00	0.00	0.00
human toxicity	kg 1,4-DB eq	177.62	145.02	143.74
photochemical oxidation	kg C_2H_4	0.01	0.01	0.01
acidification	kg SO_2 eq	0.19	0.27	0.24
eutrophication	kg PO_4--- eq	0.08	0.10	0.09
water consumption	m^3	3.01	3.36	2.94
CED	MJ	1847	2089	1842
Waste	kg	3.48	3.48	3.48

As shown in *Figure 4.6* and *Table 4.27,* Product 6B has a higher environmental impact for all categories except for human toxicity. Again, this is caused by the PAH emissions from burning black liquor. The alternative recycling scenario does not influence the results significantly.

Table 4.28 shows the variation in contribution to the different life cycle stages of the three product systems.

Table 4.28 ***Variation in contribution from different life cycle stages for Product 6A, 6B and 6BB***

Impact category	Manufacture	Transport	End of life
Abiotic Depletion	97%	2-3%	<1%
Global Warming	75-80%	2-3%	17-22%
Ozone Layer Depletion	93-94%	5-6%	0-1%
Human Toxicity	93-94%	0%	6-7%
Photochemical Oxidaton	68-73%	1-2%	23-30%
Acidification	93-95%	4-5%	1-2%
Eutrophication	49-56%	2%	42-49%

The manufacturing life cycle stage is dominant for all product codes. The land filling of the sludge from the waste water treatment plant makes a significant contribution to the eutrophication potential at end of life.

A more detailed analysis of the manufacturing phase for the three product codes is detailed in *Table 4.29* to *Table 4.31*.

Table 4.29 ***Product 6A EU roll toilet tissue: Impact profile per input to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	6.6%	20.8%	8.0%	8.7%	55.9%	<1%
global warming	5.8%	23.2%	5.6%	11.4%	53.9%	<1%
ozone layer depletion	6.7%	17.4%	1.6%	4.4%	69.8%	<1%
human toxicity	<1%	97.4%	<1%	<1%	1.4%	<1%
photochemical oxidation	10.4%	49.0%	6.3%	14.2%	20.2%	<1%
acidification	6.2%	58.6%	8.2%	17.2%	9.8%	<1%
eutrophication	3.6%	82.2%	5.1%	4.7%	4.4%	<1%

Table 4.30 ***Product 6B EUR roll toilet tissue: Impact profile per input to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	5.5%	32.5%	6.9%	7.2%	48.0%	<1%
global warming	4.5%	38.8%	4.5%	8.8%	43.3%	<1%
ozone layer depletion	5.9%	25.1%	1.5%	3.9%	63.6%	<1%
human toxicity	<1%	96.6%	<1%	<1%	1.8%	<1%
photochemical oxidation	7.5%	62.7%	4.6%	10.1%	15.0%	<1%
acidification	4.6%	69.3%	6.2%	12.5%	7.4%	<1%
eutrophication	3.0%	85.3%	4.2%	3.8%	3.7%	<1%

Table 4.31 ***Product 6BB EUR roll toilet tissue: Impact profile per input to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	5.3%	34.3%	6.7%	7.0%	46.7%	<1%
global warming	4.3%	41.9%	4.3%	8.4%	41.1%	<1%
ozone layer depletion	5.7%	27.8%	1.4%	3.7%	61.3%	<1%
human toxicity	<1%	96.7%	<1%	<1%	1.8%	<1%
photochemical oxidation	7.2%	64.5%	4.4%	9.6%	14.3%	<1%
acidification	4.4%	71.1%	5.8%	11.8%	6.9%	<1%
eutrophication	2.7%	86.5%	3.9%	3.5%	3.4%	<1%

For Product 6A, 6B and 6BB, pulp production and energy consumption during manufacturing contribute the most to each impact. For both products, the contribution to human toxicity from pulp production is above 90% of the total human toxicity potential. Product 6A consists of 100% virgin fibres, whilst Product 6B consists of 80% virgin fibres and 20% recycled fibres. The use of black liquor to produce the energy for generating virgin fibres going in to Product 6B is thus the cause of the high human toxicity potential from this product.

4.7 PRODUCT 7 – EUROPEAN COMMERCIAL WIPERS

Figure 4.7 and *Table 4.32* detail the life cycle environmental impact of the three products.

Figure 4.7 ***Comparing the three life cycles***

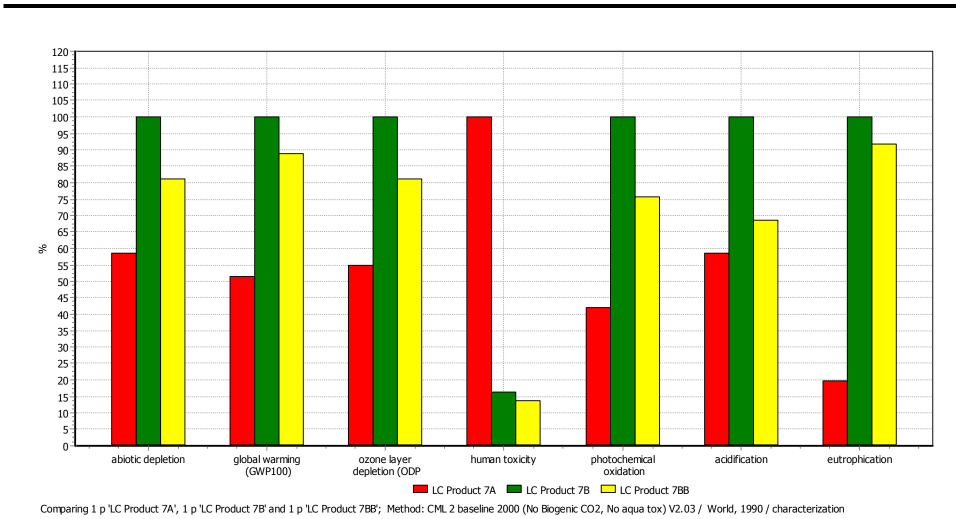


Table 4.32 Impact profile for Products 7A, 7B and 7BB (EUR commercial wipers)

Impact category	Unit	Product 7A	Product 7B	Product 7BB
abiotic depletion	kg Sb eq	4.29	7.33	5.96
global warming	kg CO_2 eq	646.00	1258.80	1117.05
ozone layer depletion	kg CFC-11 eq	3.80E-05	6.92E-05	5.61E-05
human toxicity	kg 1,4-DB eq	1325.01	216.21	182.89
photochemical oxidation	kg C_2H_4	0.09	0.22	0.16
acidification	kg SO_2 eq	2.03	3.46	2.37
eutrophication	kg PO_4--- eq	0.54	2.74	2.51
water consumption	m^3	25.9	41.45	23.45
CED	MJ	14463	23914	13578
Waste	kg	3.48	6.15	6.15

As shown in *Figure 4.7* and *Table 4.32*, Product 7B has a higher environmental impact for all categories except for human toxicity. Product 7A consists of 100% virgin fibres, whilst Product 7B consists of 100% recycled fibres which can be seen in the large difference in contribution to human toxicity. Again, this is caused by the PAH emissions from burning black liquor in virgin pulp production.

Table 4.33 shows the variation in contribution to the different life cycle stages of the three product systems.

Table 4.33 Variation in contribution from different life cycle stages for Products 7A, 7B and 7BB

Impact category	Manufacture	Transport	End of life
Abiotic Depletion	94-95%	5-6%	0%
Global Warming	77-93%	4-6%	7-17%
Ozone Layer Depletion	83-87%	12-16%	0-1%
Human Toxicity	68-96%	0-2%	4-30%
Photochemical Oxidaton	80-89%	3-5%	6-17%
Acidification	76-91%	2-10%	1-22%
Eutrophication	58-77%	2-8%	20-34%

The manufacturing life cycle stage is dominant for all product codes.
A more detailed analysis of the manufacturing phase for the three product codes is detailed in *Table 4.34* to *Table 4.36*.

Table 4.34 ***Product7A EUR commercial wipers: Impact profile per input material to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	7.5%	10.8%	2.1%	43.8%	35.8%	<1%
global warming	6.3%	12.4%	1.3%	46.2%	33.7%	<1%
ozone layer depletion	10.3%	9.0%	<1%	15.3%	65.0%	<1%
human toxicity	< 1%	95.9%	<1%	2.4%	1.3%	<1%
photochemical oxidation	12.3%	33.8%	1.7%	38.8%	13.6%	<1%
acidification	7.2%	39.3%	2.3%	44.5%	6.8%	<1%
eutrophication	5.8%	70.8%	1.5%	17.7%	4.1%	<1%

Table 4.35 ***Product 7B EUR commercial wipers: Impact profile per input material to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	5.2%	34.4%	<1%	30.2%	29.5%	<1%
global warming	3.5%	47.9%	<1%	25.7%	22.5%	<1%
ozone layer depletion	6.3%	35.9%	<1%	9.5%	48.1%	<1%
human toxicity	3.8%	57.6%	<1%	22.9%	15.2%	<1%
photochemical oxidation	6.5%	63.8%	<1%	20.6%	8.6%	<1%
acidification	4.8%	59.3%	<1%	29.8%	5.4%	<1%
eutrophication	1.0%	94.8%	<1%	3.1%	< 1%	<1%

Table 4.36 ***Product 7BB EUR commercial wipers: Impact profile per input material to manufacturing***

Impact category	Raw materials	Pulp	Packaging	Electricity	Heat	Waste
abiotic depletion	6.5%	18.5%	<1%	37.5%	36.7%	<1%
global warming	4.1%	40.0%	<1%	29.6%	25.9%	<1%
ozone layer depletion	8.0%	18.7%	<1%	12.0%	61.0%	<1%
human toxicity	4.8%	46.3%	<1%	29.1%	19.3%	<1%
photochemical oxidation	9.1%	49.4%	<1%	28.9%	12.1%	<1%
acidification	7.3%	38.2%	<1%	45.2%	8.2%	<1%
eutrophication	1.2%	94.2%	<1%	3.5%	1.0%	<1%

For both Product 7A and 7B, pulp production and energy consumption during manufacturing contribute most to each impact. For product 7A, the contribution to human toxicity from pulp production is above 90% of the total human toxicity potential. Product 7A consists of 100% virgin fibres, whilst Product 7B consists of 100% recycled fibres. Therefore there is no PAH emissions associated with the production of pulp for Product 7B.

4.8 *NORMALISATION*

In order to gain a better understanding of the relative scale of an environmental impact, a normalisation step is required. The individual impact results determined by the characterisation steps above are difficult to compare and to interpret because of their differing orders of magnitude. The normalisation step in the life cycle impact assessment methods makes this comparison possible by relating them to the total emissions or extractions over a certain period in a specific geographic area. Normalisation is an optional element of LCA. Therefore we have only included normalisation for a selection of products. In this study, we have used the total European annual effect scores in 1995 as they are included in the CML method. *Figures 4.15* and *4.16* below represent the contribution from one year of boxed facial tissue use in a large, affluent household in the Eastern US and the wiping of 1 000 kg of absorbed kitchen spills over a year in a European restaurant. Both product systems are related to total European impacts in 1995. Currently no normalisation data exist for the US thus it is not possible to measure the significance of the impacts as if they take place in the US.

The scale on the normalisation figures below represents the actual contribution that the tissue products make to the average European annual effect for each impact category (eg 1.0E-2 is 1% of the annual contribution that all Europeans contribute to an environmental impact such as global warming).

Figure 4.8 ***Normalising the life cycle results of Product 3A, 3B and 3BB (NA facial tissue)***

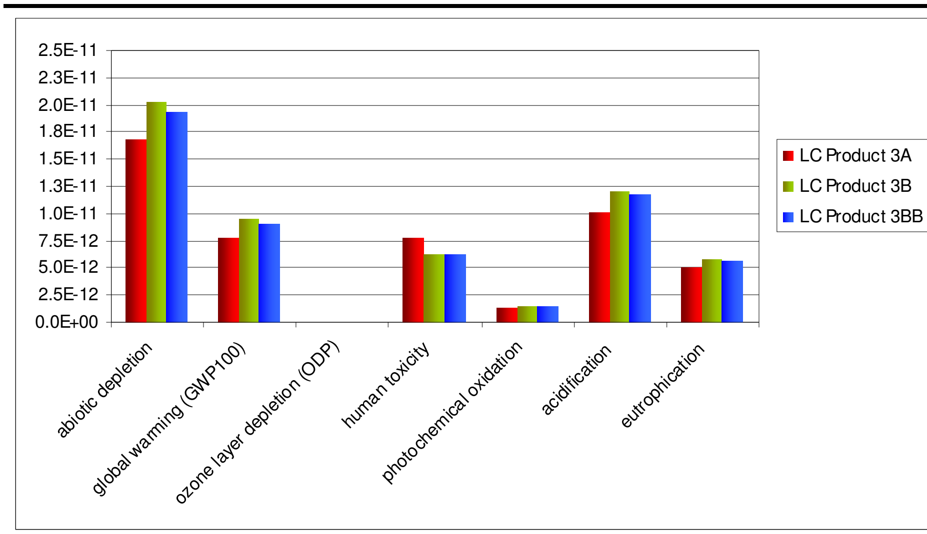


Figure 4.9 ***Normalising the life cycle results of Product 7A, 7B and 7BB (EUR commercial wipes)***

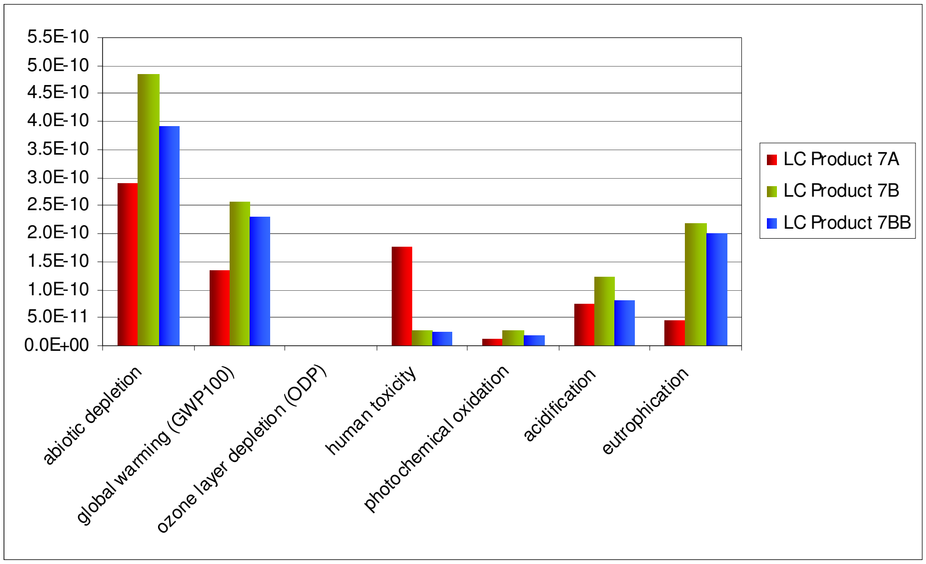


Figure 4.8 and *5.9* identify resource consumption as being the most significant in terms of the scale of burden. The abiotic depletion that represents resource consumption is predominantly associated with the extraction of oil, gas and coal reserves. In the life cycle, this is caused by energy consumption for manufacturing of tissue products and pulp manufacturing. Other impacts, such as global warming and acidification are also caused by energy consumption. The scale of the human toxicity impact is also significant due to the emissions of PAH from the use of black liquor in pulp production. Eutrophication is also significant in terms of scale of burden. Eutrophication is mainly caused by nutrient leaching, eg nitrate from landfilling paper waste or NOx emissions from energy consumption. In the case of Product 7B, the integrated mill for recycled fibre has a high output of solid paper waste which is landfilled or land applied.

5 *LIFE CYCLE INTERPRETATION*

5.1 *INTRODUCTION*

In this section, the results from the study are interpreted by evaluating whether they are meaningful. When comparing two products it is essential to address when a difference in environmental impact is meaningful.

There are three ways to determine if a difference is meaningful:

1. calculation using statistics;
2. empirical determination by observation of the input data; or
3. relating the impact to other measures of environmental impacts eg car driving.

A statistical treatment of the data was not possible.

Global warming potential is only related to the energy consumed in the life cycle which makes it directly comparable with other energy consuming activities such as miles driven in a car. We have used this approach to put the differences in global warming between the products into perspective.

For other environmental impacts other measurements of meaningfulness were used. Throughout the LCA, estimations and assumptions have been made that potentially introduce uncertainty into the final results. All data used in this study have a level of uncertainty caused by:

1. missing information in the questionnaire received;
2. inappropriate modelling for the necessary inputs and outputs eg using Scandinavian wood for US conditions; and
3. mistakes imposed by human errors.

This 'noise', which is inevitable in any LCA study, must be considered when comparing product systems to determine whether differences in environmental impact are real differences or caused by this noise (which would mean that the environmental impact from the two systems is equivalent within the accuracy of the evaluation).

In earlier studies, ERM has used a qualitative system to measure uncertainties of data collated for LCA studies by considering how the data were determined:

1. are the data measured?;
2. are the data calculated?; or
3. are the data estimated?

For measured data, we apply an uncertainty margin of ±5%; for calculated ±10% and for estimated ±25%. In this study most data collated by the suppliers were either measured or calculated so that the data used for the study are likely to vary as much as 10%. On that basis we consider that an environmental difference of 10% or more is considered meaningful. If the difference is less than 10%, the systems are considered equivalent.

An evaluation of the consistency and sensitivity of the results and conclusions has evaluated using sensitivity analysis. Sensitivity analysis is a process whereby key input parameters and method choices about which there may be some uncertainty are deliberately varied in the modelling to show the effect that such variation could have on the results of the assessment.

5.2 TRENDS ACROSS THE PRODUCT COMPARISONS

Figure 5.1 to *Figure 5.7* detail the results of all life cycles per impact category. This enables a comparison of the trends across the different products when normalised according to the product category (A,B or BB) contributing the most to each life cycle impact category. The 'worst' scoring product category is used as benchmark to show the relative contribution from the other product categories. This also details if there is any meaningful difference between the product codes. For example, in *Figure 5.1* below, there is no meaningful difference between Product 5A and 5B. All other difference between Product A and B are greater than 10%.

As mentioned earlier Product 5A consist of 60% recycled fibres and therefore the assessment of this product also includes a scenario where the waste paper comes without environmental burden up until it is collected and processed into pulp (Product 5AB).

Figure 5.1 Abiotic Resource Consumption

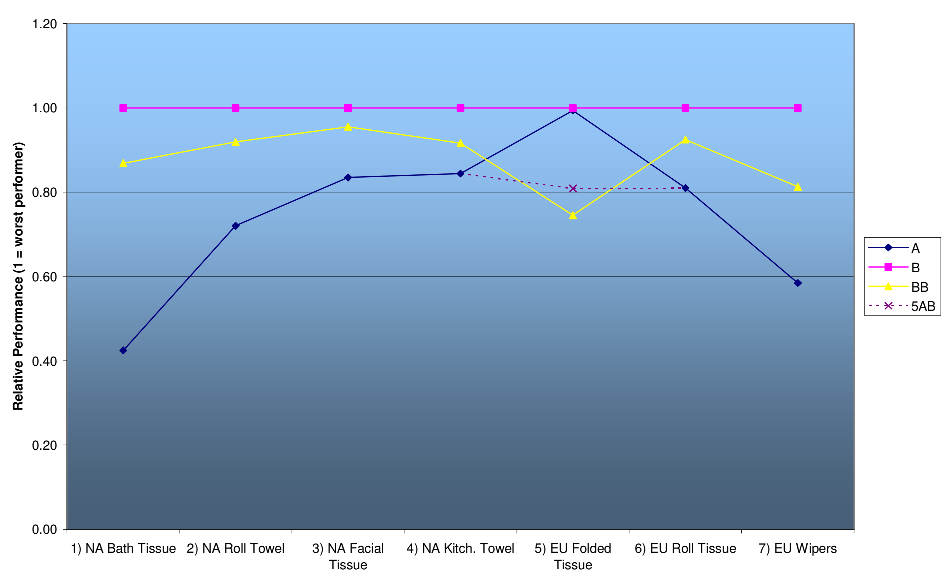


Figure 5.2 Global Warming Potential

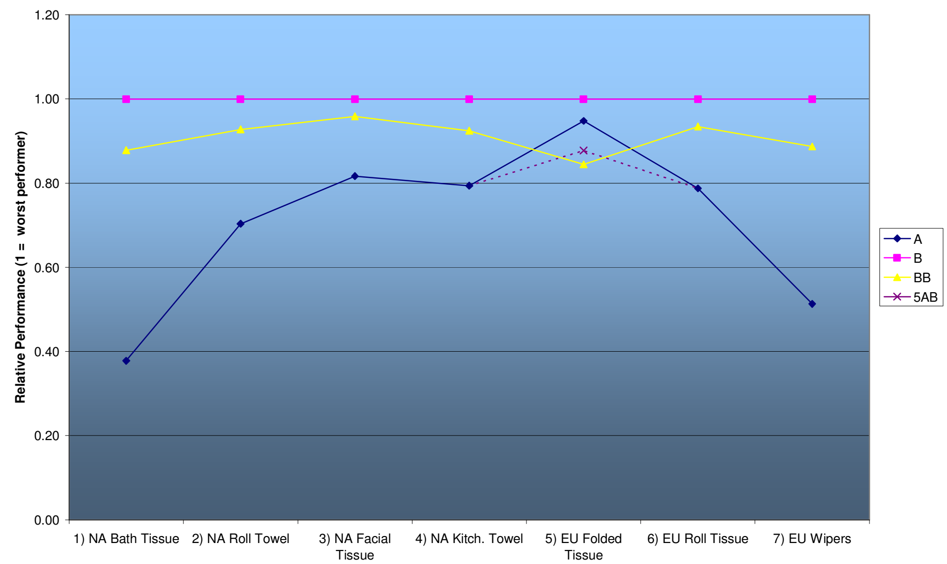


Figure 5.3 Ozone Layer Depletion

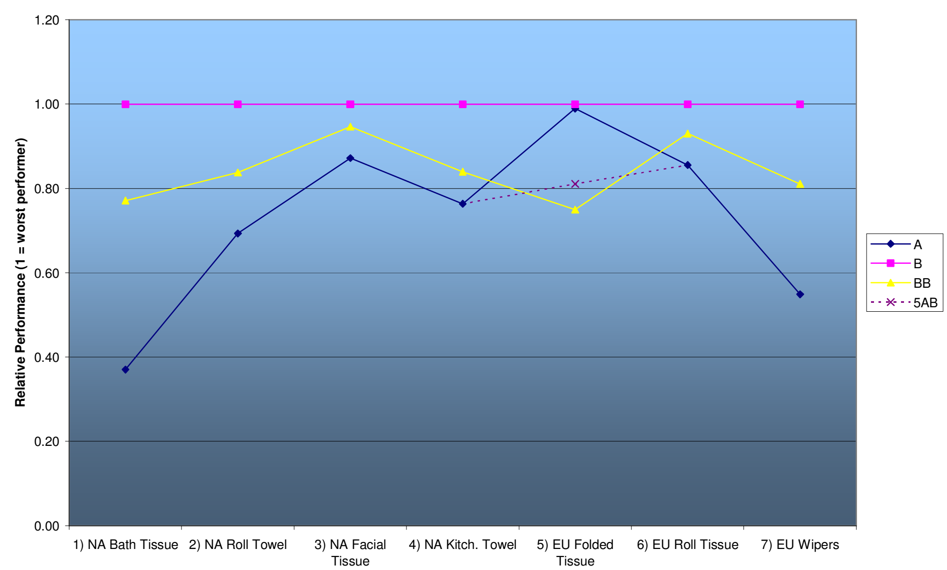


Figure 5.4 Human Toxicity

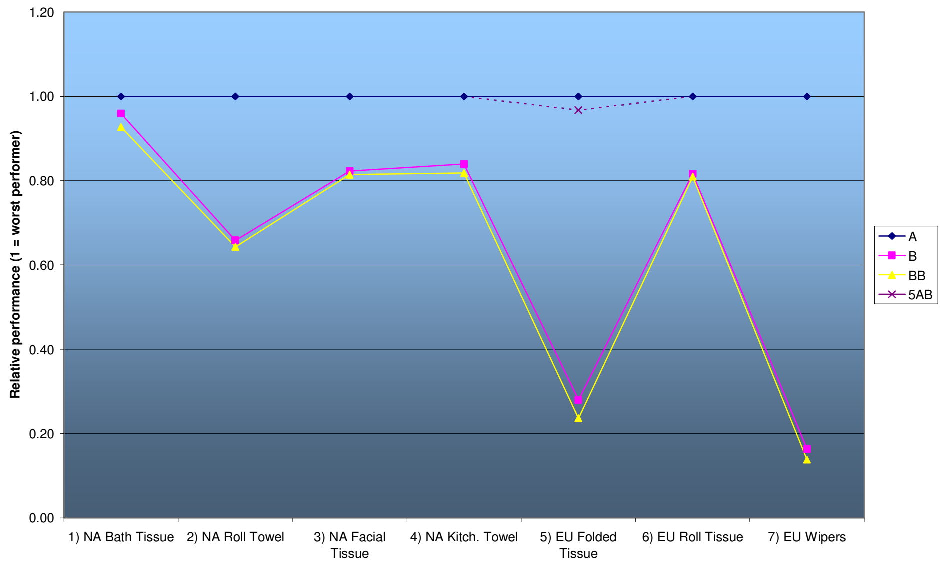


Figure 5.5 Photochemical Oxidation

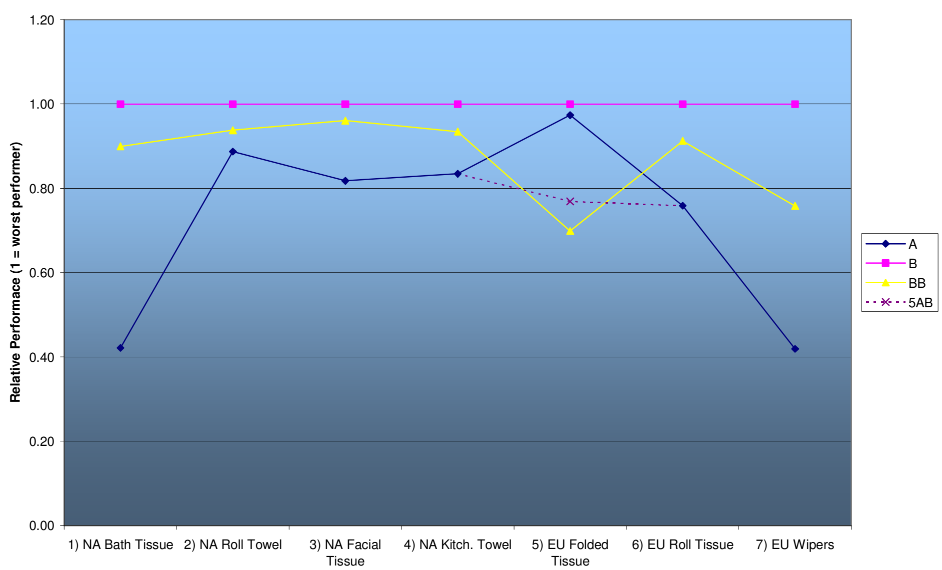


Figure 5.6 Acidification

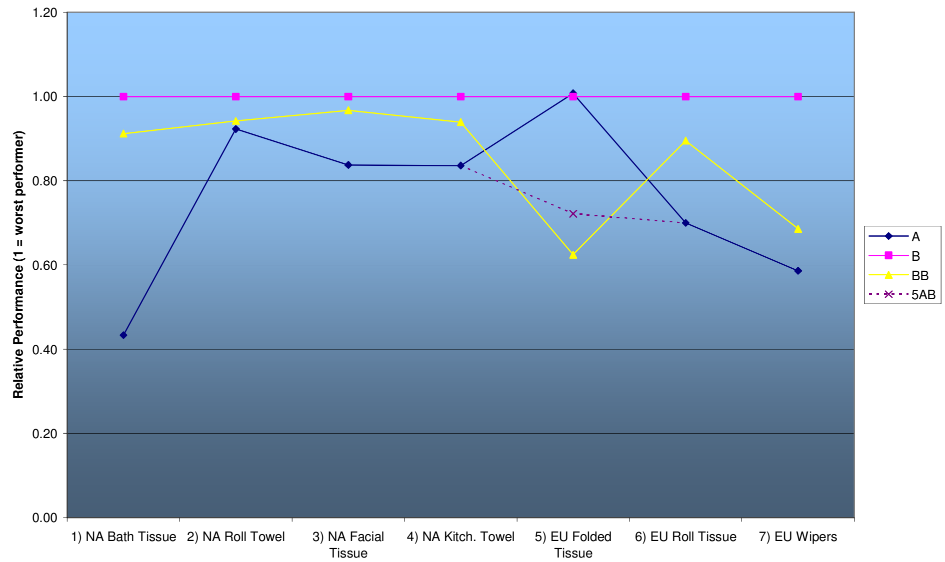
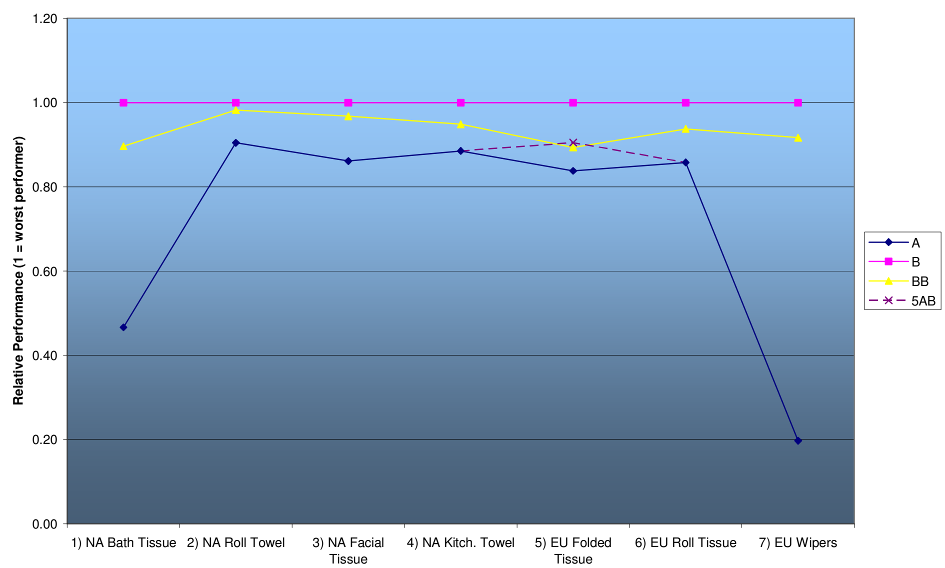


Figure 5.7 Eutrophication



5.3 *MEANINGFUL DIFFERENCE IN ENVIRONMENTAL IMPACT*

In general Product B has the highest environmental impact across all product codes, except for human toxicity where Product A performs worse across all products codes.

For all impact categories except for human toxicity, Product 5A and Product 5B have nearly identical impacts in four of the seven categories presented. This is believed to be due to the co-occurrence of two factors:

1. The use of high level of recycled fibre in Product 5A (60% RF) provides similarity in product composition.
2. The use of integrated de-inking operations to both recovered fibre and produce tissue in a single facility. This eliminates the need to dry and ship recycled fibres.

The comparison between Product 5AB and Product 5BB is also influenced by these factors.

Table 5.1 Summary of findings per impact category

Impact	Results Summary
Abiotic depletion	Six product codes suggest that virgin fibre has lower impact Product 5 does not favour either fibre type
Global Warming Potential	Six product codes suggest that virgin fibre has lower impact Product 5 does not favour either fibre type
Ozone Layer Depletion	Six product codes suggest that virgin fibre has lower impact Product 5 does not favour either fibre type
Acidification	Five product codes suggest that virgin fibre has lower impact Product 2 and 5 does not favour either fibre type
Eutrophication	Five product codes suggest that virgin fibre has lower impact Product 2 and 5 does not favour either fibre type
Human Toxicity	Five product codes suggest that recycled fibre has lower impact Product 1 does not favour either fibre type
Photochemical oxidation	Six product codes suggest that virgin fibre has lower impact Product 5 does not favour either fibre type

5.4 *MEANINGFUL DIFFERENCE IN GLOBAL WARMING POTENTIAL*

In terms of global warming, the most significant difference is between Product A and Product B for each of the codes. Therefore the significance assessment was based on these two product systems. *Table 5.38* details the differences between the products and also how this difference relates to miles driven in a car.

Table 5.38 'Miles per Tissue Paper' (one year's consumption)

	1A Bathroom tissue	1B Bathroom tissue	Difference	Converted into miles driven
Kg CO2-eq	24.84	65.77	40.92	153.64
	2A Washroom towel	**2B Washroom towel**	**Difference**	**Calculated into miles driven**
Kg CO2-eq	486.77	691.64	204.89	769.16
	3A Facial tissue	**3B Facial tissue**	**Difference**	**Calculated into miles driven**
Kg CO2-eq	37.46	45.85	8.39	31.5
	4A Kitchen towel	**4B Kitchen towel**	**Difference**	**Calculated into miles driven**
Kg CO2-eq	27.28	34.34	7.07	26.54
	5A Folded toilet tissue	**5B Folded toilet tissue**	**Difference**	**Calculated into miles driven**
Kg CO2-eq	1207.72	1273.89	66.17	248.45
	6A Roll toilet tissue	**6B Roll toilet tissue**	**Difference**	**Calculated into miles driven**
Kg CO2-eq	59.03	74.95	15.92	59.77
	7A Commercial wipers	**7B Commercial wipers**	**Difference**	**Calculated into miles driven**
Kg CO2-eq	646.00	1258.80	612.80	2300.69

All results represent a year's consumption of the product in question. In terms of miles driven, the biggest difference is for Product 7, namely 2300 miles. On average a car in the US drives 12 000 miles a year so this equals using a car for approximately 2 months or driving a mid size car from Los Angeles to Detroit.

Driving 769 miles in a car per year equals driving 64 miles a month or en extra two miles a day. As described in *Table 2.2,* 4.5 washroom towels are used per person a day. When such a small amount of washroom towels equals driving an additional two miles a day, the difference is considered meaningful.

5.5 SENSITIVITY ANALYSIS

The following parameters were investigated in the sensitivity analysis.

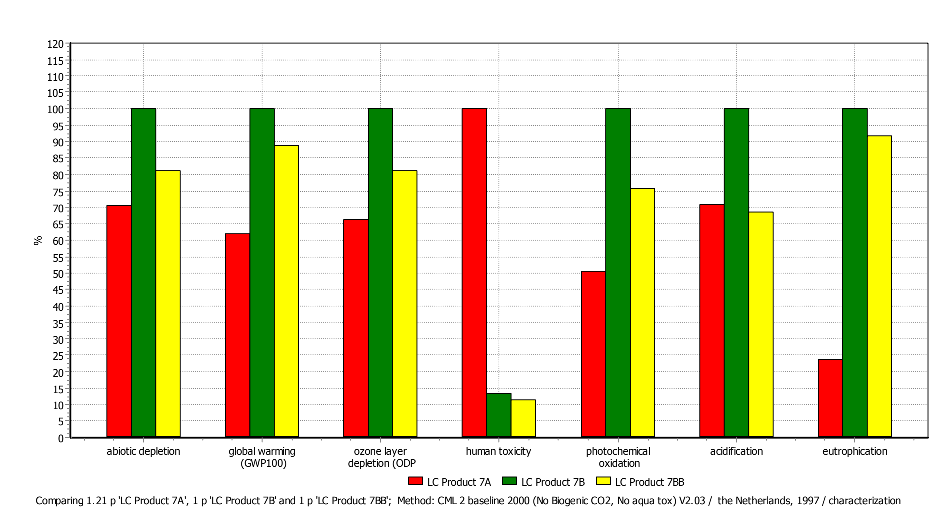
1. A specific scenario involving the EUR Commercial wipers (product 7A and 7B). Currently, the reference flows are based on product absorbency resulting in two different reference flows for the same function. In the sensitivity analysis, we varied the reference flow between the current levels and also included a scenario where the reference flow is equivalent for both products.
2. Different number of uses for office paper before it is recycled into tissue paper.
3. The decreased use of natural gas for drying of recycled pulp.

4. The use of different impact assessment methods (also including biogenic carbon). This will also include an assessment of eco-toxicity using the Impact 2002+ method.

Scenario 1 – changing the functional unit

When using absorbency as reference for wipers, the content of recycled fibres plays a significant role. Product 7A consists of 100% virgin fibres and Product 7B consists of 100% recycled fibres. To reach functional equivalence in terms of absorbency, 82 000 sheets of product 7B equal 68 000 sheets of product 7A. Comparing the products on a sheet to sheet basis is detailed in *Figure 5.8.*

Figure 5.8 Product 7A, 7B and 7BB EUR commercial wipers - Sensitivity Analysis

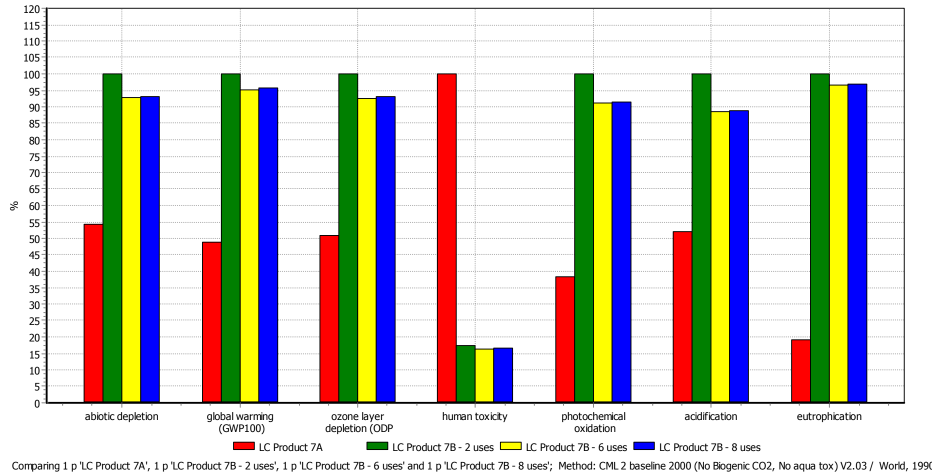


Comparing 7A, 7B and 7BB on a sheet to sheet basis, the life cycle impact from the wipers made of 100% virgin fibre increases by approximately 21%. As shown in *Figure 4.1*, the 100% recycled fibre (7B) still has a higher impact than 7A (except for human toxicity). Modelling the waste paper input free of environmental burden (7BB) changes this slightly, ie the tissue paper with 100% recycled fibre has a slightly lower contribution than 100% virgin fibre for acidification. The difference between Product 7A and 7B is meaningful.

Scenario 2 – changing the number of uses of office paper before recycling it into tissue

In this scenario the impact on the results of varying the number of uses of the office paper before it is recycled into tissue paper is assessed. When office paper is recycled into tissue paper it will not be recycled again. Ideally, office paper fibres should be recycled into office paper a number of times before they are transformed into tissue paper. In the present study, we assumed six lives. *Figure 5.9* illustrates the impact of varying the number of uses between two and eight times.

Figure 5.9 Impact on in the life cycle from different number of uses



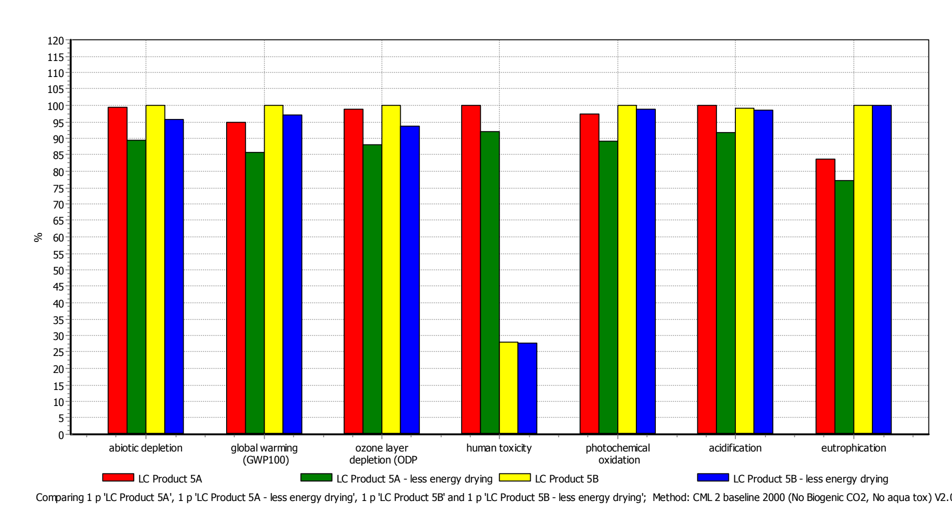
Decreasing the number of uses before conversion into tissue increases the environmental impact. For all environmental impacts except human toxicity, the product with 100% virgin material has the lowest environmental impact thus changing the number of uses will not change the conclusions of the study. Interestingly, increasing the number of uses from 6 to 8 results in a very slightly higher environmental impact since the environmental impacts from waste paper processing exceeds the environmental impact from producing the office paper. If we apply a 30% recycling rate of paper this means that 70% is not recycled. After the first use 9% (30% of 30%) is allocated to the previous life of the paper, thereafter 2.7% (9% of 30%) and so on, meaning that after 8 uses the allocation to previous lives will be minimal. Thus changing from 6 to 8 uses will basically not change the allocation factor because the systems are more or less identical.

Except for human toxicity and acidification, the difference between using the paper 2 and 6 times is not judged to be a meaningful difference in the context of this study since it is less than 10%.

Scenario 3 – use of natural gas for drying of recycled fibres

In the study it is assumed (based on data provided by K-C) that drying recycled fibres involves higher energy consumption than drying virgin fibres. This assumption is assessed in the following sensitivity scenario. Data provided by K-C showed a difference of up to 19% between the energy consumed when separating the drying of the virgin and recycled fibres and treating both fibre types equally. The highest difference between the products was for product 5A and 5B 'EUR Folded Toilet Tissue' and therefore the sensitivity was tested on these products.

Figure 5.10 The impact of energy for drying on the life cycle of Products 5A and 5B EUR folded toilet tissue



As *Figure 5.10* shows, the impact of reducing the energy used for drying fibres by up to 19% in the manufacturing of tissue paper is not meaningful. For example the difference in global warming between the two manufacturing processes of Product 5A amounts to 120 kg CO_2-eq which equals driving 450 miles in a car and is thus not a significant difference.

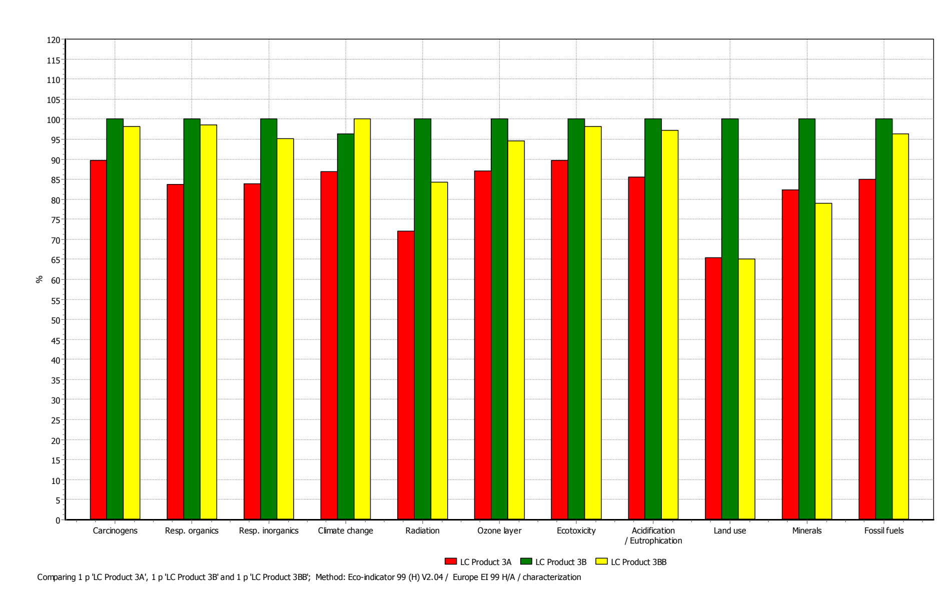
Scenario 5 – applying other life cycle impact assessment methods

Another way of consolidating the results and subsequent conclusions is to test the results using other impact assessment methods. In this context, Product 3A and Product 3B (NA facial tissue) were compared using the following assessment methods:

- Eco-indicator 99 method;
- TRACI method; and
- CML method, in which biogenic CO_2 was accounted for; and
- Impact 2002+ method.

The Eco-indicator 99 method was developed by PRé Consultants in the Netherlands, who also develop the SimaPro software. The Eco-indicator 99 method is an international recognised impact assessment method. The comparison of the three products is presented in *Figure 5.11.*

Figure 5.11 Results of Product 3A, 3B and 3BB (NA facial tissue) using the Eco-indicator 99 method

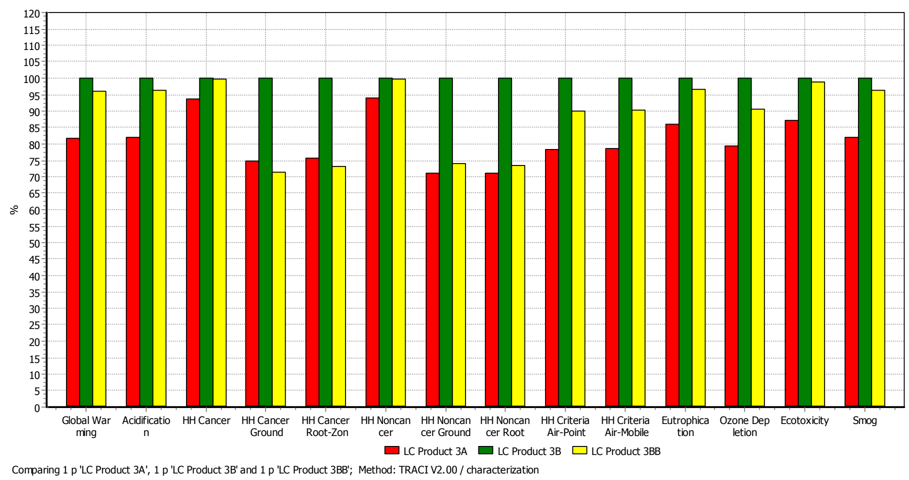


When applying the Eco-indicator 99 method to calculate the life cycle impacts of Product 3A, 3B and 3BB, it is clear that Product 3B has a higher environmental contribution to all impact categories including toxicity categories and that the difference is meaningful. This indicates that the Eco-indicator 99 method does not assign the same level of toxicity potential to PAH emissions as the CML method. The contribution of PAHs is represented in the second column 'Respiratory organics'. However, it is important to note how different life cycle impact assessment methodologies include and calculate the impact from PAH emissions. The most common life cycle assessment methods (CML, Eco-indicator etc) only include a limited number of substances and often the same substance is not represented by the same name. For example, in the current study we have added the emission of PAHs to the virgin fibre production process. The CML method picks up this emission as a potential contributor to human toxicity ie the 'substance' PAH has a characterisation value. However, PAH is not a substance; PAH is a group of substances eg benzene, naphthalene, anthracene etc. Eco-indicator 99 does not characterise PAH as a substance but includes each individual substance and its characterisation factor. The result is that when we add PAHs as a substance to our pulp process the potential human toxicity impact will not be visible in the Eco-indicator 99 method but will have a significant contribution when using the CML method. This emphasizes the importance of using more than one impact assessment method when interpreting the results of an LCA.

Using Eco-indicator 99 favours the use of virgin fibres compared to recycled fibres when accounting for first life of the waste paper. Using waste paper with no environmental burden attached, the results do not change, except for 'Minerals', but here the difference is minor.

The TRACI method was developed by the US EPA and only includes characterisation. The method represents US conditions and may therefore become the method of choice for products produced in the US. The method is still under development, however, and has not been verified by LCA experts.

Figure 5.12 Results of Product 3A, 3B and 3BB (NA facial tissue) using the TRACI method

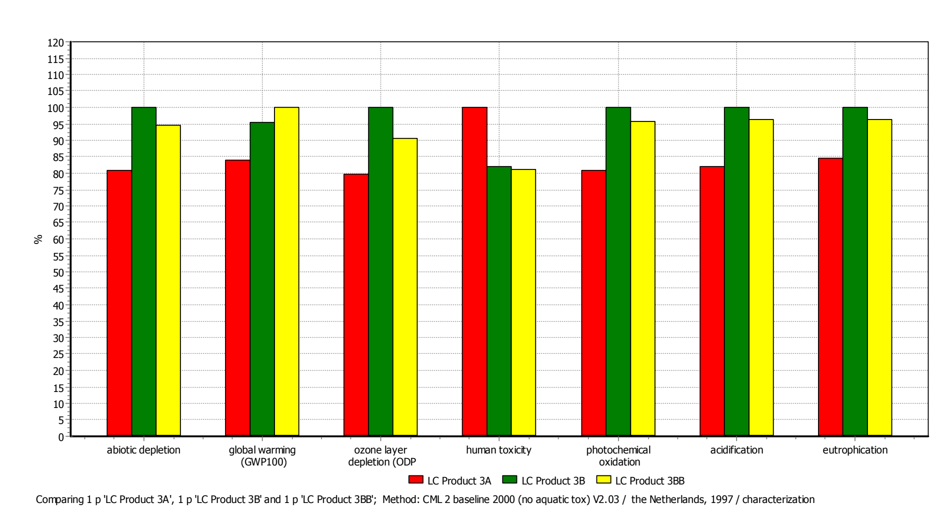


Applying the TRACI method to calculate the environmental impacts of Product 3A and 3B, we see that the product with recycled fibres contributes more to each impact category than the product with virgin fibre. Product 3BB has a lower environmental impact than Product 3A for a few of the human health categories, but the differences are not meaningful.

In TRACI, PAH is included in the same way as the Ecoindicator 99 method hence not showing the same result for human toxicity as the CML method.

In the study, we have excluded the environmental benefit associated with uptake of biogenic CO_2. The life cycle impact of including biogenic CO_2 in the CML method is presented in *Figure 5.13.*

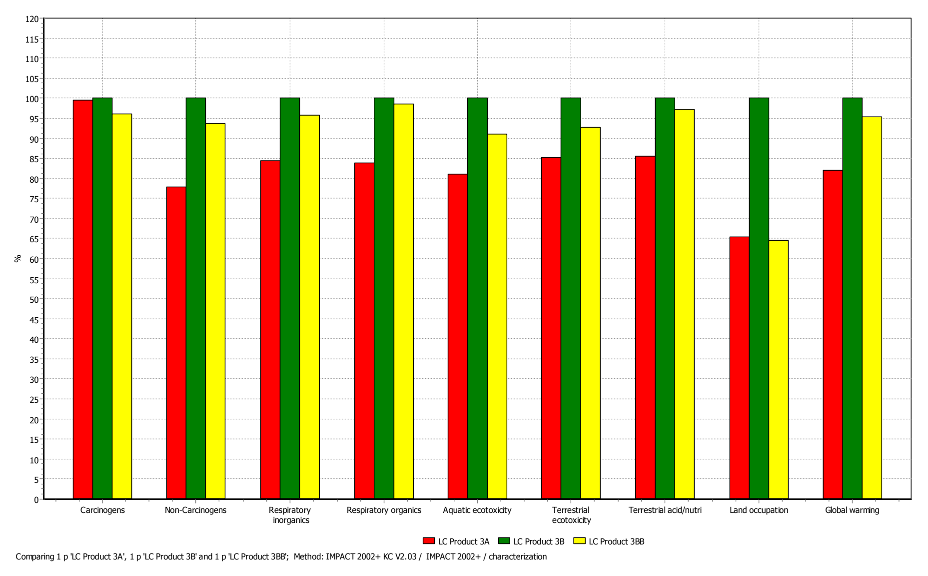
Figure 5.13 The life cycle impacts of Product 3A, 3B and 3BB (NA facial tissue) when including biogenic CO_2



Including the uptake of CO_2 in the calculation of the life cycle results of Product 3A and 3B provides further environmental benefits when using virgin fibres. In the baseline scenario, the CO_2 uptake was excluded which resulted in a global warming potential difference of 60 kg CO_2-eq (or driving 226 miles in a car) between Product 3A and 3B. When including the environmental benefit from CO_2 uptake the difference decreases to 23 kg CO_2-eq (or driving 88 miles in a passenger car). This difference is not believed to be meaningful in the context of the current study.

Impact 2002+ has been used to measure the impact on ecotoxicity from Product 3A, 3B and 3BB. This is presented in *Figure 5.14.*

Figure 5.14 The life cycle impacts of Product 3A, 3B and 3BB (NA facial tissue) using the Impact 2002+ method*



* Note that some impact categories has been removed (eg ozone depletion, mineral extraction etc) from Impact 2002+ to better illustrate the impact from ecotoxicity

Figure 5.14 shows that Product 3A's contribution to ecotoxicity is lower than Product 3B and that the difference is meaningful.

Historically the (tissue) paper industry has had an image of having a significant impact on aquatic ecosystems caused by COD, heavy metals etc in their water effluent. To assess the scale of the ecotoxicity impact from tissue paper production the normalised results of Product 3A, 3b and 3BB are detailed in *Figure 5.15*

Figure 5.15 ***The normalised life cycle impacts of Product 3A, 3B and 3BB using the Impact 2002+ method***

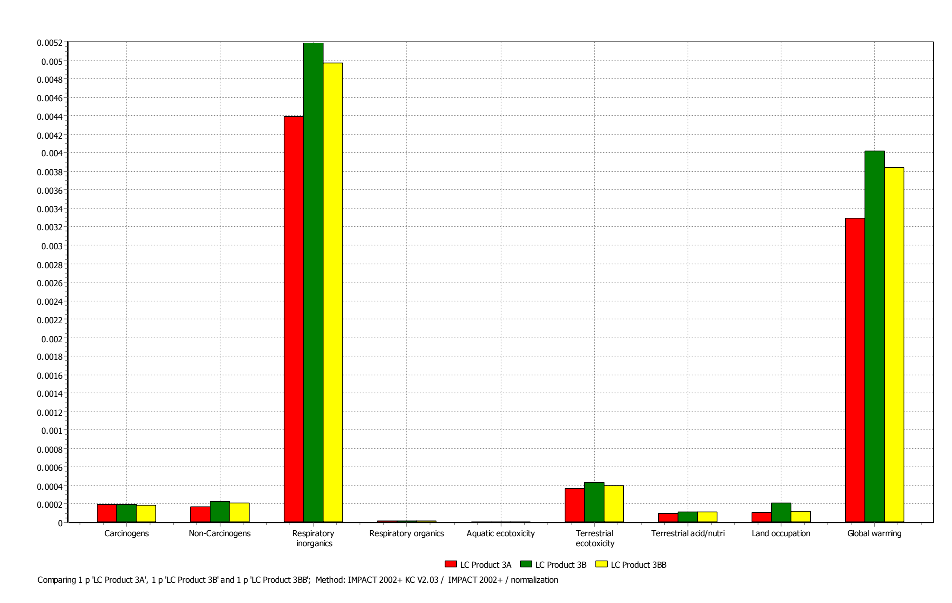


Figure 5.15 shows, that the scale of aquatic ecotoxicity, which is based on detailed effluent data from K-C's suppliers, is negligible.

5.6 *DETAILED ASSESSMENT OF SELECTED PRODUCT SYSTEMS*

The major impact areas, in terms of scale of contribution, have been identified as abiotic depletion, global warming, acidification, eutrophication and human toxicity. This is also illustrated in *Figure 5.16.*

Figure 5.16 ***Comparison of US and EUR bathroom/toilet tissue***

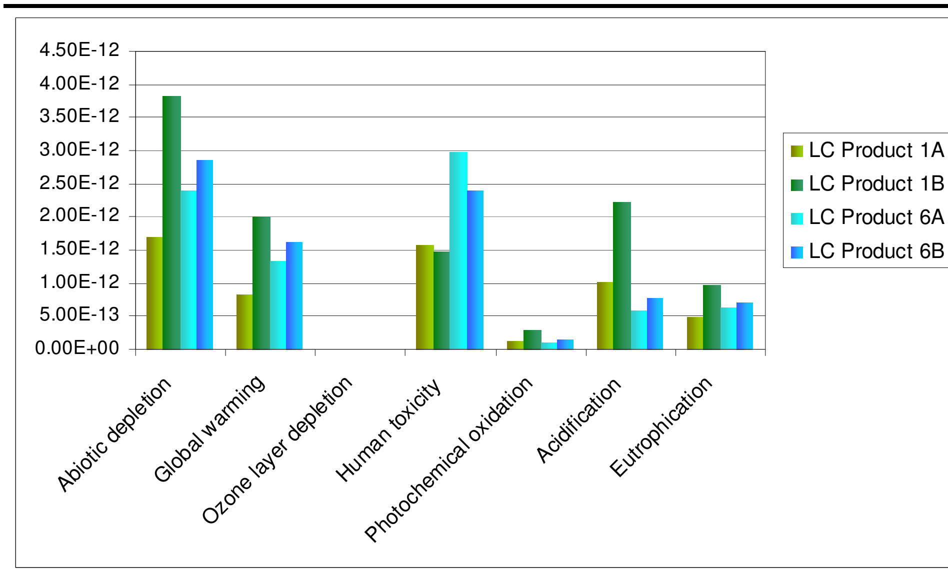


Figure 5.16 also compares the impact of producing and using the equivalent of 58 200 sheets of bathroom/toilet tissue in the US and Europe. This comparison is made to see if we can draw any conclusions from comparing the life cycle of bathroom/toilet tissue produced in the US and Europe.

Product 1A and 6A both contain 100% virgin fibres, Product 1B contains 40% recycled and 60% virgin fibres and Product 6B contains 20% recycled fibres and 80% virgin fibres.

Product 6A and 6B both weigh 27.03 kg (equivalent to 59.5 lbs). 58 200 sheets of Product 1A weighs 29.4 lbs and same amount of sheets for Product 1B weighs 44.2 lbs.

There are several reasons for the difference in the environmental impact. The content of recycled fibres in Product 1B means high energy consumption from the production of MDIP. The heavier weight of Products 6A and 6B compared to 1A and 1B means a higher consumption of raw materials, eg pulp and energy and should subsequently mean more environmental impact.

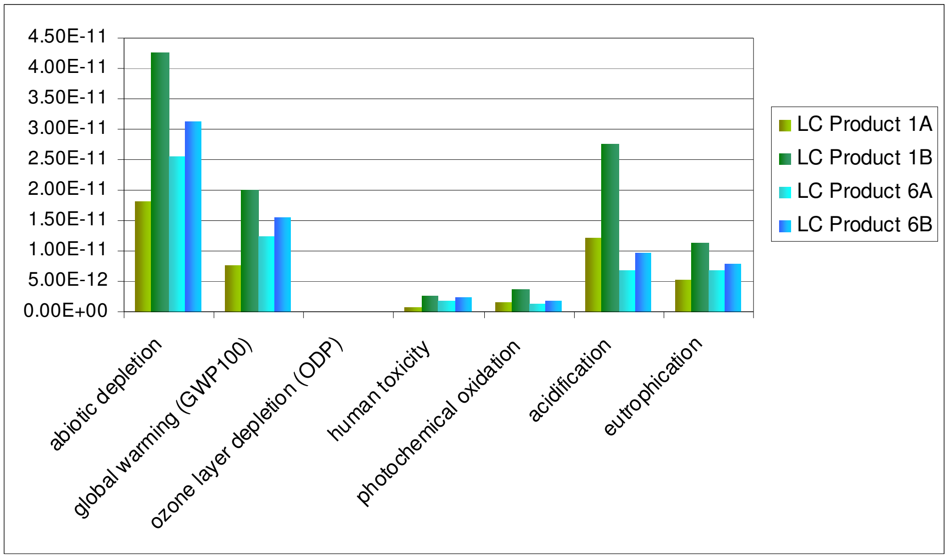
However, Product 6 is produced in France where the electricity is predominantly produced in nuclear power plants. In LCA, nuclear power has a low emission of CO_2 compared to electricity produced using fossil fuels. Even though the tissue manufacturing plant in the US uses approximately one third of the electricity to produce Product 1A compared to the electricity consumption for Product 6A, this is not recognised as being an environmental benefit due to geographic differences in electricity generation.

So should K-C produce all products in France or other countries where nuclear energy is used to produce electricity? LCA does not include risks and does not include a reliable way of modelling the potential impacts associated with the disposal of nuclear waste. As a result, other decision making tools should be involved, ie risk assessment and multi criteria assessment before such conclusions can be drawn.

Product 6A and 6B have a higher mass content of virgin pulp than Product 1A and 1B. This explains the higher contribution to human toxicity from the PAH emissions from black liquor.

Figure 5.17 shows the life cycle impacts of US and European issues without the emission of PAH from burning the black liquor to produce energy for the production of virgin pulp.

Figure 5.17 Comparison of US and EUR bathroom/toilet tissue - excluding PAH



It is clear that, if K-C can work with suppliers to address the emissions of PAH and other potentially toxic emissions in the pulp supply-chain from the pulp mills, the human toxicity potential from the life cycle of tissue paper could be reduced significantly.

6 *CONCLUSION*

Overall the results indicate that neither fibre type can be considered environmentally preferable. Both virgin fibre and recycled fibre offer environmental benefits and shortcomings. Intelligent and sustainable use of available fibre sources requires understanding the challenges associated with each fibre type and effectively managing the life cycle to minimise impacts and maximise benefits.

These conclusions are based on an assessment of the following environmental impacts, which were agreed by K-C as those to be assessed in the study:

- global warming;
- ozone depletion;
- summer smog formation;
- depletion of non-renewable resources (abiotic depletion);
- eutrophication;
- acidification;
- human toxicity;
- water consumption;
- energy consumption; and
- solid waste.

The LCA showed that based on the relative contribution and observed importance in the normalised results, the environmental impacts of global warming, acidification, resource depletion and human toxicity along with flow information on water consumption and solid waste should be considered in decision making regarding tissue product design using virgin and recycle fibres.

This assessment included the calculation of the life cycle environmental impacts for seven tissue products. They are:

1. North American bathroom tissue;
2. North American washroom towel;
3. North American facial tissue;
4. North American kitchen towel;
5. European folded toilet tissue;
6. European roll toilet tissue; and
7. European commercial wipers.

Three scenarios were calculated for each product1:

- Scenario A, where the product has a high share of virgin fibres;
- Scenario B, where the product has the highest share of recycled fibres and where environmental burden is attributed to the previous life of the paper before it is collected and processed into recycled pulp; and

- Scenario BB, which is the same product as scenario B but where the recycled paper comes free of environmental burden up until it is collected and processed into recycled pulp.

Results of the LCA indicate that across impact categories traditionally related to the burning of fossil fuels, eg global warming, acidification and abiotic resource depletion, products with high virgin fibre content offer lower environmental impacts than those with high recycled fibre content. In the specific situation when waste paper comes free of environmental burden, Product 5AB and 5BB which are produced in integrated de-inking mills offer comparable or better performance to virgin fibre products in the same impact categories.

The comparisons between recycled and virgin fibre for the environmental flows of water use and solid waste are less straightforward. The environmental flow of water use generally favour products with high virgin fibre content over the equivalent product with recycled fibres, where impact is attributed to previous lives. However, the results showed that the specific scenarios where waste paper comes free of burden the water consumption decreases significantly and goes below the water consumed for some of the virgin products (product 4, 5, 6 and 7). Still virgin fibres are favoured for product 1, 2 and 3. Although, there is a difference between the two fibre types, the only meaningful differences (difference higher than 10%) were observed for product 1, 2, 4 and 5. Thus product 1 and 2 favour virgin fibres, product 4 and 5 favour recycled fibres and product 3, 6 and 7 favour neither fibre type when comparing virgin fibres with recycled fibres produced using waste paper free of burden.

For solid waste generation, three product codes (1, 4 and 7) favour the product containing most virgin fibres, product 5 favours the use of recycled fibres and the remaining products (2, 3 and 6) do not favour either fibre type.

When using the CML impact assessment method, the products containing the most virgin fibres (Product A) have the highest human toxicity impact. This is mainly caused by PAH emissions from the virgin pulp recovery boilers which are likely to be higher than emissions from boilers used in recycling operations. This conclusion is based on limited supplier data on PAH emissions (only one out of six suppliers contacted provided PAH emission values) and limited data on potentially toxic emissions in other phases of the life cycle.

The specific case of greenhouse gas emissions is useful for illustrating the magnitude of tissue system environmental impacts. The annual use of specific tissue products in consumer households is associated with between 25 and 75 kg of CO2 equivalent emissions depending on the product selected and geographic location. These emissions are comparable to those produced by driving a typical American passenger car 65 to 195 miles per year or 0.3% to 0.9% of typical US household driving [4]. The annual use of the tissue products (hand towels or toilet tissue) studied in commercial washrooms is associated with the emission of 490 to 1300 kg of CO2 equivalent greenhouse gases, comparable to driving between 1270 and 3380 miles per year. This mileage represents between 4% and 15% of average annual mileage for a single business fleet vehicle [4].

Although the study results do not clearly favor one fibre type over the other, they do suggest opportunities exist to minimise environmental impacts when using each fibre type. Examples of opportunities for environmental improvement are specified below.

When using recycled fibres:

- source fibres from integrated de-inking operations when possible to eliminate the need for thermal drying of fibre (dry lap) or long distance transport of high water content materials (wet lap);
- manage de-inking sludge in order to maximise beneficial applications and minimise waste burden on society; and
- select high quality fibre/paper sources that enable efficient processing into recycled pulp.

When using virgin fibres:

- manage material sources to maintain legal, sustainable forestry practices through processes such as certification systems and standards; and
- encourage suppliers to consider opportunities to reduce or prevent emissions of PAH and other potentially toxic substances while increasing the use of biomass fuels.

When using either fibre type:

- improve energy efficiency in tissue manufacturing;
- examine opportunities for changing to alternative, non fossil based sources, of energy for tissue manufacturing operations;
- deliver product forms that maximise functionality and minimize consumption; and
- investigate opportunities for alternative product disposal systems that deliver socio-economic benefits from waste products.

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[3] The Ecoindicator 99, a damage oriented method for Life Cycle Assessment, Methodology Report, June 2001. Downloaded from http://www.pre.nl/download/EI99_methodology_v3.pdf

[4] US Department of Energy, *Transportation Energy Data Book*, 2007. Downloaded from http://cta.ornl.gov/data/index.shtml

Annex A

CML Impact Assessment Method

A1 CML METHOD

The impact assessment methodology employed for this study is CML 2001. The method has been developed by the Centre of Environmental Studies (CML) at the University of Leiden in the Netherlands (1). It is a problem-oriented approach impact assessment method (as opposed to a damage-oriented approach). A problem-oriented approach models the impacts at a midpoint somewhere between the emission and the damage in the environmental mechanism. The following impact categories used in life cycle assessment (LCA) are described below (2):

- depletion of abiotic resources;
- global warming potential;
- stratospheric ozone depletion;
- human toxicity;
- photo-oxidant formation;
- acidification; and
- eutrophication.

Depletion of abiotic resources: This impact category is concerned with protection of human welfare, human health and ecosystem health. This impact category indictor is related to extraction of minerals and fossil fuels due to inputs in the system. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals and fossil fuels (kg antimony equivalents/kg extraction) based on concentration reserves and rate of de-accumulation. The geographic scope of this indicator is at global scale.

Global warming potential: can result in adverse affects upon ecosystem health, human health and material welfare. Climate change is related to emissions of greenhouse gases to air. The characterisation model as developed by the Intergovernmental Panel on Climate Change (IPCC) is selected for development of characterisation factors. Factors are expressed as Global Warming Potential for time horizon 100 years (GWP100), in kg carbon dioxide equivalents/kg emission. The geographic scope of this indicator is at global scale.

Stratospheric ozone depletion: Because of stratospheric ozone depletion, a larger fraction of UV-B radiation reaches the earth surface. This can have harmful effects upon human health, animal health, terrestrial and aquatic ecosystems, biochemical cycles and on materials. This category is output-related and at global scale. The characterisation model is developed by the World Meteorological Organisation (WMO) and defines ozone depletion potential of different gasses (kg CFC-11 equivalent/ kg emission). The geographic scope of this indicator is at global scale. The time span is infinite.

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(1) http://www.leidenuniv.nl/cml/ssp/index.html

(2) *SimaPro 7, Database Manual: Methods library*. www.pre.nl/download/manuals/DatabaseManualMethods.pdf

Human toxicity: This category concerns effects of toxic substances on the humans. Health risks of exposure in the working environment are not included. Characterisation factors, Human Toxicity Potentials (HTP), are calculated with USES-LCA, describing fate, exposure and effects of toxic substances on a infinite time horizon. For each toxic substance HTP's are expressed as 1,4-dichlorobenzene equivalents/ kg emission. The geographic scope of this indicator determines on the fate of a substance and can vary between local and global scale

Photo-oxidant formation: is the formation of reactive substances (mainly ozone – O_3) which are injurious to human health and ecosystems and which also may damage crops. This problem is also indicated with "summer smog". Winter smog is outside the scope of this category. Photochemical Ozone Creation Potential (POCP) for emission of substances to air is calculated with the UNECE Trajectory model (including fate), and expressed in kg ethylene equivalents/kg emission. The time span is 5 days and the geographical scale varies between local and continental scale.

Acidification: Acidifying substances cause a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems and materials (buildings). Acidification Potentials (AP) for emissions to air are calculated with the adapted RAINS 10 model, describing the fate and deposition of acidifying substances. AP is expressed as kg SO_2 equivalents/ kg emission. The time span is eternity and the geographical scale varies between local scale and continental scale.

Eutrophication: (also known as nutrification) includes all impacts due to excessive levels of macro-nutrients in the environment caused by emissions of nutrients to air, water and soil. Nutrification potential (NP) is based on the stoichiometric procedure of Heijungs (1992), and expressed as kg PO_4 equivalents/ kg emission. Fate and exposure is not included, time span is eternity, and the geographical scale varies between local and continental scale.

Annex B

Critical Review

"Life Cycle Assessment of Tissue Products"

Critical Review

according to ISO 14040 and 14044

prepared for

Kimberly-Clark Corporation

by

Walter Klöpffer (Chair)

Mary Ann Curran

and

Jim Bowyer

December 2007

1 Procedural Aspects of this Critical Review

The critical review was commissioned by Environmental Resources Management (ERM), Oxford, UK, on behalf of Kimberly-Clark Corporation (K-C), USA, in February 2007. The LCA study has been performed by ERM, the practitioner, for K-C, the commissioner.

Since the reviewers were involved from the start of the study, the critical review can be considered as an accompanying or interactive review, as recommended by SETAC [1]. The performance of critical review studies in the accompanying mode is not requested by ISO 14040 [2], but preferable to the a posteriori mode out of experience [3]. The chair of the panel was invited to attend the kick-off meeting of the project February 15th 2007 at the European headquarters of K-C near London.

Formally, this critical review is a review by "interested parties" (panel method) according to ISO 14040 §7.3.3 [2] and ISO 14044 § 6.3 [4]. The co-reviewers invited to join the panel were selected under the aspects of competence and country (USA as main production region and market). The reviewers also fulfill, beyond competence, the requirement to be neutral and independent from particular commercial interests. It was therefore not necessary – and hardly possible due to the tight time frame of the study - to invite any other interested parties. Furthermore, there are no comparative assertions to be deduced from the results of the study, since only products manufactured by K-C were analyzed. The review by interested parties is, thus, not obligatory but rather voluntary in this study.

The first piece of the study to be reviewed was the chapter "Goal and Scope", provided for review in March 2007. This important chapter was carefully reviewed by the panel in consultation with ERM. Most questions of the reviewers could be answered satisfactorily by the practitioner. There was no mid-term report (e.g. after completion of the Inventory analysis), so that the draft final report, delivered November 6, 2007, was the next text to be scrutinized. This proved to be the main work of the panel and provided a great amount of critical comments, as well as editorial suggestions by all reviewers. It was decided to deal with the most urgent items and the measures to be taken during a conference-call, which took place November 29 2007. This call involved the panel members, David Spitzley (K-C), and Jacob Madsen (ERM). It was decided that a revised Final Draft Report would be prepared by ERM and reviewed within one week by the panel. The task to check in depth the full set of inventory data of one of the systems studied was taken by Mary Ann Curran.

The revised Final Draft Report was delivered December 7, 2007. Most comments made by the reviewers on the basis of the first version of the Final Draft were taken into account by the practitioner. The statements and comments below are based on this revised report and the additional data supplied for system 3 (NA facial tissue).

The critical review process took place in an open and constructive atmosphere. The resulting critical review report is consensus between the reviewers. The commissioner was informed about the progress made and took part in the final phase of the review process as well as in its initiation.

2 General Comments

First, it should be mentioned that the practitioner performed the main part of the extensive study (7 tissue systems, four produced in North America, three in Europe), in only 8 months. This may explain some data problems commented in the review of the first final draft report. Data acquisition is a time-consuming process and cannot always be accelerated.

The Final Report has been significantly improved compared to the first draft and most comments made by the reviewers (including all important ones) were taken into account. Additional files were transmitted to the reviewers answering to the request for more information, especially regarding the Life Cycle Inventory data. Improvements were done even in the last days of the review.

The report also deserves recognition for the fine graphical presentation and lay-out.

3 Statements by the reviewers as required by ISO 14040

According to the LCA-framework standard ISO 14040 [2]

"The critical review process shall ensure that:

- *the methods used to carry out the LCA are consistent with the international Standard;*

- *the methods used to carry out the LCA are scientifically and technically valid;*
- *the data used are appropriate and reasonable in relation to the goal of the study;*
- *the interpretations reflect the limitations identified and the goal of the study;*
- *the study report is transparent and consistent."*

In the following sections 3.1 to 3.5 these items are discussed to our best judgment and considering the recently revised ISO standards 14040 [2] and 14044 [4]. These standards superseded the familiar old series ISO 14040-43 (1997-2000) in October 2006. The two standards are linked in such a way that it is not possible to use the LCA framework (14040) without using the strict rules (the “shalls”) contained in 14044, see also [5].

3.1 Are the methods used to carry out the LCA consistent with the International Standard?

In the final report it is claimed that this study has been performed according to the international standards ISO 14040 and 14044 [2,4]. This includes that the structure of LCA [2] as well as the detailed rules for the four components [4] have been observed. Concerning the structure it can be said the four main chapters 2 to 5 in the last version of the report correspond to the four components “Goal and scope definition” (2), “Inventory analysis” (3), “Impact assessment” (4) and “Interpretation” (5) of LCA. They are rounded up by a short chapter “conclusions” (6), a short introduction (1) and this critical review. Not only the structure, but also the content follows closely and in sufficient detail the standards.

The complete life cycle inventory modeling is in accordance with ISO and state of the art. It is well presented and understandable. Although the input data are not presented for reasons of confidentiality, the LCI results are presented both in tables and in flow diagrams. This presentation of LCI is far above average.

Life cycle impact assessment (LCIA) is performed according to CML in the main part. Since ISO does not prescribe any specific set of LCIA methods, this question belongs more to the next section. Normalization, an optional component of LCIA, is included in this study.

Other variants of LCIA categories and indicator models are used in sensitivity analyses including the very relevant impact category "aquatic eco-toxicity" which is absent in the restricted set of categories used in the main analysis. The same is true for the important impact category "land-use" or "land-occupation".

In the LCA component Life cycle interpretation, the method of sensitivity analysis has been used together with other methods of comparison. An explicit data uncertainty analysis was not carried out.

The new requirement by ISO 14044 saying that the critical review panel shall consist of at least three experts was accomplished.

We can therefore state **that the methods used are consistent with the international standard.**

3.2 Are the methods used to carry out the LCA scientifically and technically valid?

The methods used for collecting original data, to model the system and to calculate the inventory table are scientifically and technically up to date (see also section 3.1). In addition to the base scenario, which is as near to the present state of production and waste removal as possible, a few modifications were calculated. The software used is SimaPro 70, one of the most used software systems worldwide. The method of sensitivity analysis, used to investigate the influence of ambiguous assumptions, is state of the art.

The LCIA method used in the main part (CML) is the dominant impact assessment method, at least in Europe. The US counterpart, TRACI, was used as a sensitivity analysis. As stated in the report, TRACI is not yet peer reviewed internationally. This will change soon, however. Eco-indicator 99, used for sensitivity analysis, is also very widely used. This method should not be used for studies "supporting comparative assertions intended to be disclosed to the public". This is not the aim of this LCA study, however, dealing with K-C product systems exclusively. For the same reason, some very restrictive and detailed prescriptions laid down in ISO 14044 [4] are not obligatory in this study (even if it will be published).

In conclusion, it can be stated that **the methods used are scientifically and technically valid** within the framework of this study.

3.3 Are the data used appropriate and reasonable in relation to the goal of the study?

The data used in this study can be distinguished as

- Original data, collected in the production sites of the commissioner (foreground data), and
- Generic (background) data, especially for transports, energy, materials and commodities

The first item is a great asset of this LCA study due to the international nature of K-C, so that North American as well as European plants delivered original data. This regionally mixed set of original data is the exception rather than the rule in LCAs.

With regard to generic data, the primary source in this study was the Swiss Ecoinvent 2000 database [6], which is one of the most recent European data collections in a unified format (ecoSPOLD). This is problematic, since the majority of tissue systems are based in North America (4 out of 7). Although in NA no very large, consistent data banks exist which could be compared with Ecoinvent, this does not mean that no NA-specific data collections exist. The US/NA-data bank prepared by Franklin Ass. Ltd. has been used, but frequently Ecoinvent is cited as the source of generic data. There is also the intermediate case that original LCI data provided by the K-C plants were further processed using Ecoinvent to be useable for LCIA.

As said above, the original input data are not revealed in this study. In order to scrutinize at least a part of the input data, the original data for system 3 (NA facial tissue) were supplied by the practitioner and checked by one of us (MAC):

The data that were delivered for the review are extractions from the SimaPro software (the reviewers did not have access to SimaPro v7 to properly view the data). Because they are presented as a summarized report, the formatting is minimal (lacks some headings) and is difficult to track back to the source of the data and how the calculations were done. Nor do the data sheets given an indication of how the data met the data quality requirements. As a result, this review is very superficial.

Nonetheless, the data appear to have been collected in a logical way and consistent with the goal of the study. The data are grouped according to Inputs, Energy Use, Water Use, Wastewater Effluents (TSS and BOD), Non-Hazardous and Hazardous Waste, and Air Emissions (CO_2, N_2O, CH_4, PM, NO_x, CO, SO_x, and VOC).

In a detailed check, some discrepancies were detected in the data sheets supplied which were explained by the practitioner by the use of Ecoinvent (i.e. European) emission factors applied to NA production data. Assuming that NA emission control technology and regulations are similar to those in Europe, this explanation is acceptable. The full critical data report has been transmitted to the commissioner and the practitioner.

Another important issue related to the question of using a more “homogenous" data-set concerns the main topic of the project, namely the influence of recycling and virgin fibers on the environmental performance of the tissue products. In the opinion of both commissioner and practitioner, this distinction might have been obscured if regional differences prevailed.

To sum up, it can be stated that – despite the limitations exhibited above - **the data used are appropriate and reasonable in relation to the goal of the study.**

3.4 Do the interpretations reflect the limitations identified and the goal of the study?

The strength of the interpretation phase rests in the use of sensitivity analyses with regard to the uncertainties identified. In comparing systems, a 10% limit of significance was introduced, since all original data were either measured or calculated (no estimated values). This may be a bit too optimistic (except for energy), but it is a reasonable basis for the comparisons.

A thorough discussion of data quality (e.g. the use of European data as proxies for NA) is missing. This is especially true for some counter-intuitive results, e.g. the low score in “land-use” for a tissue system “A” (virgin fibers). Is the land-occupation by the forests not counted? Another case is the very low score for normalized aquatic eco-toxicity; it is unclear whether the low score represents reality or is simply the result of a lack of data availability. The high human toxicity scores, due to PAHs, on the other hand, are discussed in a plausible manner (similar emissions are often named differently).

In order to visualize the abstract energy data per functional unit, a "translation" into miles driven (car) is given in the comparisons, e.g. for the use of natural gas in drying fibers. This is a welcomed help for readers who do not frequently use Megajoules.

Within the limitations identified, it can be stated **that the interpretations reflect the limitations identified and the goal of the study.**

3.5 Is the study report transparent and consistent?

The report is well written, illustrated with colored diagrams and the length seems to be appropriate for the systems studied. Readability seems to be the main goal (certainly a good one), but also the structure is now clear and suggests to the trained reader that the international standards were followed. The strongest part is the inventory analysis, showing the results in detail (in contrast to the input data for the reasons discussed).

The transparency of the report is as high as it is possible with the data policy given. There is no executive summary in this report. This is unusual. If such a summary will be produced later, it is advisable to send it to the review team for comment. Otherwise it cannot claim to belong to this – critically reviewed – Final report.

The report is transparent and consistent.

4 Résumé and recommendations

This LCA study has been conducted according to the ISO standards 14040 and 14044. The quality of this study is a good example for an up-to-date LCA. Sensitivity analyses were used on most relevant issues. The study is probably unique in the treatment of different geographical regions (North America and Europe) with a unified method and using original foreground data for all systems studied.

A short version should be published in a scientific journal in order to expose it to a broader public interested in LCA in general and environmental assessment of tissues in particular. Additional publications in specialized technical journals may follow, but without undue generalizations.

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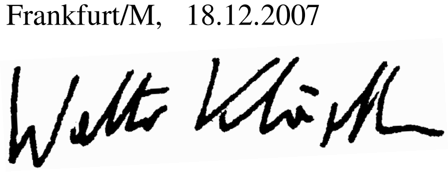

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Annex C

Glossary

GLOSSARY

BAT	Best Available Technique (Not Entailing Excessive Costs)
BCTMP	Bleached Chemi-Thermo-Mechanical Pulp
BOD	Biochemical Oxygen Demand
CED	Cumulative Energy Demand
CFC	Chloro-Fluoro-Carbon
CH	Switzerland
CH4	Methane
CML	Centrum voor Milieukunde Leiden
CO2	Carbon Dioxide
COD	Chemical Oxygen Demand
CORRIM	The Consortium for Research on Renewable Industrial Materials
DB	Dichlorobenzene
DFO	Distillate Fuel Oil
EI99	Ecoindicator 99
EPA	Environmental Protection Agency
ERM	Environmental Resources Management
EU	European Union
EUR	European
FR	France
FSC	Forestry Stewardship Council
GB	Great Britain
GMT	Geometric Mean Tensile
HGV	Heavy Goods Vehicle
HVAC	Heating Ventilation and Air Conditioning
ICMM	International Council on Mining and Metals
IEA	International Energy Agency
ISO	International Standards Organisation
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
MDIP	Market De-inked Pulp
MJ	MegaJoule (1,000,000 Joules)
MW	MegaWatt (1,000,000 Watts)
NA	North America
NBSK	Northern Bleached Softwood Kraft (pulp)
NREL	National Renewable Energy Laboratory
PAH	Polycyclic Aromatic Hydrocarbon
PM	Particulate Matter (e.g. PM10 ~ particles under 10 microns)
PO4	Phosphate
PR	Producer Responsibility
RBK	Recycled Bleached Kraft
RF	Recycled Fibres
SETAC	The Society of Environmental Toxicology and Chemistry
SO	Sulphur Oxide
SO2	Sulphur Dioxide
SS	Suspended Solids
SW	Softwood Bleached Kraft (pulp)

TRACI	Tools for the Reduction and Assessment of Chemical and other environmental Impact
TSS	Total Suspended Solids
UCTE	Union for the Coordination of Transmission of Electricity
UK	United Kingdom
UNEP	United Nations Environment Programme
USA	United States of America
VOC	Volatile Organic Compound