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Life Cycle Analysis of hand-drying systems

A comparison of cotton towels and paper towels

Technical report

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Contents

List of figures

List of tables

Summary

The European Textile Service Association (E.T.S.A.) commissioned Öko-Institut to compare two mechanical hand drying systems: the continuous cotton roll system and the paper towel system. Goal of this study was to gain more information on the environmental impacts of these two systems and to compare these systems with the objective to identify the one with the better environmental performance.

Against this background Öko-Institut carried out a Life Cycle Assessment (LCA) study according to the ISO 14040 series. For the two different hand drying systems three mechanical hand drying options were analysed altogether within this study:

- Hand drying with continuous cotton rolls, based on conventionally grown cotton,
- Hand drying with paper towels made from virgin luxury paper (VLP) and
- Hand drying with paper towels made from partly (i.e. 50 %) recycled fibres (RCF).

The functional unit of the study was specified with 10,000 hand-dryings in Europe providing the mechanical removal of water, remaining dirt and micro-organisms. As standard scenario in order to fulfil this functional unit, 10,000 pulls of the cotton roll system were compared with 20,000 paper towels. Non-mechanical hand drying systems (e.g. hot air dryers) were not part of the comparison because they were regarded as not having the same functionality, especially concerning the removal of dirt and micro-organisms.

E.T.S.A. intends to use the results of the study to inform the public on environmental impacts of hand drying systems. Furthermore, the results are designated for marketing purposes and should also disclose optimisation potentials for the analysed systems. Thus, according to the ISO 14040 series a critical review has to be carried out.

For the three analysed options the whole life cycle was taken into account: from cotton agriculture and tree nursing to towel production and use of the towels up to recycling / final disposal. In contrast to the paper towels, the cotton towels can be used approx. 100 times when washed in between until they end up - in most cases - as cleaning cloths.

In order to obtain a valid data basis for the laundering and distribution / redistribution processes of the cotton rolls, seven textile service companies from six European countries were investigated. These companies provided specific data from altogether 32 laundry sites. The technological standard applied in these laundry sites differs significantly, which is illustrated by a set of key parameters in the following table (Table 1).

Table 1 Range of laundering process parameters

parameter	unit	weighted average	range
specific electricity demand	kWh/kg	0.1	0.1 - 0.3
specific heat energy demand	MJ/kg	4.1	3.5 - 12.4
source for heat energy		natural gas	natural gas, oil
specific detergent and chemical use	g/kg	26.1	8.1 - 38.9
specific water use	l/kg	9.4	6.0 - 14.0
cotton roll use	g/pull	16.2	12.9 - 25.0
cotton roll per functional unit	kg	1.62	1.29 - 2.50
number of washing cycles		103.3	70 - 130
packaging material		none, PVC, PE, PP	
end of life use of cotton roll		88% as cleaning cloths (none - 100 %)	

In contrary to the laundering process, the production of the cotton-rolls was modelled with generic data. For this purpose, within an expert consultation process, existing studies (e.g. Brune / Krauch 1991, Kalliala / Nousiainen 1999) were analysed, adapted and updated where necessary.

Furthermore, modelling of paper towels was done on the basis of BREF documents for pulp and paper industry (European Commission 2001). For both VLP and RCF tissue production European average values representing the prevalent technological standard were selected and validated / adjusted with correspondent data published in recent environmental reports of relevant companies (such as SCA Hygiene Products GmbH).

The set of key parameters used for calculating the environmental impacts of the paper towel system is shown in Table 2.

Table 2 Range of paper towel production parameters (European Commission 2001)

parameter	unit	VLP		RCF	
		average	range	average	range
chemical bleached pulp	kg/kg	1.015	1.010 - 1.020	-	-
recovered paper	kg/kg	-	-	1.505	1.010 – 2.000
specific electricity demand	kWh/kg	1.5[1]	1.0 - 3.0	1.6[2]	1.2 – 3.0
fuel for steam generation	MJ/kg	15	5 - 25	15	5 - 25
source for heat energy		natural gas	coal, oil, natural gas	natural gas	coal, oil, natural gas
specific auxiliary material use	g/kg	66	0 - 132	75	0 - 150
specific water use	l/kg	53.5	7 - 100	52.5	5 - 100
paper use	g/hand drying	8	-	8	-
paper use per functional unit	kg	80	-	80	-
packaging material		none	-	none	-

In LCA all environmental parameters are analysed, of special concern for these compared systems are waste and water use, which are disclosed in the inventory results. After having calculated the environmental inventory of the compared systems, the environmental impact assessment was performed using the following impact categories:

- Global Warming Potential (GWP)
- Acidification Potential (AP)
- Eutrophication Potential (EP)
- Photochemical Ozone Creation Potential (POCP)

Aquatic toxicity was only assessed qualitatively.

In addition to these impact categories, also the results of relevant life cycle inventory (LCI) indicators are presented. These indicators comprise the following input / output parameter, which were regarded as characteristic for the systems under investigation:

[1] This value is not the arithmetic mean of the correspondent range. However, for certain reasons this value was chosen for the modelling (cf. section 3.2.2.1).

[2] This value is not the arithmetic mean of the correspondent range. However, for certain reasons this value was chosen for the modelling (cf. section 3.2.2.2).

- Cumulated Energy Demand (CED)
- Water use
- Waste generation.

In general, in the standard scenario, the cotton towel roll system is better than the paper towel system regarding all impact assessment indicators. Only the water demand of the cotton roll system is higher than the one of the paper options. Figure 1 illustrates the results of the impact assessment indicators compared to the cotton roll system (100 %).

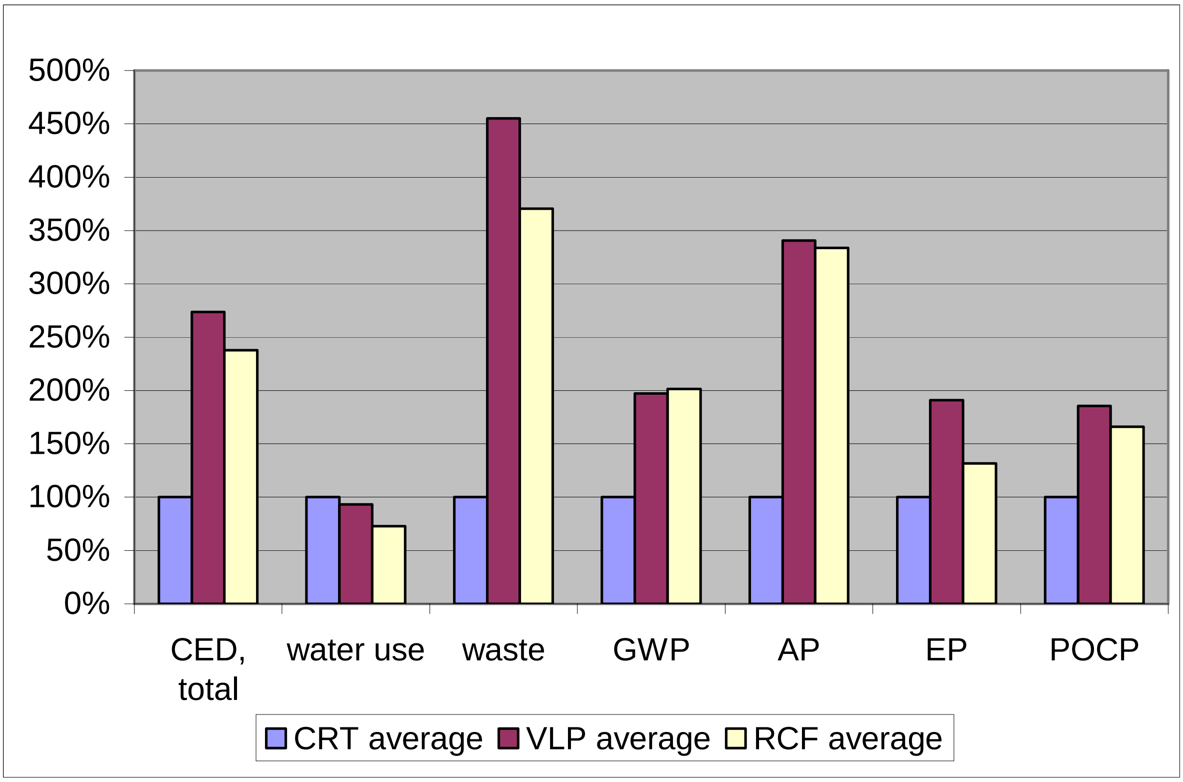

Figure 1 Comparison of the environmental impacts for the analysed hand drying systems (standard scenario)

Consequently, the main environmental impact of the paper towel system is derived from the towel production for all indicators. In contrast, for the cotton roll system, the main impact is sometimes caused by laundering (CED, GWP) and sometimes by towel production (water, EP). For the AP, towel production and laundering have nearly the same impact whereas for POCP it is laundering and distribution which nearly have the same impact.

These results refer to a cotton roll life time of about 100 washing cycles. If the life time is shorter, being the case in some of the investigated laundries, the environmental burden of cotton roll towel production increases by nearly 50 %. This would lead to significantly higher impacts particularly for water demand, EP and AP. In contrast, a longer cotton roll life time, which was also found in the laundries investigated, leads to about 20 % lower impacts. Respectively, this is most relevant for the three above mentioned indicators.

The amount of paper towels used to dry hands resp. the cotton roll pulls for hand drying also have a great influence: but even if only one paper towel is used for hand drying, the standard use scenario for the cotton roll system is still better for 3 out of 7 parameters / indicators (CED, waste, AP). However, in a minimum scenario results change for two indicators and paper towels get better than the cotton roll system. Nevertheless, even if more paper towels are used than in the standard scenario, the results will change: in the maximum use scenario the paper towel system is worse than the cotton roll system for all investigated parameters / indicators. In contrast, even in a maximum use scenario (assuming 2 pulls per hand drying), continuous cotton roll towels are better than the paper towel system for 3 out of 7 parameters / indicators (standard use scenario): this is the case for CED, waste and AP. However, in the maximum scenario, for water use, EP and POCP the cotton roll system is inferior to the paper system.

As conclusion and seeing that the use behaviour of the washroom clients will influence the environmental assessment of both systems significantly, it can be stated that the cotton roll system for standard use causes less environmental impacts than the paper towel system.

1 Introduction

The question which hand drying system is best concerning environmental impacts has been discussed in the past (e.g. Brune / Krauch 1991). Particularly with regard to cotton towels and paper towels, but also air dryers have been discussed (e.g. ERM 2001). In the meantime many processes e.g. laundering of cotton rolls, but also paper industries have improved. Thus, the European Textile Service Association (E.T.S.A.) decided to commission Öko-Institut – Institute for Applied Ecology, an independent German environmental research institute, to carry out a Life Cycle Study with the aim to compare two mechanical hand drying systems: continuous cotton roll towels and paper towels.

The report in hand analyses those two mechanical hand drying systems. In section 2 the goal and scope of the study are described. Section 3 gives an overview of the modelling and the data basis used; section 4 explains the results of the life cycle assessment. Finally, section 5 discusses the results and gives some conclusions.

2 Goal and scope

This section specifies the goal and scope of the study: in section 2.1 the goal of the study and the intended audience are described; section 2.2 gives a short description of the investigated systems. The functional unit and the function of the product systems are described in section 2.3; data quality requirements and sensitivities are described in section 2.5 and the impact assessment methodology is described in section 2.6. Allocation procedures are characterised in section 2.7; section 2.8 describes the limitations of the study and section 2.9 the critical review process.

2.1 Goal of the study and intended audience

Goal of this Life Cycle Assessment (LCA) is to gain more information on the environmental impacts of two hand drying systems (paper towels and textile towel rolls) and therefore to compare these systems with the aim to identify the one with less environmental impacts concerning the investigated parameters. It is intended to use the results of the study to inform the public on environmental impacts of hand drying systems. Furthermore, the results are designated for marketing purposes and should also disclose optimisation potentials for the analysed systems.

The results of the study are expected to be of relevance to the following interested parties: Washroom operators (as “users” of textile towels and / or paper towels), professional laundries, paper towel and cotton roll manufacturers, laundry detergent manufacturers, environmental policy makers / administrators and the interested public in general. At a second level, the results could also be of interest to organisations representing branches of industry and trades where cotton rolls and paper towels are used.

The LCA presented in this study was performed on behalf of the European Textile Service Association (E.T.S.A.), industry association of the European industrial laundries. It was coordinated by Henrik Grüttner, EcoForum Denmark. The LCA was carried out by Öko-Institut – Institute for Applied Ecology, an independent environmental research institute, following the requirements of the ISO 14040 series standards (ISO 1997, ISO 1998, ISO 2000a, ISO 2000b).

The present report is not intended to be published actively, but will be publicly available from E.T.S.A. or Öko-Institut on request. Therefore a critical review will be carried out (cf. section 2.9).

2.2 Short description of investigated systems

In this LCA two mechanical hand drying systems will be analysed: Hand drying with continuous cotton rolls and hand drying with paper towels.

- **Cotton roll system**:
  The cotton roll system uses continuous cotton towels, which can be reused by washing in professional laundries. The cotton rolls are produced and manufactured from cotton fibre ("lint") from conventional agriculture. From the production site the cotton rolls go to laundries for washing and from there they are distributed to washrooms, where they are put into towel roll dispensers and used by washroom clients. After usage the cotton rolls are transported to laundries and washed in washing machines with different types of detergents and chemicals, used for hygiene washing processes. Whereas the electricity used for washing and finishing is provided by grid, the used steam is produced in-house. After 70 - 130 washing cycles the cotton rolls have reached the end of their life-time and are (in most cases) cut and used as disposable cleaning cloths. Finally, they are treated within a waste incineration plant.
- **Paper towel system**:
  In contrast to the cotton rolls, the paper towel system is a one-way system using paper towels, which cannot be re-processed. The paper towels investigated represent two different paper qualities: high quality paper and medium quality paper. The high quality paper (virgin luxury paper) towels investigated are manufactured from fresh pulp, the medium quality paper towels are manufactured partly from fresh pulp (50 %) and partly

from recycling paper (50 %).[3] The paper towels are transported from the towel manufacturer to the laundry (as the service provider) and are further distributed to washrooms. After their use by washroom clients spent towels are collected within bin liners and are finally disposed of after treatment with energy recovery in waste incineration plant.

2.3 Functional unit and function of the product systems

In general, there are two different ways to dry hands: mechanical water removal or thermal water removal. Hand drying systems which work with mechanical removal of water, also remove an (not quantifiable) amount of micro-organisms and remaining dirt. In contrast, systems which work with thermal removal of water will not do so. Another difference between mechanical and thermal hand drying systems is the time needed for drying hands: mechanical hand drying is less time-consuming than thermal drying. Thus, it can be observed that a lot of persons completely skip hand drying if only a hot air dryer is available. This shows that mechanical and thermal systems have a different utility for the user and therefore are not comparable within a LCA focusing on hand-dryings. Thus, in this LCA only mechanical hand-drying systems will be compared.

The “drying performance” of the mechanical hand drying systems depends on the amount of towel(s) used and on the quality of the towels: the towels have to provide mechanical removal of water, remaining dirt and micro-organisms. Following E.T.S.A. members experience,[4] standard in washrooms to dry hands is either to pull once at a continuous cotton roll towel or to use two paper towels[5].

In accordance with E.T.S.A. 10,000 hand dryings in Europe were set as functional unit of this study. When assuming that one pair of hands is covered with approx. 5 g of water in average[6], the functional unit implicates the removal of approx. 50 kg of water.

Thus, in this study as standard scenario 10,000 pulls of the cotton roll system or 20,000 paper towels are calculated to fulfil the functional unit. In sensitivity analyses minimum and maximum use scenarios will be calculated, but will not be surveyed as such (cf. sections 3.1.7, 0, 4.3). All results in the study will be given according to the functional unit in the standard scenario unless it is stated differently.

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3 The 50% recycling and 50% fresh pulp variant was chosen because this is the most common composition for medium quality paper towels used by E.T.S.A. member laundries.

4 Nearly all of the investigated textile service companies not only offer continuous cotton roll towels to washrooms but also paper towels.

5 Size of the paper towels: approx. 31 cm x 24 cm, C-fold; weight: approx. 4 g.

6 This value was determined empirically in order to give the reader an illustration. It is not further used in the study.

2.4 System boundaries of the product systems

Life cycles of mechanical hand drying systems differ depending on the materials used for hand drying: life cycle steps they have in common are the production of the materials for hand drying and the use of it in washrooms. Differing life cycle steps are the materials used, and therefore the production processes of the materials, and the possibilities of reuse after hand drying.

The following figure (Figure 2) shows the three options of mechanical hand drying investigated in this study:

- Option 1: Continuous cotton roll system, based on conventionally grown and produced cotton.
- Option 2a: Paper towel system, based on virgin luxury paper.
- Option 2b: Paper towel system, based on partly (50 %) recycled medium quality paper.

The investigated systems and options will be described in detail in section 3.

For the textile towel systems, the following life cycle stages will be included within this study (cf. Figure 2):

- production of the cotton towels – from cotton growing to final product;
- laundering of the towel rolls;
- transport of all products and materials;
- secondary use of towel rolls as cleaning cloths (balanced as credits);
- disposal of towels and packaging (incineration7).

[7] Within this study, incineration was chosen as the only disposal option as this treatment is obligatory in Germany and the majority of the cotton rolls are laundered in Germany.

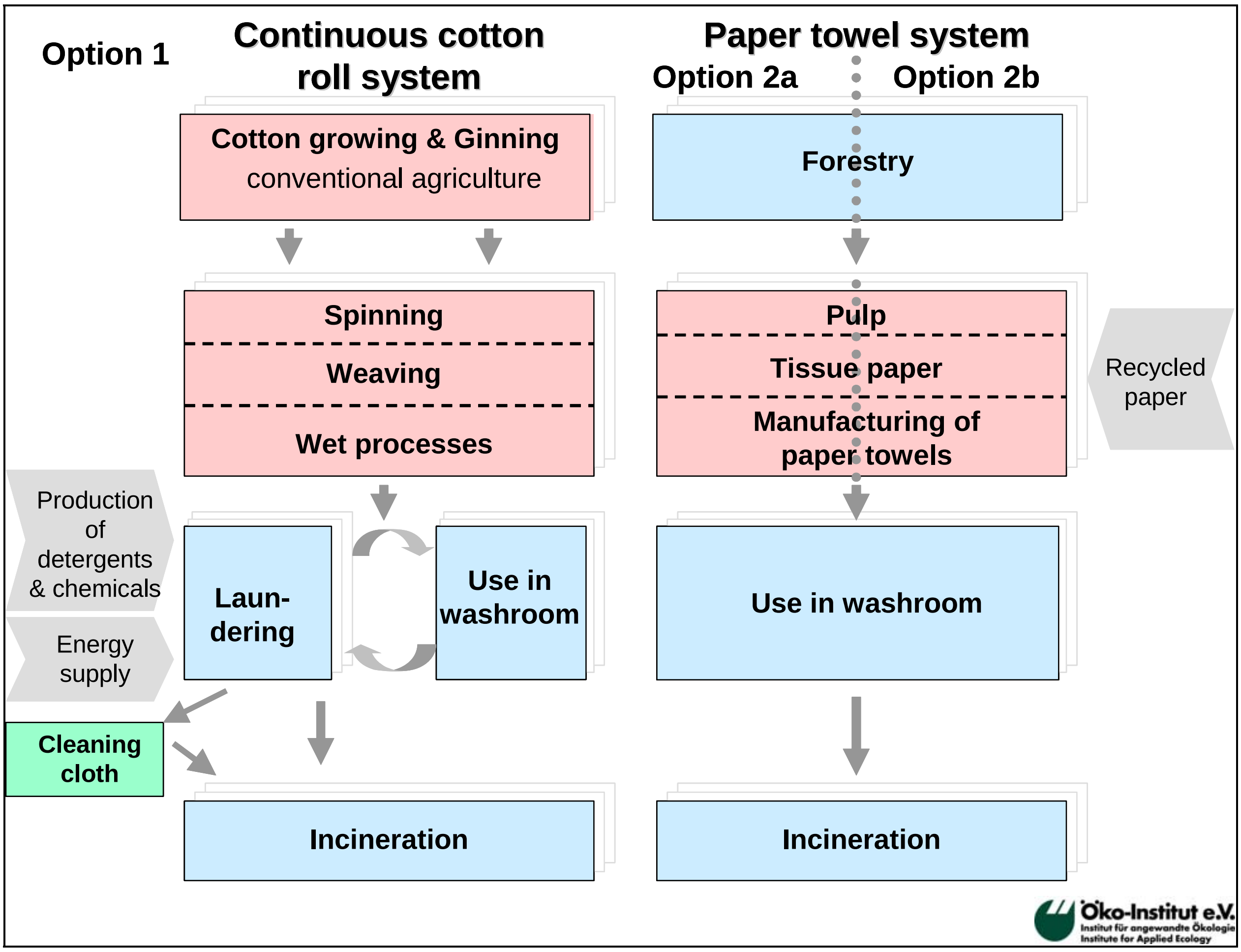

Figure 2 Life cycles of both investigated systems

The production of towel roll dispensers will not be included for the reason that the impacts are expected to be very limited. Furthermore, cabinets for the paper alternative are also excluded (Figure 3).

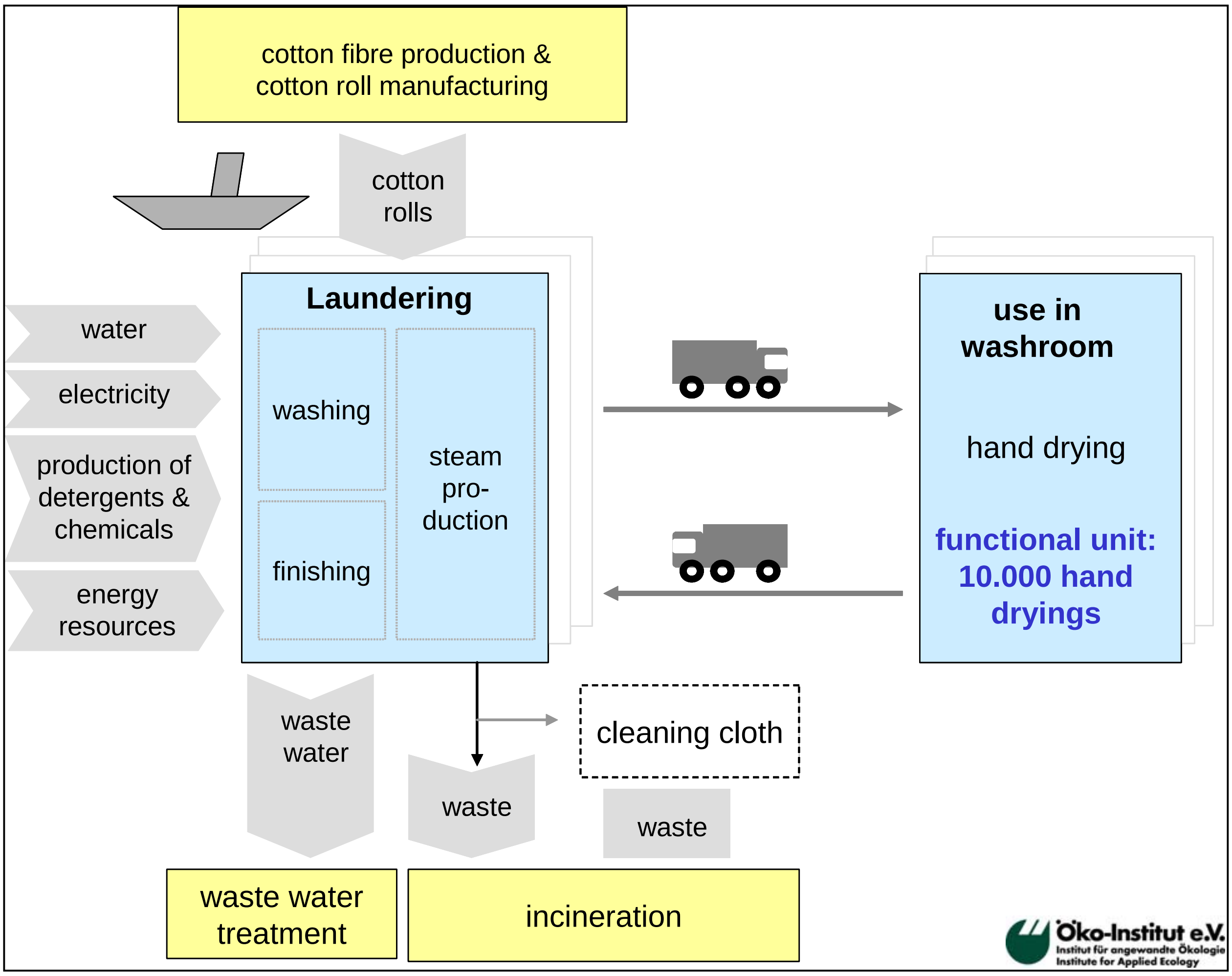

Figure 3 System boundaries for the cotton roll product system

For the paper towel system, following life cycle stages will be included in this study (cf. Figure 4):

- production of paper towels – from tree nursing to final product;
- production of bin liners and packaging materials;
- transport of all materials;
- disposal of towels, bin liners and packaging (incineration[8]).

[8] Within this study, incineration was chosen as the only disposal option as this treatment is obligatory in Germany and the majority of the cotton rolls are laundered in Germany.

Again the production of dispensers and bins will be excluded from the paper alternatives due to two reasons: the impacts are expected to be very limited and the huge variety of different designs and materials used.

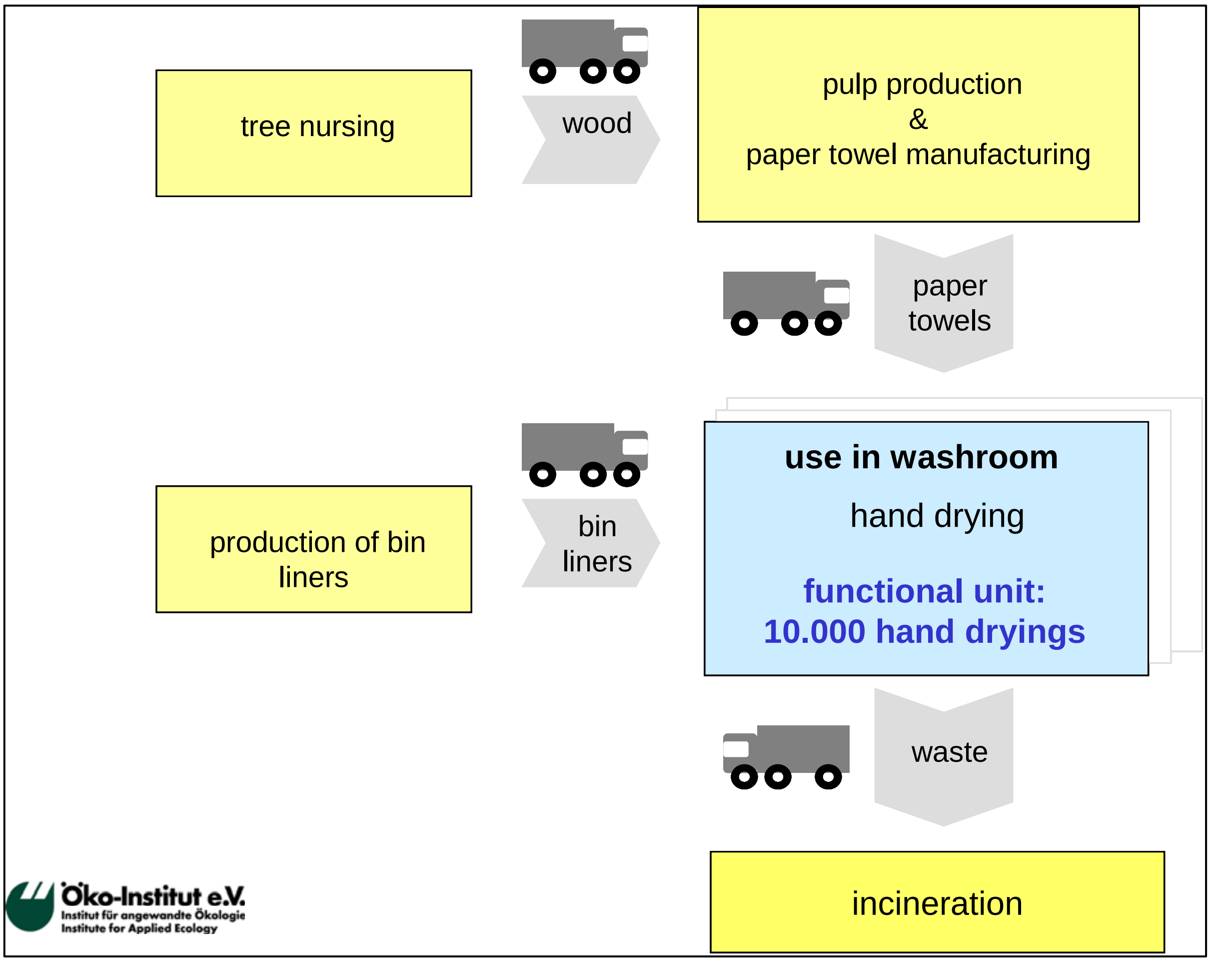

Figure 4 System boundaries for paper towel product system

Also the so-called capital equipment (e.g. machines for fibre and towel production, production of transport vehicles) is excluded from the investigation for the same reason as dispensers and towel cabinets are excluded. The impact is expected to be very limited.

In general, all processes comprising less than 1 % of the total mass and energy balance are not incorporated within this study, whereas the sum of all excluded processes must not exceed 5 % of the total balance (cut-off criteria).

2.5 Data quality requirements and sensitivities

According to EN ISO 14040 and EN ISO 14041 data quality requirements should be included for the following parameters:

- Time-related coverage: For this LCA study only data is used, which is not older than 10 years.[9] For the core processes (washing / finishing as well as pulp & tissue production) only data is used, which is not older than 5 years.
- Geographical coverage: Concerning supply chain processes (e.g. cotton production, paper production) the geographical coverage is correspondent to the assumed supply chain (world for cotton production, Europe for paper production), concerning core processes (washing / finishing) the collected data refer to Europe, the electricity supply for the core processes will cover the UCPTE[10] countries.
- Technological coverage (i.e. technological standard of production, transport, use and disposal processes): For the core processes (washing / finishing as well as pulp & tissue production) all data within this study refer to state-of-the-art (i.e. status quo) processes used in Europe; for cotton production and cotton towel manufacturing and other supply chain processes the data refer to the status quo in the respective country / region.
- Precision, completeness and representativeness, uncertainty of the data and data sources: Within this LCA study representative data is used, whenever available. The representativeness of the data and data sources is checked. For some detergent ingredients reviewed LCAs for example are still missing. For those ingredients only screening inventories could be used, this is stated in the report (cf. Table 6). For background data the description of general requirements is included in the sources and not further described within this report. For core data for instance this is included in this report (cf. section 3).
- Consistency and reproducibility of the methods used: The methods used throughout this LCA are consistent and reproducible, if other methods as the preferred methods are used this is clearly stated.

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9 For some unit processes it might be necessary to make an exception from this requirement due to data availability, e.g. for some detergent ingredients. However, these processes will have only minor impact in the total result and will be further specified in section 3. Furthermore, an exception was made for the UCTE electricity mix as the original and current data set from the Umberto library was used. In fact, this electricity mix is from 1994 (UCPTE), albeit not so much different from the current one (1994: 49% fossil, 36% nuclear, 15% water; 2004: 54% fossil, 33% nuclear, 13% water). Actually, when using the 1994 data, a slight bias in favour of the paper alternative occurs, which can be regarded as a conservative assumption. Furthermore, the applied UCPTE mix provides consistency with the energy mix used for the modelling of the detergents.

10 Union for the Coordination of Transmission of Electricity.

The data sources used for the study's inventory can be distinguished in general and specific data:

- General data are average values representing the average technological standard used for the investigated process within a specified geographical coverage and are often appropriate for up-chain and down-chain processes. Within this study, for example, general data is used for the electricity production and the regarded transport processes.
- Specific data, however, represent the circumstances at a specific production site and therefore have to be preferred when modelling the core processes of the investigated system. Thus, within this study especially the washing and distribution processes are inventoried with specific data provided by the individual enterprises.

Sensitivity analysis measures will be carried out in order to assess the extent to which changes in the life cycle inventory analysis influence the indicator results. Within this study, sensitivity analyses will be carried out for dominating input values and parameters.

The data basis as well as the sensitivity analyses to be carried out are described in detail in section 3.

2.6 Impact assessment methodology and life cycle indicators

In general terms, impact assessment involves assessing the results of the life cycle inventory in relation to their relevance to the environment. To this end, EN ISO 14042 lays down that relevant impact categories have to be selected (including the associated indicators and models). Afterwards, the life cycle inventory results have to be classified by category and subsequently their contribution has to be taken into account through characterisation. These results together form what is called the "impact assessment profile".

It should be kept in mind that LCA has some inherent limitations (cf. ISO 14042, section 8), study specific limitations are given in section 2.8.

Beyond this, there are optional components for presentation and further aggregation of the results; however, there is no consensus yet among the experts concerning the data, models and procedures that have to be used for this purpose. Against this background, this study avoids these other possible methods of interpretation. The characterisation factors used for calculation of impact categories are oriented at CML 2004.

Based on the objectives of the study and bearing data availability in mind, the following impact categories are described in quantitative terms:

- ***Global Warming Potential:*** ***.***
  The global warming potential represents the contribution of anthropogenic emissions to the radiative forcing or heat radiation absorption in the atmosphere and therefore is a indicator to express the so-called "greenhouse-effect". Pollutants, which contribute to the global warming phenomenon are inventoried and aggregated taking their *G*lobal *W*arming *P*otential (*GWP*) into account. The GWP denotes the pollutant impact of the

different substances in relation to carbon dioxide (CO_2). As an indicator for the emission of greenhouse gases the global warming potential is expressed in terms of CO_2 equivalents. 100 years are set as the inventory period for calculating values.

- ***Acidification Potential (air, water, soil)***:
  Pollutants which are acids or cause acidification processes in air, water and soil will be inventoried and aggregated taking their *A*cidification *P*otential (*AP*) into account. The problem of acid rain has gradually abated; however, the long term effects on soil, vegetation and edaphone (the sum of all soil organisms) is still problematic. Concerning the correlation between acids in air, water and soil, a single measure was chosen to assess acidification. The AP denotes the pollutant effect of a substance as an acidifier defined as the number of H+-ions produced relative to sulphur dioxide (SO_2). As an indicator for pollution, the acidification potential is expressed in terms of SO_2 equivalents. Regarding the quantitative contribution the major acids or acidifiers are ammonia, nitrogen oxides and sulphur dioxide.
- ***Eutrophication Potential***:
  Nutrient enrichment in water and soil can cause a shift in species composition and an increasing biomass production in aquatic and terrestrial ecosystems. In aquatic ecosystems added biomass can lead to a consumption of oxygen. The *E*utrophication *P*otential (*EP*) for the relevant emissions is assessed with respect to that of phosphate in order to enable phosphate as a reference. In addition, the chemical oxygen demand is used as a measure for the entry of organic carbon. As a simplification it is assumed that all emissions of nutrients (N and P) into air, water and soil and of organic matter to water can be aggregated into a single measure, because this method allows both terrestrial and aquatic eutrophication to be assessed. Eutrophication potential is expressed in terms of PO_4^{3-} equivalents.
- ***Aqua toxicity Potential***:
  The aqua toxicity is relevant for the pollution of water with toxic substances. It is quite difficult to get a good and valid data basis, because for some wastewater ingredients characterisation factors are still not available and for some processes it is quite difficult to obtain wastewater data (e.g. pesticide use in cotton agriculture). Even if all characterisation factors were available they would be very uncertain. Thus, in the study aqua toxicity will be addressed only qualitatively and not quantitatively.
- ***Photochemical Ozone Creation Potential:***
  Pollutants which contribute to tropospheric ozone formation are aggregated within the Photochemical Ozone Creation Potential (POCP). The formation of reactive chemical compounds such as ozone under the influence of sunlight through photochemical oxidation of Volatile Organic Compounds (VOC) and carbon monoxide under the presence of nitrogen oxides (NO_x) is often referred to as photochemical smog or summer smog.

Ozone causes harmful effects on the human respiratory systems and affects plants. The POCP is expressed in ethylene equivalents.

- As ozone depletion is not relevant for the analysed processes (e.g. Eberle 2000) this impact category will not be described in quantitative terms in the study.

Besides of the mentioned impact categories, also the most important life cycle inventory indicators are taken into account. These comprise the following input / output parameter, which were regarded as most relevant for the systems under investigation:

- ***Use of energy resources:***
  The **C**umulative **E**nergy **D**emand (CED[11]) is a measure for the total demand of energy resources necessary for the supply of a product or a service. Within the CED also the amount of energy is accounted for that is still available within the product itself (e.g. in a wooden component). The CED specifies all non-renewable (i.e. fossil and nuclear energy) and renewable energy sources as primary energy values. It is calculated on the basis of the net calorific value[12] (in the case of combustibles) respectively – in the case of electricity from nuclear power plants – based on the degree of thermal utilisation of the nuclear power plant (no other losses are taken into consideration). It is expressed in mega joules (MJ). Primary energy demand that cannot clearly be specified as non-renewable or renewable is subsumed in the class “CED, others”. Finally, the different CED classes are aggregated to the total CED. No characterisation step is being undertaken.
- **Water use**
  Concerning water use, the different water inputs are taken into account, i.e. ground water, surface water and industrial water (including process and cooling water). Concerning the amount of water, one has to take into account that the amount does not necessarily say anything about the importance of the water consumption (related to local or regional scarcity). Hence, it can be very difficult to conclude which is the best and worst alternative based on the inventory of the water consumption.
  Furthermore, the Chemical Oxygen Demand (COD) and the Biological Oxygen Demand (BOD) is calculated in order to estimate the waste water pollution connected with the water use.
- **Waste generation**
  Within this impact indicator, all elementary flows contributing to waste generation are considered. One has to take into account that the amount of waste does not necessarily

[11] In German the CED is known as “Kumulierter Energie-Aufwand (KEA)”.
For more details see http://www.oeko.de/service/kea/

[12] The use of the net calorific value is a historical convention.

say anything about the importance of the waste, as different types of waste can have very different potential hazards. Hence, it can be very difficult to conclude which is the best and worst alternative based on the inventory of the total waste generated.

Further information, especially regarding classification and characterisation within the used impact indicators can be found in Annex 7.6 and in Möller et al. (2005).

2.7 Allocation

When performing LCA studies, allocation procedures are necessary when more than one product is generated within the investigated processes (e.g. fibre and seed production during cotton growing). Another pre-requisite for allocation are so-called multi-input processes (e.g. waste incineration) where the resulting emissions and the ancillaries needed have to be assigned to the different inputs. Within this study allocation procedures are necessary for the following processes:

- cotton growing (seeds)
- washing process in laundries
- production of cleaning cloths
- waste incineration

Basically, according to ISO 14041 the use of system expansion is used in this study whenever possible in order to avoid allocation procedures. However, in some cases, the nature of the data sets necessitates the use of allocation procedures. For example, regarding the data set on cotton growing, system expansion could not be used. Modelling according to system expansion would require appropriate data for oil and animal feed for crediting the benefits of the cotton seeds as the co-products of cotton growing. As this data was not available, the allocation by value (between lint and seed) makes most sense and thus was used.

Further specification of the allocation assumptions can be found in section 3.

2.8 Limitations

This study compares the environmental impacts of two mechanical hand drying systems. The following limitations of the studies results have to be taken into consideration:

In respect to the impact assessment it has to be stated that the impact categories used for impact assessment in LCA can not display all environmental effects caused by the analysed systems (e.g. effects on biodiversity can not be displayed). Beyond this, the aqua toxicity potential can only be assessed verbal-argumentative, due to the problem that for many substances characterisation factors are still missing (cf. section 2.6).

In respect to the data basis used, it has to be considered that this LCA covers the status quo of the investigated textile service companies (as weighted average on the basis of the amount of washed cotton towels) and the theoretical status quo for the paper towel system (based on the BREF documents). Taking this into account, no recommendations can be given concerning the improvement of the "real practice" in paper towel production. In contrast, those recommendations can be given for cotton roll laundering. However, no recommendations can be given for specific laundry sites as the companies were taken as entities and not specific laundry sites.

Regarding the textile service companies has to be considered, that the basis of the status quo are the seven European companies investigated, which do not represent 100 % of cotton roll laundering in Europe. But it can be assumed that more than 50 % of cotton rolls washed all over Europe is washed in these laundry companies (ETSA 2005). However, like all industrial processes, these two systems are subject to a continuous process of change / improvement. In the case of unilateral changes / improvements the results and conclusions derived from this study might also be influenced.

Furthermore, not for all parameters analysed valid data in all life cycle stages are available. For example, for paper towel production data for water emissions are mostly missing. So the aqua toxicity for paper towels could not be assessed. Beyond this, for some life cycle stages of the cotton roll system, e.g. spinning, sizing and weaving, data which meet the time related scope of the study are not available. In the study this problem was solved using older data, assuming that this will be a conservative approach in account of the cotton roll system.

2.9 Description of critical review process

According to EN ISO 14040 series a critical review shall be conducted for LCA studies used to make a comparative assertion that is disclosed to the public. The critical review is a technique to verify whether the LCA study has met the requirements of the international standard concerning methodology, data and reporting:

- consistency of the method used with accepted practice (ISO standards),
- scientific and technical validity of the method used,
- appropriateness and reasonability of the obtained data for fulfilling the study's goals,
- appropriateness of interpretation and conclusions in respect to the data obtained, the limitations identified and the goal of the study,
- transparency and consistency of the study report.

Another purpose of the Critical Review is to improve both the quality and the credibility of the study.

According to the goal of this study the results are intended to be used within marketing activities (cf. section 2.1). Thus, a critical review process with an external expert review has to be carried out.

A **critical review by experts** was chosen for this study. Jeppe Frydendal (LCA consultant, Denmark) was selected as external expert to act as chairperson of the review panel. In consultation with the E.T.S.A., Michael Collins (LCA consultant, Great Britain) was selected as further member of the Critical Review Panel by the chairperson. Both experts chosen are familiar with the ISO 14040 series.

3 Modelling and data basis

In the following the investigated options and the data basis will be described in detail:

- Option 1: textile towel roll system based on conventionally grown and produced cotton (section 3.1) and
- Option 2: paper towel system (section 3.2).

The specific data were obtained by a questionnaire developed in accordance with E.T.S.A. and send out to E.T.S.A. member laundries. The questionnaire is documented in Annex 7.1.

3.1 Continuous cotton roll system

The model of the continuous cotton roll system encompasses the following life cycle stages:

- production of the cotton towels – from cotton growing to final product, including the transport to the laundry (section 3.1.1);
- laundering of the towel rolls (section 3.1.2),
- distribution to the customer (section 3.1.3),
- use in washrooms (section 3.1.4),
- redistribution (section 3.1.5) and
- end-of-life treatment (incineration) after the secondary use of towel rolls as cleaning cloths (section 3.1.6).

The calculation of the life cycle assessment was carried out by using the LCA tool “Umberto”, Vol. 4.3. Figure 5 shows the above mentioned life cycle stages in the Umberto interface.

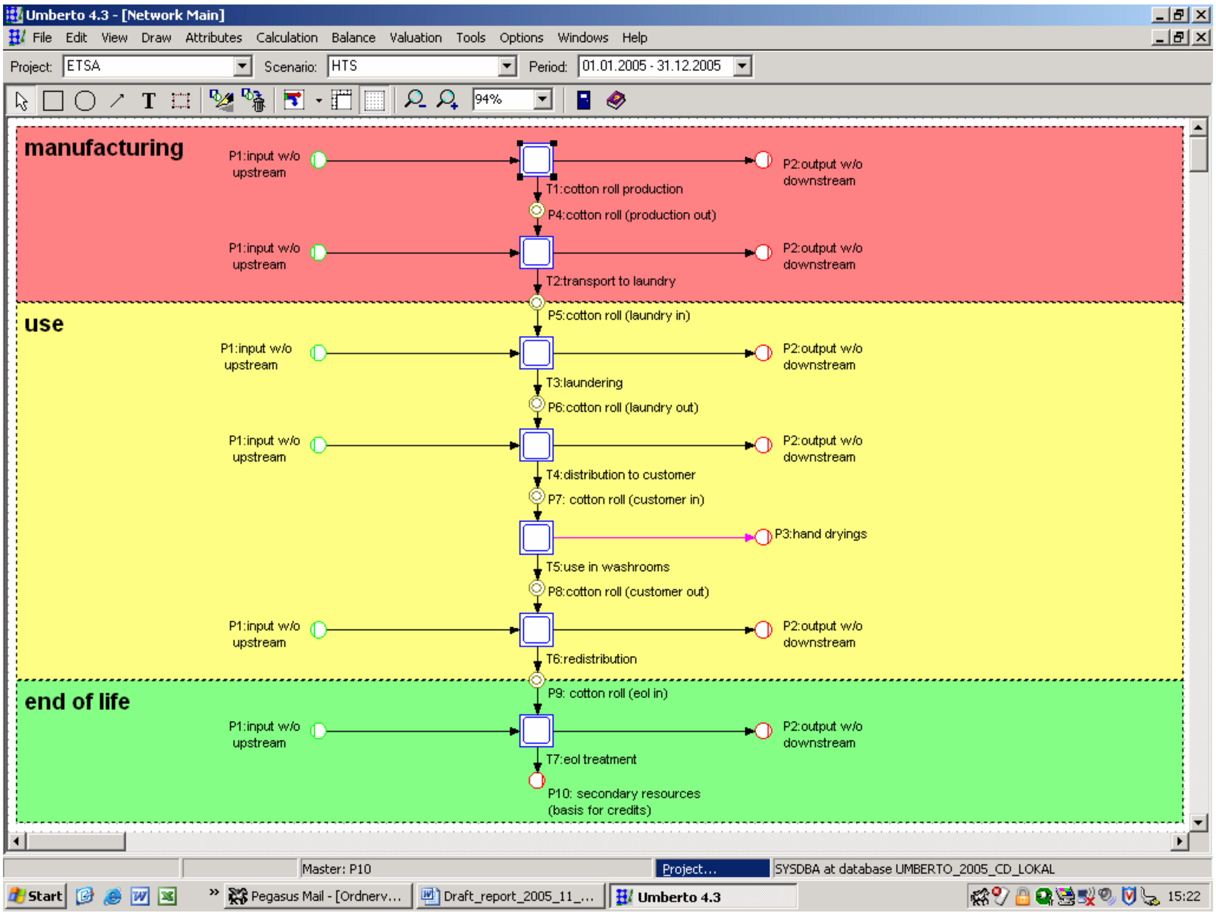

Figure 5 LCA network of the cotton roll system

In the following sections, the process steps and unit processes of these life cycle stages will be specified regarding their modelling assumptions and data basis. Within Umberto, the unit processes are linked together and thus form a balance network for the life cycle stage, which is then connected with the other life cycle stages in order to establish a balance network for the whole product system (i.e. the life cycle of the cotton roll). In Figure 5 the life cycle stages of the cotton roll system are represented by squares with double border lines symbolising the existence of a subnet for the different life cycle stages (cf. Figure 6). Connections between the subnets of the life cycle stages are depicted as concentric circles. Withdrawals from the environment (e.g. raw material extraction) are represented by circles with vertical lines on the left hand side, whereas releases into the environment (e.g. emissions) are displayed as circles with vertical lines on the right hand side. Eventually, on the basis of this data network, the energy and material flows for the function unit can be calculated.

3.1.1 Production of cotton rolls

The sub-network of the cotton roll production consists of the following process steps (cf. also Figure 6):

- cotton fibre production,
- spinning,
- sizing,
- weaving,
- de-sizing, scouring and bleaching.

The process step of cotton fibre production was modelled according to Frydendal (2001). The data provided by this report represent the world average of cotton growing (from land preparation up to ginning). The time-related coverage refers to 1999. Due to irrigation, this process step is regarded to have a major impact on the total water use of the cotton roll system. Therefore, the modelling concerning the combined production of cotton lint (i.e. fibre) and cotton seeds during cotton growing has to be selected carefully. Within this study, the economical allocation method (Frydendal 2001, p. 39) was chosen. As already mentioned, modelling according to system expansion was not possible, as the necessary data was not available (cf. section 2.7). Also the physical allocation method (considering the mass share of lint and seeds) was disapproved. This method would imply that the production of lint and seed was a coequal goal of cotton growing, which is not the case. Furthermore, this method would favour the cotton roll system and thus would not be consistent with the conservative approach of the study.

Regarding modelling of the de-sizing / scouring / bleaching process, step data were taken from a correspondent BREF document (Reference Document on Best Available Techniques for the Textiles Industry) of the European Commission (BREF textiles 2003). Besides data on Best Available Technology (BAT) this document also includes status quo emission and consumption levels for the mentioned wet processes. For the purpose of this study, average values were derived from the BREF study (BREF textiles 2003, see 137 pp.).

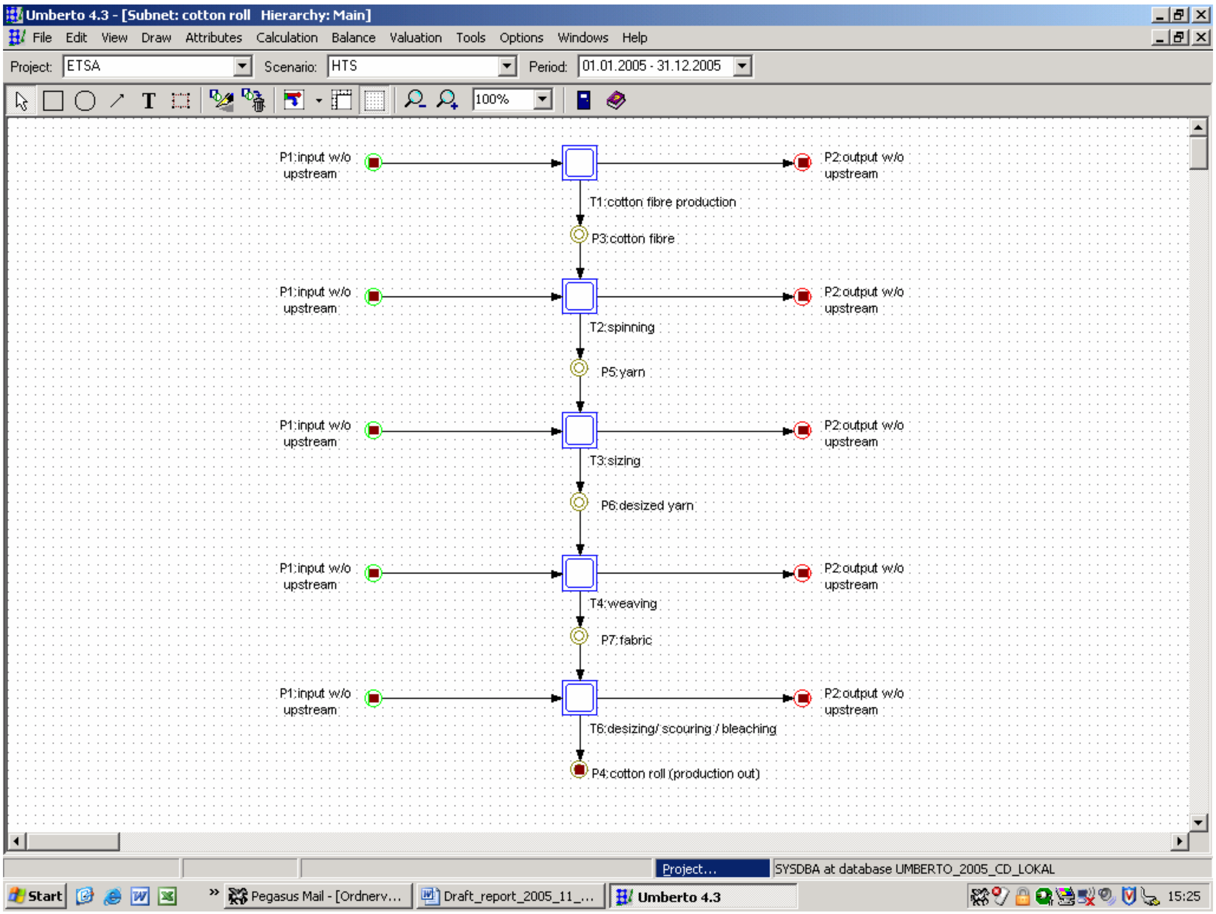

Figure 6	Sub-network of the cotton roll production

Unfortunately, the BREF document on textile industry does not include quantitative data for emission and consumption levels concerning the processes of spinning, sizing and weaving. Due to the lack of other alternative data sources, these processes had to be modelled with the data of (Brune / Krauch 1991). Current data is estimated to bear less environmental impact. However, the processes of spinning, sizing and weaving have only a minor impact on the total impact indicator results.

Fibre losses were only assumed within the spinning process, whereas 10 % loss (conservative assumption in account of the cotton roll system) is estimated. This conservative assumption in account of the cotton roll system already includes minor fibre losses during weaving. Furthermore it is assumed, that there are no losses during cutting and sewing of the cotton rolls, which can be justified by consistent modelling for the paper towel system (cf. section 3.2.2.1). Another key assumption is that all process steps of the cotton roll production are located in East Asia (especially China). This constitutes another rather conservative assumption in account of the cotton roll system and represents the tendency for relocation of these process steps to the Far East.

Within the following table, the data basis for all the mentioned process steps of the cotton roll production is documented. In addition to the reference for the considered unit processes information regarding the coverage of the data is also provided.

The life cycle inventory of the process steps of cotton fibre production, spinning, sizing, weaving and de-sizing / scouring / bleaching with their correspondent input / output data is presented in Annex 7.2.

Table 3 Data basis for the production of cotton rolls

process step	unit process	reference	comment
cotton fibre production	nitrogen fertilizer	Umberto 4.3 2004	production of an average N fertiliser; time-related coverage: 1997
	phosphorous fertilizer	Umberto 4.3 2004	production of an average P fertiliser; time-related coverage: 1997
	potassium fertilizer	Umberto 4.3 2004	production of an average K fertiliser; time-related coverage: 1997
	organo-phosphorous pesticide	ecoinvent 1.1 (process_lib)	geographical coverage: US American and European conditions; time-related coverage: 1997
spinning	electricity mix China	GEMIS 4.2 2004	
	heating boiler	Umberto 4.3 2004	production of thermal energy in a heating boiler fired by fuel oil (light) with a rating of 25 MW(th), including the pre-chains from production and transport of the energy sources and auxiliary materials. The combustion takes place via a fan burner; time-related coverage: 2001
sizing	corn starch	Boustead 4.2 2001	
weaving	electricity mix China	GEMIS 4.2 2004	time-related coverage: 2001
	heating boiler	Umberto 4.3 2004	see above
De-sizing / scouring / bleaching	sodium hydroxide	Umberto 4.3 2004	geographical coverage: Europe; time-related coverage: 1994
	hydrogene peroxide	Umberto 4.3 2004	time-related coverage: 1993
	electricity mix China	GEMIS 4.2 2004	time-related coverage: 2001
	heating boiler	Umberto 4.3 2004	see above
transport to laundry	offshore vessel	Umberto 4.3 2004	general cargo vessel; distance: 20,000 km (from China to Central Europe)
	heavy fuel oil	Umberto 4.3 2004	time-related coverage: 1999

3.1.2 Laundering process

For this study seven textile service companies from six European countries were considered:

- ALSCO, Germany
- Berendsen, Denmark
- ELIS, France
- Hokatex, Netherlands
- HTS, Germany
- Lindström, Finland and
- Salesianer, Austria.

Altogether, these companies - all member of the European Textile Service Association (E.T.S.A.) - represent 32 laundry sites in Austria, Denmark, Finland, France, Germany and the Netherlands.

Cotton rolls have to be washed in a hygiene washing process to ensure that there is no risk of contamination from the washed laundry after the laundry process. In practice this may be achieved in various different ways (e.g. Eberle 2003):

- Thermal disinfection, i.e. disinfection is mainly achieved thanks to the high washing temperature (e.g. 90°C, 10 minutes);
- Chemo-thermal disinfection, i.e. disinfection is achieved by a combination of disinfection agents and/or detergents and washing temperature (e.g. per acetic acid at 60 – 70°C; 10 – 15 minutes) or
- Chemical disinfection, i.e. the disinfective effect is achieved using disinfection agents in combination with detergent(s) and exposure time (e.g. room temperature; > 1 hour).

The laundries investigated use thermal or chemo-thermal washing processes using different detergents and chemicals for washing and disinfection, and different washing temperatures corresponding to the chemicals used for disinfection.

Basically, the investigated companies treat other products besides cotton rolls (e.g. work wear, mats). However, data collection predominantly could be carried out without using allocation. This could be achieved by selecting laundry sites with exclusive treatment of cotton rolls or the possibility of cotton-roll specific data collection (due to separation of production lines). Only in very few cases (i.e. concerning the laundries of one company[13]) it was not possible to collect the energy flows specifically for cotton-rolls. Thus, regarding this company the allocation of the energy flows was done according to the correspondent production volume.

Table 4 describes the weighted average and the range (minimum / maximum) of the relevant input parameters for the laundering processes.[14] Table 6 shows the variety of detergents and chemicals used. Figure 7 illustrates the modelling of the laundering process in the Umberto interface.

Table 4 Range of laundering process parameters per kg cotton roll

parameter	unit	weighted average	range
specific electricity demand	kWh/kg	0.1	0.1 - 0.3
specific heat energy demand	MJ/kg	4.1	3.5 - 12.4
source for heat energy		natural gas	natural gas, oil
specific detergent and chemical use	g/kg	26.1	8.1 - 38.9
specific water use	l/kg	9.4	6.0 - 14.0
cotton roll use	g/pull	16.2	12.9 – 25.0
cotton roll per functional unit	kg	1.62	1.29 - 2.50
number of washing cycles		103.3	70 - 130
packaging material		none, PVC, PE, PP	
end of life use of cotton roll		88 % as cleaning cloths (none - 100 %)	

Source: company specific data

[13] Within this company, the most important input besides cotton rolls is work wear. As work wear is considered to require similar or even higher amounts of energy, water and detergents, allocation on the basis of production volume of the different items handled was regarded as appropriate.

[14] However, the calculation of the life cycle inventories was based upon confidential company-specific data that are more detailed than the average data presented in Table 4.

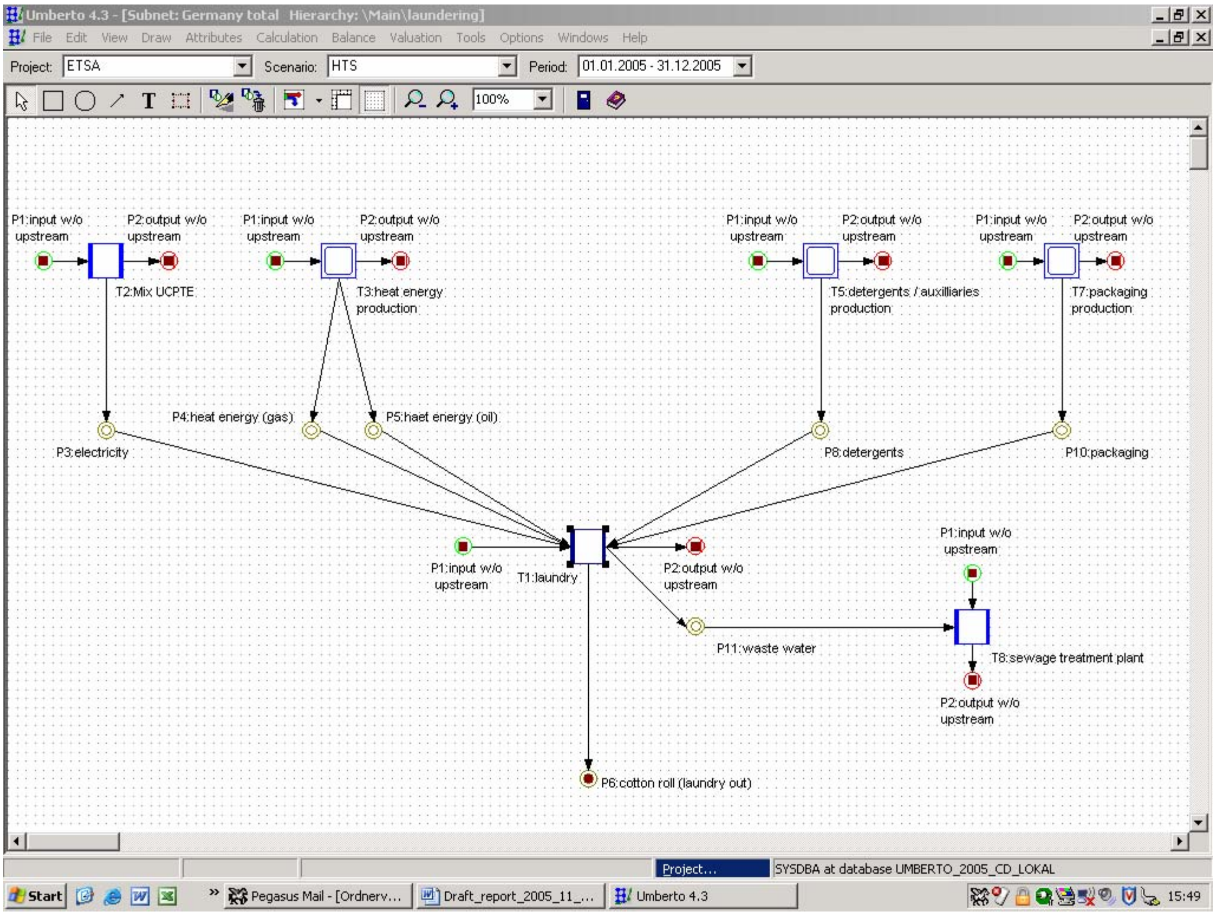

Figure 7 Sub-network of the laundering process

The following tables (Table 5, Table 6) show the data basis for all mentioned process steps of laundering sub-network including chemicals. In addition to the reference for the considered unit processes information regarding the coverage of the data is also provided.

Table 5 Data basis for the laundering process at the different companies

process step	unit process	reference	comment
electricity generation	electricity Mix UCPTE	Umberto 4.3 2004	geographical coverage: average electricity generation within the (former) twelve UCPTE countries (Union pour la coordination de la production et du transport de l'électricité); time-related coverage: 1994
heat energy generation	natural gas heating station	Umberto 4.3 2004	medium-sized natural gas district heating station with fan burner with a rating of 1.0 MW(th); utilisation ratio of 87,5 %; time-related coverage: 2001
	light fuel oil heating station	Umberto 4.3 2004	medium-sized natural light fuel oil district heating station with fan burner with a rating of 1.0 MW(th); utilisation ratio of 85 %; time-related coverage: 2001
detergent formulation	Phosphate-(free)-detergent, Liquisan A and B, Sterisan, Per acetic acid	Eberle 2002	Geographical coverage: Germany, Time-related coverage: 2000
	Softener	Eberle / Grießhammer 2001	Geographical coverage: Germany, time-related coverage: 1999
packaging production	PE film	Umberto 4.3 2004	included are the production of the polymer resin, the transport of the resin to the converter, the conversion process itself and the packaging of the finished component for onward dispatch; geographical coverage: UK; time-related coverage: 1993
	PP film	Umberto 4.3 2004	included are the production of the polymer resin, the transport of the resin to the converter, the conversion process itself and the packaging of the finished component for onward dispatch; geographical coverage: UK; time-related coverage: 1995
	PVC film	Umberto 4.3 2004	included are the production of the polymer resin, the transport of the resin to the converter, the conversion process itself and the packaging of the finished component for onward dispatch; geographical coverage: Germany; time-related coverage: 1995
sewage treatment	sewage treatment plant	Umberto 4.3 2004	sewage treatment plant with biological treatment including up-chain processes; geographical coverage: Germany; time-related coverage: 1994

Table 6 Data basis for detergent ingredients and chemicals

unit process	reference	comment
Acetic acid	Grießhammer et al. 1997	
Alcohol (C13) ethoxylates	Dall'Acqua et al. 1999	all inventoried as Alcohol(C13) ethoxylate, EO 7, time-related coverage: 1998
Carboxymethyl-cellulose	Dall'Acqua et al. 1999	
Chlorine	Umberto 4.3 2004	input material for sodium hypochlorite production; geographical coverage: Europe; time-related coverage: 1994
Esterquat	Eberle / Grießhammer 2001	50 % from suet, 50 % from coconut oil / palm oil time-related coverage: 1999
Fluorescer, biphenyl-distyryl type	Dall'Acqua et al. 1999	time-related coverage: 1999
Fluorescer, stilbene type	Dall'Acqua et al. 1999	time-related coverage: 1999
Formic acid	Umberto 4.3 2004	time-related coverage: 1989
Hydrogen peroxide	Umberto 4.3 2004	time-related coverage: 1993
Oleic acid	Dall'Acqua et al. 1999	inventoried as Alcohol(C13) ethoxylate, EO 7
Pentasodium-triphosphate	Dall'Acqua et al. 1999	time-related coverage: 1998
Per acetic acid	Eberle 2002	screening inventory
Phtalimidoperoxy-hexanoic acid (PAP)	Eberle 2002	screening inventory
Polycarboxylate	Grießhammer et al. 1997	
Sodium bisulfite	Römpp 1985	production via stoichiometric reaction of sulphur dioxide and sodium hydroxide
Sodium chloride	Umberto 4.3 2004	geographical coverage: Europe; time-related coverage: 1994
Sodium citrate	Grießhammer et al 1997	
Sodium hydroxide solution (30 %)	Umberto 4.3 2004	geographical coverage: Europe; time-related coverage: 1994
Sodium hypochlorite	Römpp 1985	production via stoichiometric reaction of chlorine gas and 15 % solution of sodium hydroxide; thermo-dynamical estimation of necessary cooling energy
Sodium metasilicate-pentahydrate	Fawer 1996	
Sodiumcarbonate	Fawer 1997	
Sodiumdisilicate	Fawer 1996	inventoried as sodium metasilicate-pentahydrate
Talc soap	Eberle / Grießhammer 2001	
Terpinolene	Umberto 4.3 2004	inventoried as n-paraffine
Zeolite P	Fawer 1996	inventoried as Zeolite A, 50 % suspension, 50 % powder

Because there were no life cycle data available, inventories for the following detergent ingredients or auxiliaries used in the laundries are missing: 2-Butoxyethanol, silicon-based antifoam, hydroxyethyldiphosphonic acid, hexadecyltrimethylammonium chloride, sodium salt of diethylen-triamin-pentamethylen-phosphonic acid, sodium salt of nitrilotriacetate, Triclosan. These ingredients not considered in the inventories represent 0.11 per cent in relation to the weight of the detergent needed for washing cotton rolls. However, those ingredients were considered as part of waste water and thus included in the qualitative assessment of the aquatoxicity as well as in the assessment of the eutrophication potential.

3.1.3 Distribution to the customers

The distribution of the cotton rolls was modelled according to data availability of laundry companies.

Within the questionnaire, the favoured parameter requested from laundries was the length of an average distribution tour. If this parameter could be provided, distribution was modelled with lorry module #1 (Table 7), whereas the delivery distance of an average cotton roll is exactly half of the distance of the average tour.

In some cases, laundry companies were not able to provide data on the average tour. However, information was available regarding the mileage of the truck fleet and the correspondent delivered cotton rolls. Thus, distribution was modelled with lorry module #2 (Table 7), which is parameterised with the driven mileage.

Table 7 Data basis for distribution process

process step	**unit process**	**reference**	**comment**
distribution	lorry #1, < 7.5 tons	Umberto 4.3 2004	functional unit: transported goods; geographical coverage: Germany; time-related coverage: 1997-1999
	lorry #2, < 7.5 tons	UBA 2004	functional unit: driven mileage; technology standard: Euro 2 geographical coverage: Germany; time-related coverage: end 1990ies
	Diesel fuel	Umberto 4.3 2004	geographical coverage: Germany; time-related coverage: 2001
	engine oil	GaBi 3.2 2001	geographical coverage: Germany;

3.1.4 Use in washrooms

Depending on the size of the cotton roll (width and total length) and the length for one pull the amount of cotton roll required for one hand-drying varies significantly. Thus, the minimum was calculated with only 12.9 grams per hand-drying (or 129 kg per functional unit), which is only about half of the identified maximum value of 25 grams per hand-drying (or 250 kg per functional unit, respectively).

3.1.5 Redistribution

Modelling of redistribution of cotton rolls was analogue with the distribution process (cf. section 3.1.3). Dependent on data availability the redistribution process was either represented by lorry module #1 or lorry module #2 (Table 8).

Table 8 Data basis for redistribution process

process step	unit process	reference	comment
redistribution	lorry #1, < 7.5 tons	Umberto 4.3 2004	functional unit: transported goods; geographical coverage: Germany; time-related coverage: 1997-1999
	lorry #2, < 7.5 tons	UBA 2004	functional unit: driven mileage; technology standard: Euro 2 geographical coverage: Germany; time-related coverage: end 1990ies
	Diesel fuel	Umberto 4.3 2004	geographical coverage: Germany; time-related coverage: 2001
	engine oil	GaBi 3.2 2001	geographical coverage: Germany

3.1.6 Reuse and end-of-life treatment

After having reached the end of their primary life-cycle (i.e. after 70-130 washing cycles, Table 9), the worn-out cotton rolls are used as industrial / cleaning cloths in most companies under investigation. It is assumed that these cleaning cloths made from secondary resources are actually able to substitute paper tissue cleaning cloths made from virgin fibres. This constraint can be confirmed by the specific advantages of cotton roll cleaning cloths (e.g. high tear strength and absorbency) against paper tissue cleaning cloths.

Finally, all cotton rolls (either with or without secondary usage as industrial / cleaning cloths) are treated within a waste incineration plant. According to current legislation, waste disposal without thermal pre-treatment is neglected. When modelling waste incineration, recovery of thermal and electric energy can be assumed. However, in most cases, only electricity represents a relevant secondary product of a waste incineration plant. Thus, only the production of electric energy was considered within the model.

According to the general setting of this study (and all other LCA studies carried out at Öko-Institut), only 50 % of the ecological benefits derived from the modelling of cotton roll reuse and electricity production during incineration are credited to the cotton roll system – an approach which is also favoured by the German Federal Environmental Agency (Umweltbundesamt).

The avoided disposal of the paper towels with energy recovery was not included in the model, as this aspect is below the cut-off criteria[15].

Table 9 shows the data basis for all mentioned end-of-life process steps. Again, in addition to the reference for the considered unit processes information regarding the coverage of the data is also provided.

Table 9 Data basis for end-of life processes

process step	unit process	reference	comment
reuse	virgin luxury paper (VLP)	cf. section 3.2	credit item for the cotton rolls when used as cleaning / industrial cloths; geographical coverage: Europe; time-related coverage: 2001
	electricity Mix UCPTE	Umberto 4.3 2004	credit item for cotton rolls due to electricity generation within the waste incineration plant (see below); geographical coverage: average electricity generation within the (former) twelve UCPTE countries (Union pour la coordination de la production et du transport de l'électricité); time-related coverage: 1994
waste treatment	waste incineration plant	Umberto 4.3 2004	consideration of the elementary composition and the lower heat value (17 MJ/kg) of the worn out cotton rolls); technological standard: limit values according to 17. BImSchV; geographical coverage: Germany; time-related coverage: 1994-1999
	calcium hydroxide	Umberto 4.3 2004	input material for the waste incineration plant; time-related coverage: 1997

15 Constraints are as follows: 1.62 kg cotton rolls per functional unit, in average 88% are used as cleaning cloth, 2,880 kJ electricity recovery in the waste incineration plant per kilogram treated paper, 50% benefits according to Umweltbundesamt rule (see above); this results in approx. 6 MJ CED per functional unit (equals 0.4% of the total CED).

3.1.7 Sensitivity analyses

For the continuous cotton roll system there are three parameters which influence the result significantly:

- number of pulls per hand drying,
- life time of cotton rolls,
- washing process practice in laundries.

For these parameters sensitivity analyses have been carried out. In section 4.3, the results of the sensitivity analyses for the number of pulls per hand drying supplementary to the baseline scenario (i.e. 20,000 towels per functional unit; also 40,000 towels were calculated) and the cotton roll life time are illustrated.

The results of the sensitivity analysis for the washing practice in laundries are included in a confidential annex.

3.2 Paper towel system

For the paper towel system two options were investigated, differing in the paper towel quality used:

- Option A: virgin luxury paper (VLP) and
- Option B: (partly) recycled medium quality paper (RCF).

In the following the life cycle stages and data sources are described in detail for the two options:

- production of the paper towels – from virgin pulp production (section 3.2.1) to tissue production (section 3.2.2), including transport to the laundry;
- distribution to the customer (section 3.2.3)
- use in washrooms, including the production of bin liners (section 3.2.4);
- redistribution, i.e. transport of used paper towels to end-of-life treatment (section 3.2.5) and finally
- end-of-life-treatment, i.e. incineration (section 3.2.6).

In analogy with the cotton roll system, the modelling of the paper towel product system was carried out by using the LCA tool “Umberto”, Vol. 4.3. Figure 8 shows the above mentioned life cycle stages in the Umberto interface. Further explanation of the modelling procedure and the Umberto icons can be found in section 3.1 .

In the following sections, the process steps and unit processes of the paper towel life cycle stages will be specified regarding their modelling assumptions and data basis.

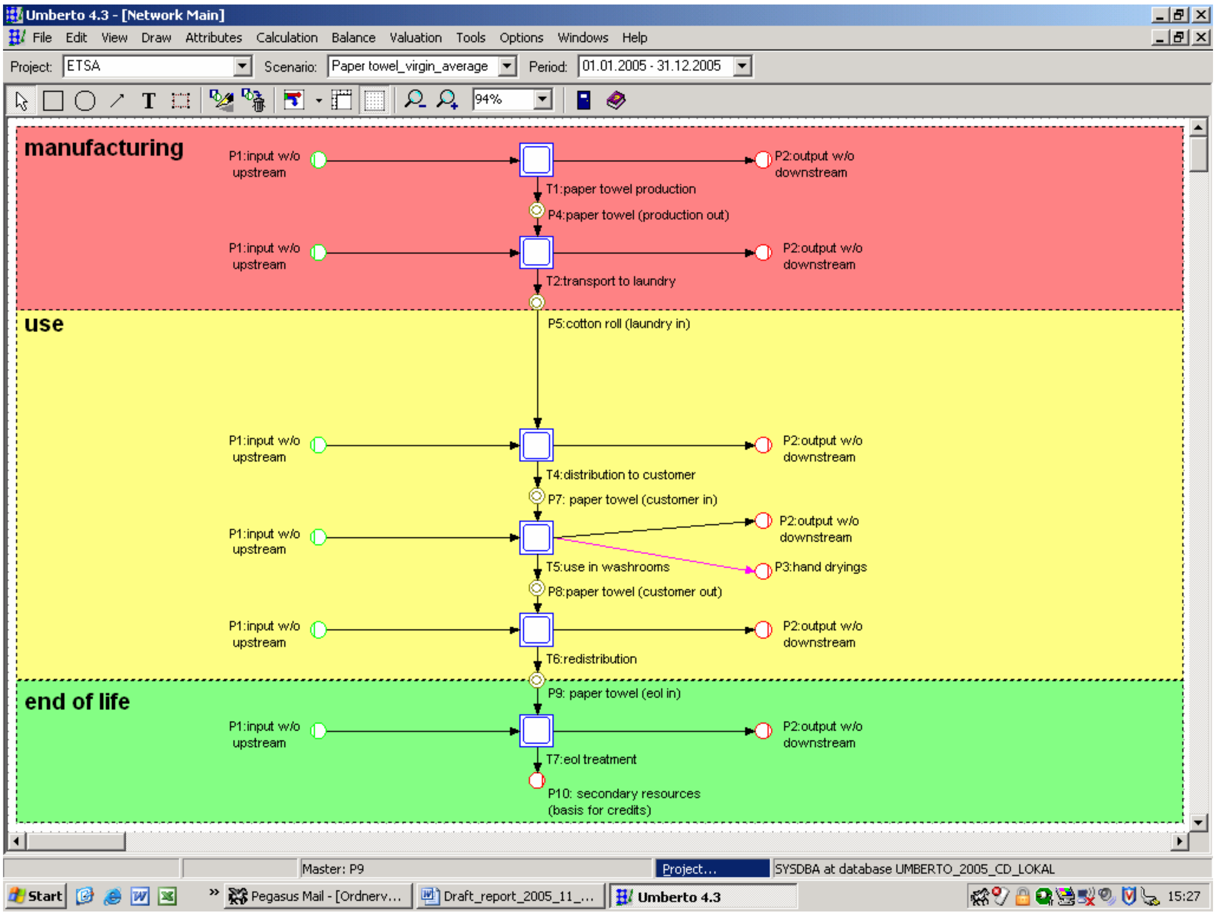

Figure 8 LCA network of paper towel system

3.2.1 Virgin pulp production

The modelling of the pulp production process was done by taking data from a correspondent BREF document (Reference Document on Best Available Techniques for the Pulp and Paper Industry) of the European Commission (BREF pulp & paper 2001). Besides data on Best Available Technology (BAT) this document also includes status quo emission and consumption levels for the mentioned wet processes.

Table 10 Range of virgin pulp production parameters (European Commission 2001)

parameter	unit	average	range
specific electricity demand	kWh/kg	0.7	0.6 - 0.8
fuel for steam generation	MJ/kg	12	10 - 14
source for heat energy		wood residues	wood residues
specific auxiliary material use	g/kg	123	59 - 187
specific water use	l/kg	70	30 - 110

Figure 9 shows the input materials for the pulp production process according to the used BREF document in the Umberto interface.

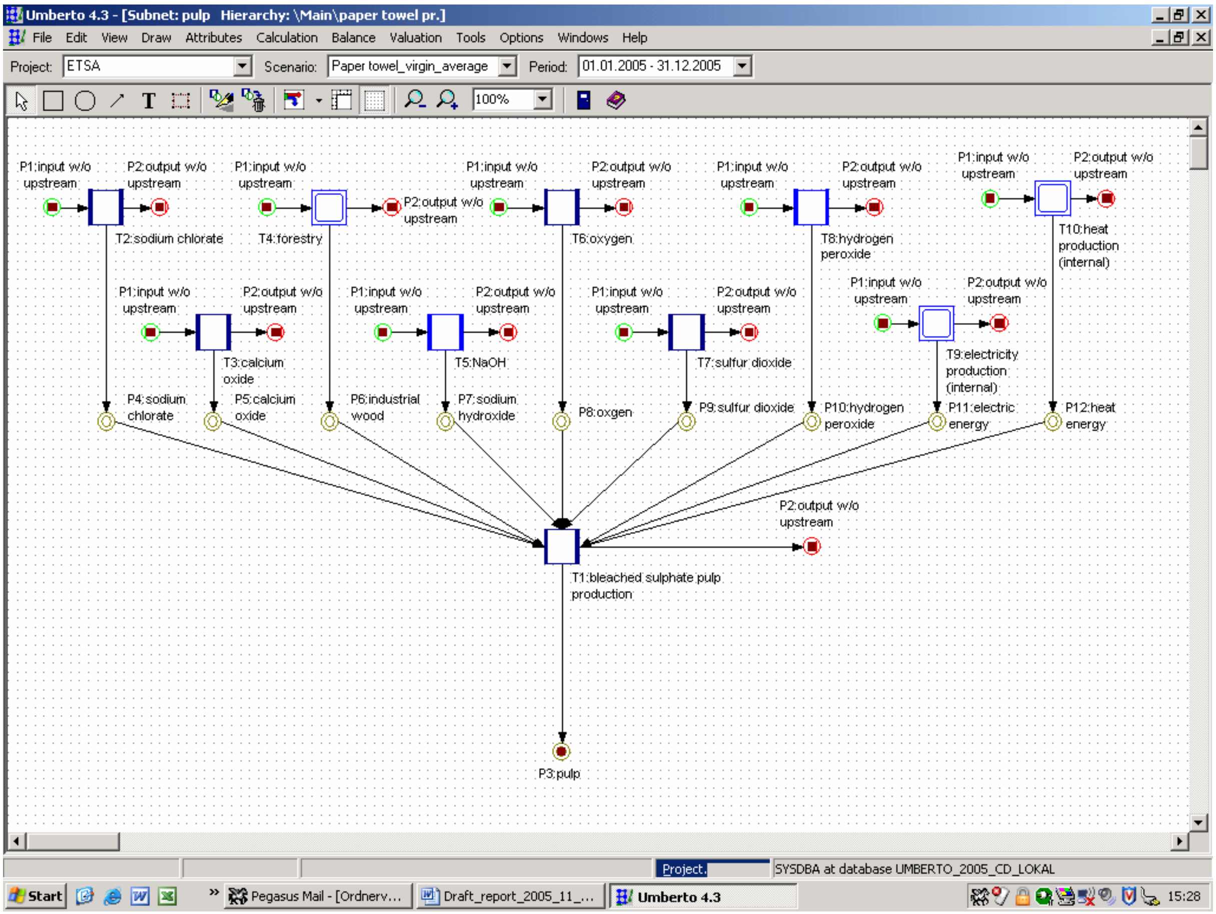

Figure 9 Sub-network of pulp production

For the purpose of this study, average values were derived from this BREF study for all relevant input and output materials (BREF pulp & paper 2001, see 30pp). According to the BREF document it is assumed that the pulp is self-serving regarding electricity and heat, i.e. the energy consumed by the process is provided on-site by energy recycling of wood residues. This is regarded as a rather conservative assumption.

Within the following table (Table 11), the data basis for pulp production is documented. In addition to the reference for the considered unit processes information regarding the coverage of the data is also provided.

The life cycle inventory of the pulp production process with the correspondent input / output data is presented in Annex 7.3.1 .

Table 11 Data basis for the pulp production process (sulphate pulp)

process step	unit process	reference	comment
forestry	industrial wood production	UBA 2000	geographical coverage: Northern Europe; time-related coverage: 1995
	Calcium oxide	UBA 2000	input material for industrial wood production; geographical coverage: Northern Europe; time-related coverage: 19
chemicals production	Calcium oxide	UBA 2000	geographical coverage: Northern Europe; time-related coverage: 1995
	Hydrogen peroxide	Umberto 4.3 2004	time-related coverage: 1993
	Oxygen	UBA 2000	geographical coverage: Europe; time-related coverage: 1995
	Sodium chlorate	UBA 2000	geographical coverage: Europe; time-related coverage: 1995
	Sodium hydroxide solution (30 %)	Umberto 4.3 2004	geographical coverage: Europe; time-related coverage: 1994
	Sulphur dioxide	UBA 2000	geographical coverage: Europe; time-related coverage: 1995
electricity production	cogeneration plant	UBA 2000	fuel: wood residuals; geographical coverage: Germany; time-related coverage: 1990ies
heat production	cogeneration plant	UBA 2000	fuel: wood residuals; geographical coverage: Germany; time-related coverage: 1990ies
pulp mill	kraft pulp mill	BREF pulp & paper 2001	BREF document, see 30pp; use of average values; geographical coverage: Europe; time-related coverage: end 1990ies

3.2.2 Tissue production

The tissue production has to be distinguished in

- tissue made from fresh fibres as basis for virgin luxury paper towels (section 3.2.2.1) and
- tissue made from partly recycled fibres as basis for (partly) recycled paper towels (section 3.2.2.2).

3.2.2.1 Tissue made from fresh fibres (VLP)

As already practised for pulp production, for virgin tissue production data from the pulp & paper BREF document was also chosen for all relevant input and output materials (BREF pulp & paper 2001).

Table 12 Range of VLP tissue production parameters (European Commission 2001)

parameter	unit	average	range
chemical bleached pulp	kg/kg	1.015	1.010 - 1.020
recovered paper	kg/kg	-	-
specific electricity demand	kWh/kg	1.5	1.0 - 3.0
fuel for steam generation	MJ/kg	15	5 - 25
source for heat energy		natural gas	coal, oil, natural gas
specific auxiliary material use	g/kg	66	0 - 132
specific water use	l/kg	53.5	7 - 100
paper use	g/hand drying	8	-
paper use per functional unit	kg	80	-
packaging material		none	-

Figure 10 shows the input materials for the tissue production process according to the used BREF document in the Umberto interface.

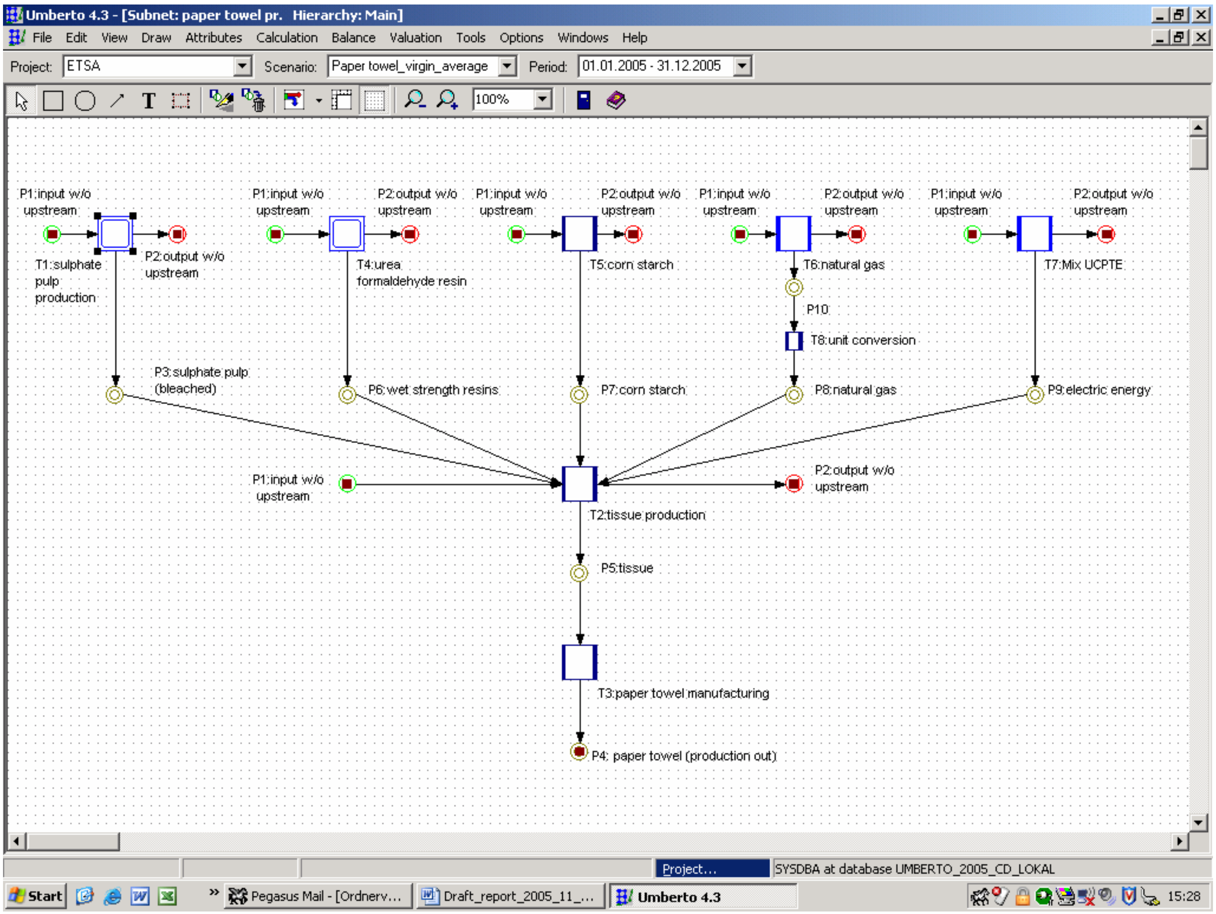

Figure 10 Sub-network of the tissue made from fresh fibre

Again, average values for the status quo emission and consumption levels were derived from the BREF study for all relevant input and output materials (BREF pulp & paper 2001, see 327pp). These average values were validated with company data published in environmental reports of actual tissue producer (SCA 2001). This procedure resulted in an adjustment of the electricity demand. Instead of the calculative average value of the BREF document (2.0 kWh/kg tissue), only 1.5 kWh/kg tissue was assumed. This can be justified by the fact that the upper end of the BREF range refers to tissue mills using Through Air Drying (TAD[16]) or re-creping techniques. The heat energy demand (supplied by natural gas), however, was unchanged, as the average value of the BREF document (15 MJ/kg tissue) was well approved by the analysed environmental report (16.5 MJ/kg tissue).

16 To operate TAD enormous volumes of air need to be moved by large fans, which results in considerable electricity demand. TAD paper towels were not used in the comparison of this study, as they are of only minor importance for the hand towel market (less than 10 %).

Furthermore, it is assumed, that there are no losses during cutting of the paper towels, which can be justified by consistent modelling for the cotton towel system (cf. section 3.1.1).

Within the following table (Table 13) the data basis for pulp production is documented. In addition to the reference for the considered unit processes also information regarding the coverage of the data is provided. The life cycle inventory of the pulp production process with the correspondent input / output data is presented in Annex 7.3.2 .

Table 13 Data basis for the tissue production process

process step	unit process	reference	comment
pulp production	sulphate pulp	cf. section 3.2.1.1	
chemicals / fuel production	corn starch	Boustead 4.2 2001	
	natural gas	Umberto 4.3 2004	geographical coverage: Germany; time-related coverage: 2000
	wet strength agent	Gruber / Schempp	urea formaldehyde resin; production via stoichiometric reaction of urea and formaldehyde
electricity production	electricity Mix UCPTE	Umberto 4.3 2004	geographical coverage: average electricity generation within the (former) twelve UCPTE countries (Union pour la coordination de la production et du transport de l'électricité); time-related coverage: 1994
tissue production	non-integrated paper mill	BREF pulp & paper 2001	BREF document, see 327 pp.; use of (partly modified) average values; geographical coverage: Europe; time-related coverage: end 1990ies
transport to laundry	lorry > 32 tons	Umberto 4.3 2004	transport distance: 1000 km (from Northern Europe to Central Europe); utilisation ratio: 80 %; functional unit: transported goods; geographical coverage: Germany; time-related coverage: 1997-1999
	Diesel fuel	Umberto 4.3 2004	geographical coverage: Germany; time-related coverage: 2001

3.2.2.2 Tissue made from recycled fibres (RCF)

According to the goal and scope definition, the recycled paper towel is made from partly, i.e. 50 % recycled paper. Thus, 50 wt% of the paper towel were modelled as described in section 3.2.2.1 .

For the other 50 wt%, data for the production of recycled tissue was chosen from the pulp & paper BREF document (BREF pulp & paper 2001). The data basis used is shown in Table 16.

Table 14 Range of RCF tissue production parameters (European Commission 2001)

parameter	unit	average	range
chemical bleached pulp	kg/kg	-	-
recovered paper	kg/kg	1.505	1.010 – 2.000
specific electricity demand	kWh/kg	1.6[17]	1.2 – 3.0
fuel for steam generation	MJ/kg	15	5 - 25
source for heat energy		natural gas	coal, oil, natural gas
specific auxiliary material use	g/kg	75	0 - 150
specific water use	l/kg	52.5	5 - 100
paper use	g/hand drying	8	-
paper use per functional unit	kg	80	-
packaging material		none	-

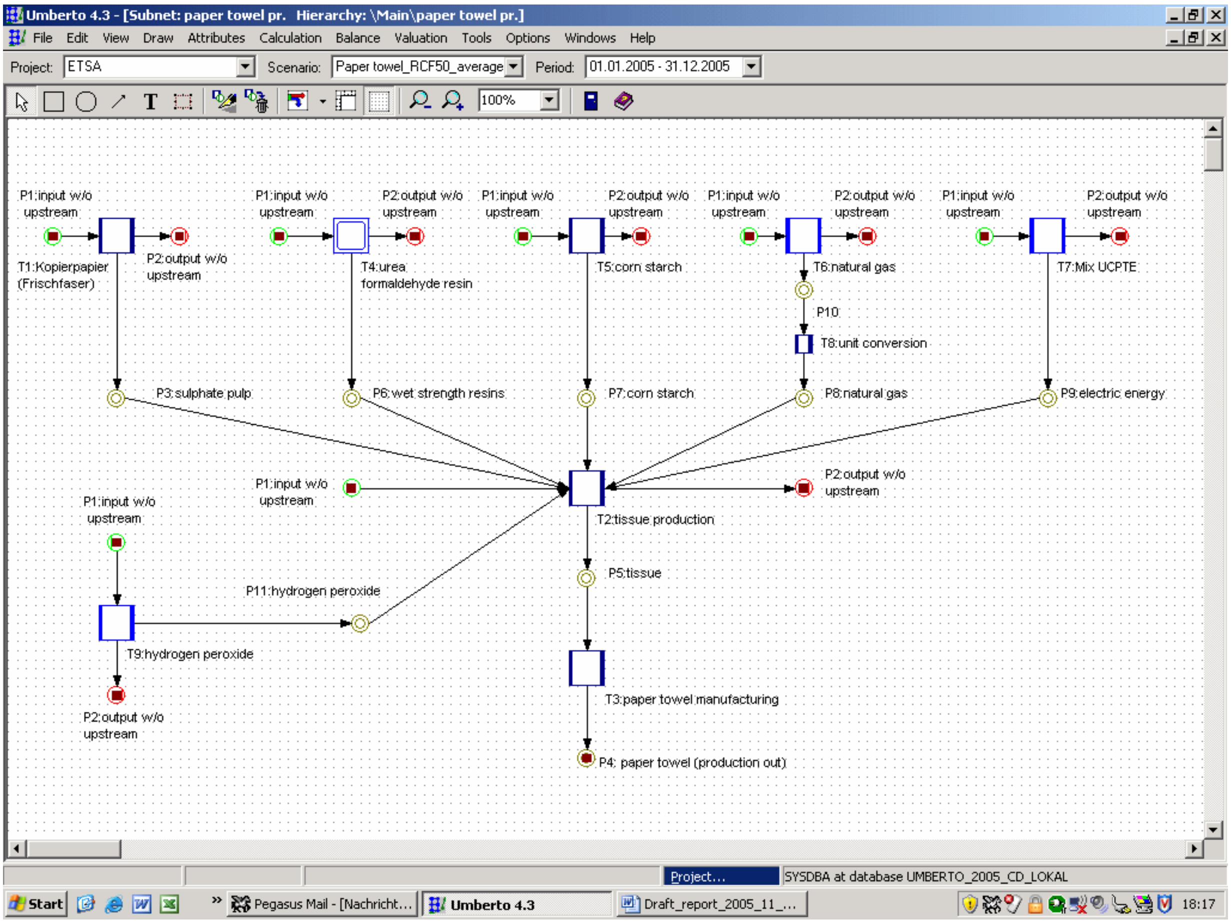

Figure 11 Sub-network of tissue made from recycled fibres

[17] This value is not the arithmetic mean of the correspondent range. However, for certain reasons this value was chosen for the modelling (cf. section 3.2.2.2).

Figure 11 shows the input materials for the recycling process according to the used BREF document in the Umberto interface.

In consistency with virgin tissue, average values for the status quo emission and consumption levels were derived from the BREF study for all relevant input and output materials of the recycling process (BREF pulp & paper 2001, see 2287pp). Again, these average values were adjusted concerning the electricity demand. Instead of the calculative average value of the BREF document (2.1 kWh/kg tissue), only 1.6 kWh/kg tissue were assumed. This can be justified by the fact that the upper end of the BREF range refers to tissue mills using Through Air Drying (TAD) or re-creping techniques (cf. section 3.2.2.1).

Basis for the modelling of the recovered paper as the major input of the recycling process was the assumption that recycling of recovered paper results in gradual shorting of fibres. Per tonne of recycled tissue produced a fibre loss of approx. 220 kg is reported (Riise / Berens-Bredahl 2005). This fibre loss has to be compensated by 220 kg of virgin fibres added to the system.

Within the following table (Table 15), the data basis for pulp production is documented. In addition to the reference for the considered unit processes information regarding the coverage of the data is also provided.

The life cycle inventory of the pulp production process with the correspondent input / output data is presented in Annex 7.3.3 .

Table 15 Data basis for tissue production process

process step	unit process	reference	comment
virgin fibre production	virgin pulp	cf. section 3.2.1	cf. section 3.2.1
chemicals / fuel production	corn starch	Boustead 4.2 2001	
	hydrogen peroxide	Umberto 4.3 2004	time-related coverage: 1993
	natural gas	Umberto 4.3 2004	geographical coverage: Germany; time-related coverage: 2000
	wet strength agent	Gruber / Schempp	urea formaldehyde resin; production via stoichiometric reaction of urea and formaldehyde
electricity production	electricity Mix UCPTE	Umberto 4.3 2004	geographical coverage: average electricity generation within the (former) twelve UCPTE countries (Union pour la coordination de la production et du transport de l'électricité); time-related coverage: 1994
tissue production	integrated RCF paper mill	BREF pulp & paper 2001	BREF document, see 228pp; use of (partly modified) average values; geographical coverage: Europe; time-related coverage: end 1990ies
transport to laundry	lorry > 32 tons	Umberto 4.3 2004	transport distance: 1000 km; utilisation ratio: 80 %; functional unit: transported goods; geographical coverage: Germany; time-related coverage: 1997-1999
	Diesel fuel	Umberto 4.3 2004	geographical coverage: Germany; time-related coverage: 2001

3.2.3 Distribution to customers

The following table (Table 16) shows the data basis for all the distribution of the paper towel system. According to information provided by laundry companies, paper towels are delivered to customers by using the same logistics. Thus, the transportation distance for the paper towel distribution process amounts to 100 km, which is also the typical distribution distance for cotton roll towels.

Table 16 Data basis for distribution process

process step	unit process	reference	comment
distribution	lorry #1, < 7.5 tons	Umberto 4.3 2004	utilisation ratio: 80 %; functional unit: transported goods; geographical coverage: Germany; time-related coverage: 1997-1999
	Diesel fuel	Umberto 4.3 2004	geographical coverage: Germany; time-related coverage: 2001

3.2.4 Use in washrooms

It is assumed that washroom clients use two paper towels to dry their hands at an average. The average paper towel, both made from virgin luxury paper or recycled fibres, is calculated with 4 grams. Thus, the paper towel consumption for one hand drying constitutes 8 grams (or 80 kg for the functional unit, respectively).

Furthermore, within washrooms consumption of bin liners is also modelled. As specifications could be provided by laundry companies for bin liners, following assumptions were made (Table 17):

Table 17 Data basis for use in washrooms process

process step	unit process	reference	comment
production of bin liners	PE film	Umberto 4.3 2004	weight of bin liner: 9 g (weighing of an actually existent bin liner within a washroom); assumption: one bin liner can hold 100 used paper towels (equals 50 hand dryings); geographical coverage: UK; time-related coverage: 1993

3.2.5 Redistribution

For the paper towel system, modelling of redistribution differs from the correspondent life cycle step of the cotton roll system. Due to the fact, that recycling of used paper towels is not possible, used paper towels are directly transported to a waste treatment facility. It is assumed, that in average the closest available waste incineration plant is situated at a distance of 50 km from the washroom. Following table (Table 18) shows the data basis for this transport process.

Table 18 Data basis for redistribution process

process step	unit process	reference	comment
redistribution	lorry, 14 - 20 tons	Umberto 4.3 2004	refuse collector; utilisation ratio: 50 % (starts tour empty and returns full) functional unit: transported goods; geographical coverage: Germany; time-related coverage: 1997-1999
	Diesel fuel	Umberto 4.3 2004	geographical coverage: Germany; time-related coverage: 2001

3.2.6 End-of-life treatment

After having reached the end of their life-cycle used paper towels are treated within a waste incineration plant. According to current legislation, waste disposal without thermal pre-treatment is neglected. When modelling waste incineration, recovery of thermal and electric energy can be assumed. However, in most cases, only electricity represents a relevant secondary product of waste incineration plants. Thus, only production of electric energy was considered within the model.

According to the general setting of this study (and all other LCA studies carried out by Öko-Institut), only 50 % of the ecological benefits derived from electricity production during incineration are credited to the paper towel system. The other 50 % would be credited to the (fictitious) product systems that apply these secondary resources.

The following table (Table 19) shows the data basis for all mentioned end-of-life process steps. Again, in addition to the reference for the considered unit processes information regarding the coverage of the data is also provided.

Table 19: Data basis for end-of life processes

process step	unit process	reference	comment
reuse	electricity Mix UCPTE	Umberto 4.3 2004	credit item for cotton rolls due to electricity generation within the waste incineration plant (see below); geographical coverage: average electricity generation within the (former) twelve UCPTE countries (Union pour la coordination de la production et du transport de l'électricité); time-related coverage: 1994
waste treatment	waste incineration plant	Umberto 4.3 2004	consideration of the elementary composition and the lower heat value (17 MJ/kg) of the worn out cotton rolls); technological standard: limit values according to 17. BImSchV (German regulation which defines strict limit values for emissions from waste incineration plants); geographical coverage: Germany; time-related coverage: 1994-1999
	Calcium hydroxide	Umberto 4.3 2004	input material for the waste incineration plant; time-related coverage: 1997

3.2.7 Sensitivity analyses

For the paper towel system the following parameters influence the results significantly:

- number of towels used per hand drying,
- practice in towel manufacturing,
- share of recycled paper (only relevant for RCF),
- crediting within the end-of-life stage.

Sensitivity analyses were carried out concerning the share of recycling paper within the RCF tissue paper towel. In addition to modelling with 50 wt% of recycled paper also 100 % recycled tissue were analysed (for assumptions and data base cf. section 3.2.2.2). Another sensitivity analysis was carried out for the number of paper towels necessary for fulfilling the functional unit. Supplementary to the baseline scenario (i.e. 20,000 towels per functional unit), also 40,000 towels were calculated. Furthermore, sensitivity analyses were carried out within the end-of-life stage. In addition to the baseline scenario (50% credits), also full crediting (100%) and no credits were analysed.

Results of sensitivity analysis for the manufacturing practice for paper towels are included in a confidential annex.

Concerning tissue production, the choice of the electricity mix can also have influence on the results. Paper is mainly produced in Northern Europe, where UCPTE is not representative. In Sweden, for example, the electricity is mainly produced from hydropower and nuclear power. However, the consequences can only be described when looking at the marginal electricity technology in this region. As this technology is most probably hard coal[18], significant differences are not expected for the chosen impact categories. On the contrary, results for the paper towel systems would be even slightly worse, because the used UCPTE mix has less environmental impact than electricity from hard coal. Thus, regarding the used electricity mix the results were regarded as robust and no sensitivity analyses were carried out.

4 Results

In the following inventory results (section 4.1) and impact assessment results (section 4.2) of the two systems investigated will be presented. Section 4.3 describes results from the sensitivity analysis.

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18 cf. Finnveden et al: Life Cycle Assessments of Energy from Solid Waste, Stockholm 2000.

4.1 Inventory analysis

Within this section, the life cycle inventory (LCI) indicators are presented for both systems under comparison. These indicators comprise the most important input / output parameters, i.e. the Cumulated Energy Demand (CED), the water use, the Chemical Oxygen Demand (COD), the Biological Oxygen Demand (BOD) and waste generation. In section 4.1.1, the LCI results of the continuous cotton roll system are shown; in section 0 those of the paper towel system are presented. Finally, section 4.1.3 compares inventory results of both systems investigated. All results are displayed for the functional unit of the study (10,000 hand dryings) for the standard scenario (1 pull / hand drying resp. 2 towels / hand drying) unless it is stated differently (cf. section 2.3).

4.1.1 Continuous cotton roll system

Results for the life cycle inventory for selected parameters are presented in Table 20. For 10,000 hand-dryings, the weighted average of the laundries investigated is 1,500 MJ cumulated used primary energy and 13,300 kg of used water. The COD caused by the cotton roll system is approx. 400 grams per 10,000 hand dryings, the BOD approx. 300 grams. Furthermore, the cotton roll system generates 8.1 kg of waste along its life cycle. Inventory results in overview are given in the table below (Table 20). The complete life cycle inventory results for gross values and the benefits are given in Annex 7.4.

Table 20 Selected Life Cycle Inventory results (net values) for cotton roll system for 10,000 hand dryings (standard scenario)

parameter	unit	Cotton roll system (weighted average)
CED, total	MJ	1,500
CED, not renewable	MJ	1,470
CED, renewable	MJ	21
CED, others	MJ	3
water use	kg	13,300
COD	kg	0.4
BOD-5	kg	0.3
waste	kg	8.1

The results also show (Table 21) that the share of cotton roll production is about one fifth of the total energy demand (18 %), approx. one quarter of the waste generation (27 %), but more than three quarters of the total water demand (86 %). The main share of energy consumption (81 %) and waste generation (75 %) belongs to the laundering process, which causes also 16 % of the water demand. Distribution of cotton towels causes 6 % of total energy demand, 3 % of the waste generation and nearly zero per cent of water demand.[19]

Table 21 Selected LCI results (net values) for cotton roll system for CED and water demand and different life cycle stages for 10,000 hand dryings (standard scenario)

parameter	unit	Cotton roll system average
Cotton towel production		
CED, total	MJ	260
water use	kg	11,300
waste	kg	2.2
Laundering		
CED, total	MJ	1,190
water use	kg	2080
waste	kg	6.1
Distribution		
CED, total	MJ	90
water use	kg	0.3
waste	kg	0.2
End of life		
CED, total	MJ	-50
water use	kg	-73
waste	kg	-0.3

4.1.2 Paper towel system

The LCI results for the two paper options investigated are presented in Table 22.

The results show that the virgin luxury paper option (VLP) is slightly worse than the partly recycled paper option (RCF) concerning energy and water demand: for 10,000 hand dryings, total energy demand for VLP is 4,040 MJ, for RCF it is 3,510 MJ (about 13 % lower). Water consumption for VLP is 12,270 kg, for RCF it is 9,600 kg (about 22 % lower). The COD caused by the paper towel system is approx. 4.2 kg (VLP) resp. 2.5 kg (RCF) per 10,000 hand dryings, the BOD 1.8 kg (VLP) resp. 1.0 kg (RCF). Concerning waste[20], the VLP system generates 37 kg and the RCF system 30 kg. Inventory results in overview are given in the table below (Table 22). The complete life cycle inventory results for gross values are given in the Annex 7.5.

[19] Shares higher than 100 percent derive from credits given to the system for reuse of cotton towels as industrial / cleaning rags (cf. section 3.1.6).

[20] The waste accumulation is dominated by ashes and slags: approx. 26 kg for VLP and 20 kg for the RCF.

Table 22 Selected Life Cycle Inventory results (net values) for paper towel system for 10,000 hand dryings (standard scenario)

parameter	unit	Paper towel system	
		VLP average	RCF average
CED, total	MJ	4,040	3,510
CED, not renewable	MJ	2,890	2,830
CED, renewable	MJ	1,140	670
CED, others	MJ	1	1
water use	kg	12,270	9,600
COD	kg	4.2	2.5
BOD-5	kg	1.8	1.0
waste	kg	37	30

Results show (Table 23) that for both options investigated the main share in energy consumption, water demand and waste generation belong to paper towel production: concerning energy demand the share is 105 % for both options. The share of water demand for towel production is 104 % for VLP and 105% for RCF. Regarding waste, the share is approx. 80 % for VLP and approx. 70 % for RCF. The use stage including distribution and bin liner production has a share of 7 % (VLP) and 5 % (RCF) in total energy demand and approx 1 % in water demand for both options investigated.[21] Concerning waste generation, the end-of-life stage has a significant contribution (20 % for VLP and 25 % for RCF, respectively).

21 Shares higher than 100 percent derive from credits given to the system for electricity generation by waste incineration (cf. section 3.2.6).

Table 23 Selected LCI results (net values) for paper towel system for CED and water demand and different life cycle stages for 10,000 hand dryings (standard scenario)

parameter	unit	Paper towel system	
		VLP average	RCF average
Paper towel production			
CED, total	MJ	4,220	3,700
water use	kg	12,750	10,080
waste	kg	29	22
Use stage (distribution / bin liner production)			
CED, total	MJ	260	260
water use	kg	115	115
waste	kg	0.2	0.2
End of life			
CED, total	MJ	-450	-450
water use	kg	-600	-600
waste	kg	7.6	7.6

4.1.3 Comparison of the two systems

Results (Table 20, Table 22) show that an average laundry needs less energy than both paper towel options: energy consumption is about 2.5 times higher for the best paper towel option (VLP) (Figure 12).

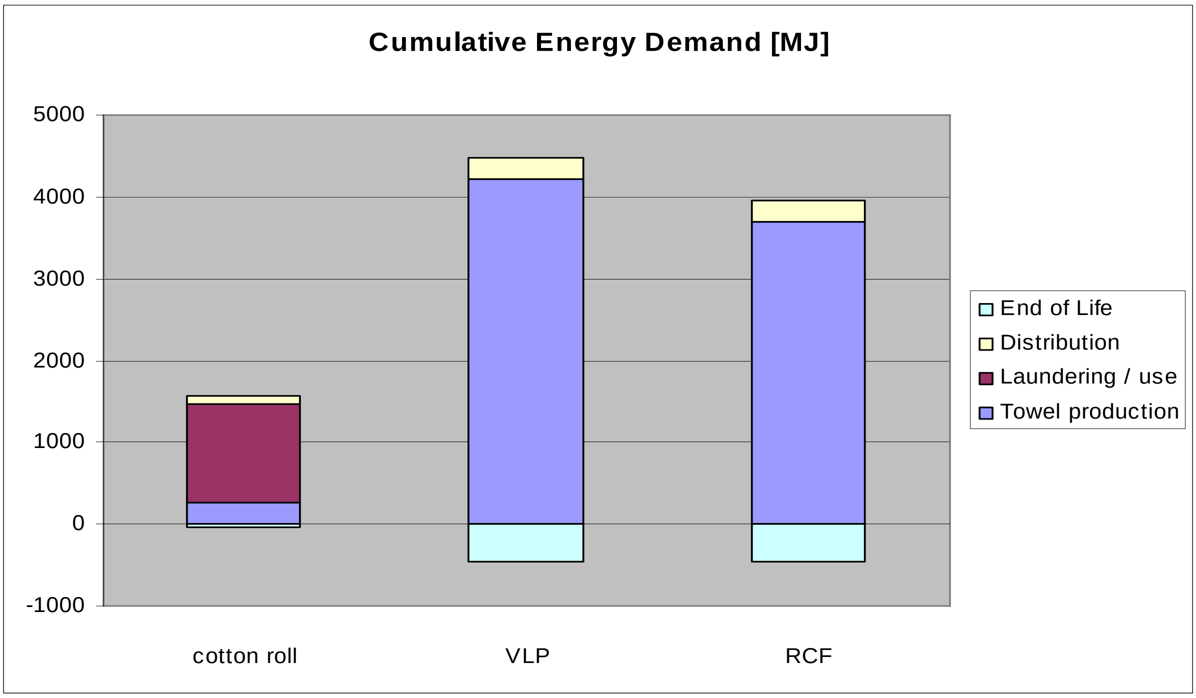

Figure 12 Comparison of energy demand for cotton roll and paper towel systems (average) for 10,000 hand dryings (standard scenario)

However, the cotton roll system needs more water. Water demand for the average of the cotton roll system is about 8% higher than VLP and 14% higher than RCF, mainly caused by cotton towel manufacturing, in particular cotton fibre growing (Figure 13)[22]. Regarding the COD and the BOD the cotton roll system is better than both paper towel options: for COD the emissions are approx. 12 times lower than those of VLP and more than 6 times than those of RCF. Concerning the BOD the emissions caused by the cotton roll system are 7 times lower than those of the VLP and more than 4 times than those of RCF. However, the limited reliability of COD and BOD data in general has to be kept in mind, especially with no data available regarding e.g. pesticide use in cotton agriculture.

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22 Concerning the amount of water one has to take into account that the amount does not necessarily say anything about the importance of the water consumption (e.g. related to local or regional scarcity). Thus, making it quite difficult to conclude which alternative is best or worst.

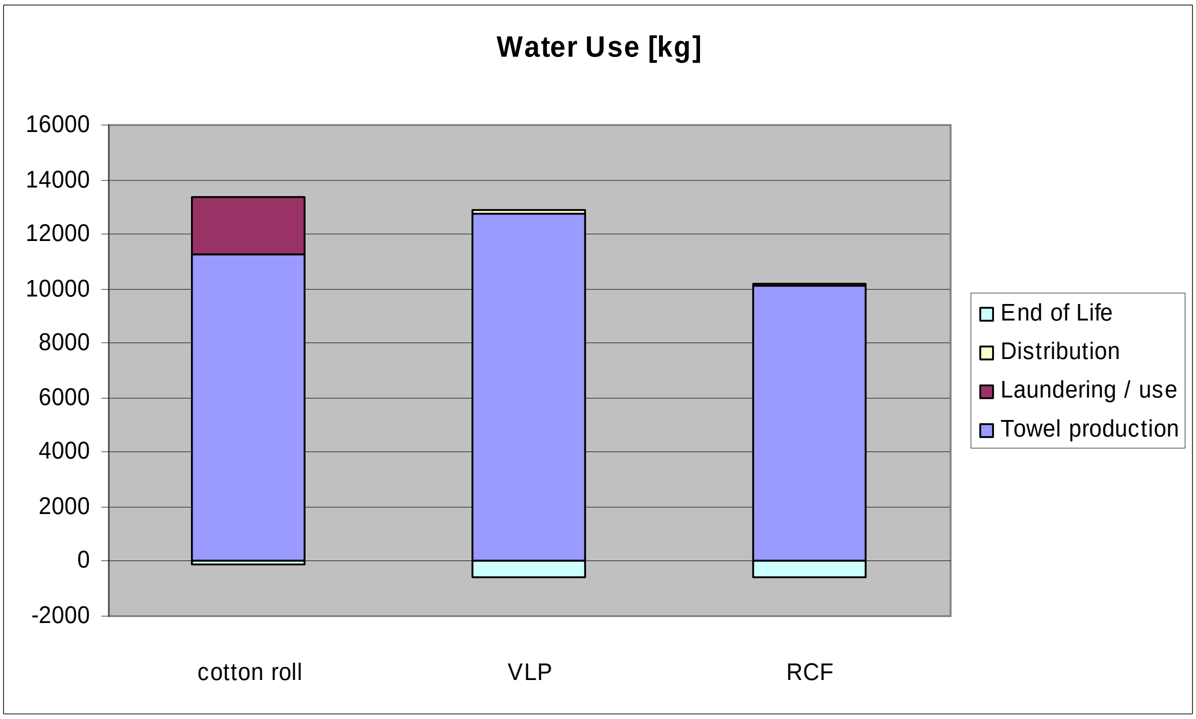

Figure 13 Comparison of water demand for cotton roll and paper towel systems (average) for 10,000 hand dryings (standard scenario)

Moreover, the cotton roll system generates also by far less waste than both paper towel options: the waste generation of the VLP system is approx. 5 times higher and the RCF system generates about 4 times more waste than the cotton roll system (Figure 14)[23].

[23] Concerning the amounts of waste generated one has to take into account that the amount does not necessarily say anything about the importance of waste (e.g. related to different potential hazards). Thus, it is difficult to conclude which is the best and worst alternative based on the amount of waste generated.

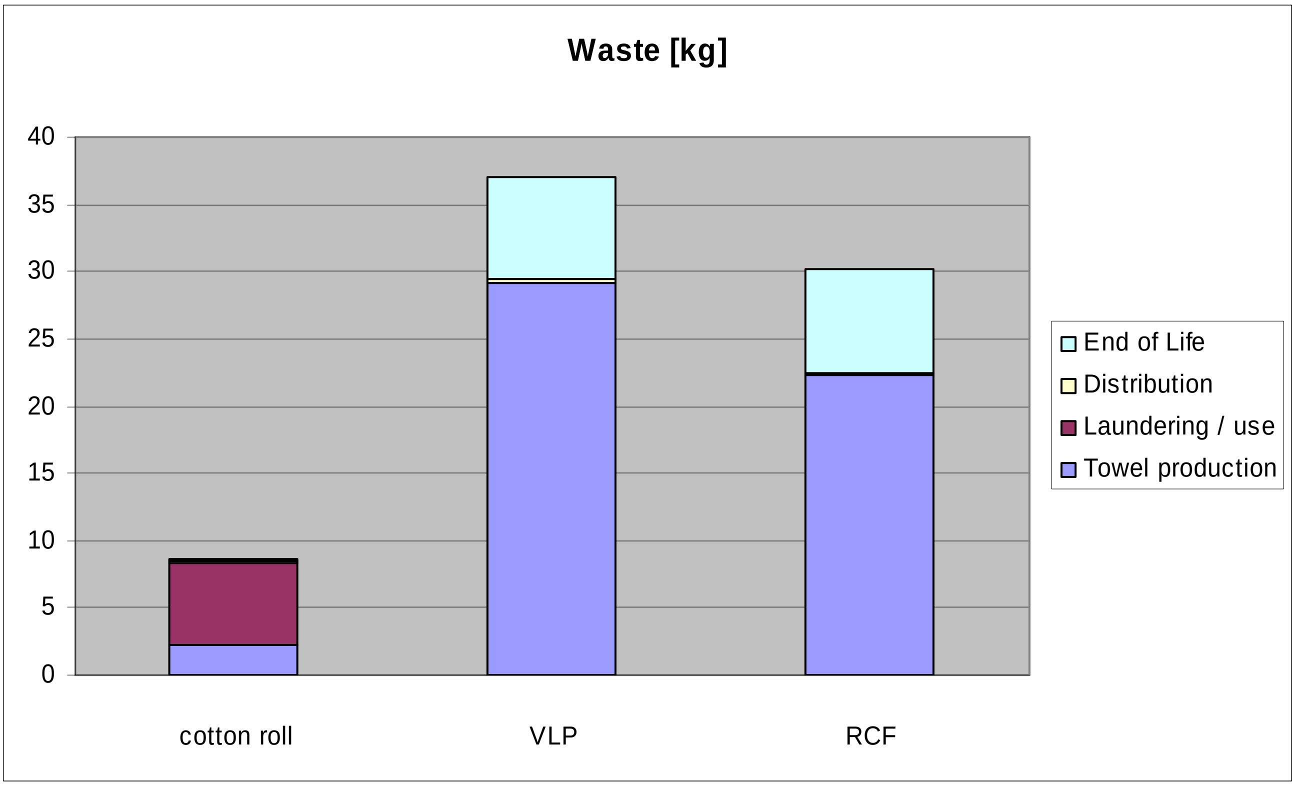

Figure 14 Comparison of waste generation for cotton roll and paper towel systems (average) for 10,000 hand dryings (standard scenario

4.2 Impact assessment

In the following impact assessment results are shown. In the first two chapters impact assessment results of the cotton roll system (section 4.2.1) and the paper towel system (section 0) will be described, and finally impact assessment results of the both systems investigated will be compared (section 4.2.3). All results are displayed for the functional unit of the study (10,000 hand dryings) for the standard scenario (1 pull / hand drying resp. 2 towels / hand drying) unless it is stated differently (cf. section 2.3).

4.2.1 Continuous cotton roll system

Impact assessment results show that for 10,000 hand dryings, the environmental burden (weighted average of investigated laundry companies) is 93 kg CO_2-equivalents for the Global Warming Potential (GWP), 0.60 kg SO_2-equivalents for the Acidification Potential (AP), 0.08 kg PO_4-equivalents for the Eutrophication Potential (EP) and 0.05 kg ethylene equivalents for the Photochemical Ozone Creation Potential (POCP) (Table 24).

Table 24 Impact assessment results for continuous cotton roll system (net values) for 10,000 hand dryings (standard scenario)

Parameter	unit	Cotton roll system average
Global Warming Potential	kg CO2-eq.	93
Acidification Potential	kg SO2-eq.	0.60
Eutrophication Potential	kg PO4-eq.	0.08
Photochemical Ozone Creation Potential	kg Eth-eq.	0.05

In contrary to all the other impact categories, the Aquatic Toxicity Potential (ATP) was investigated in a verbal-argumentative way, as a commonly accepted quantitative approach does not exist yet. Within this assessment relevant substances of the washing process were analysed and evaluated with their correspondent removal rates in sewage treatment plants (cf. Annex, Table 44). Data for the use of aqua toxic substances, e.g. pesticides, in the cotton towel production, in particular for cotton fibre growing, could not be obtained and therefore not assessed within this study. But it has to kept in mind, that conventional grown cotton has high environmental impacts, e.g. due to pesticide use.

Regarding the substances used in the cotton roll system, of particular interest concerning aqua toxicity are terpinolene, sodiumsilicates, sodiumcarbonate and methylhydroxyethylcellulose and chlorine or chlorinated products: Terpinolene is of interest because of the high characterisation factor (CF). But as terpinolene is only to a lower extent ingredient of the chemicals and detergents used in the laundries investigated, this causes a minor impact to aqua toxicity.

Concerning aqua toxicity sodiumsilicates, sodiumcarbonate and methylhydroxyethylcellulose have only minor negative effects on water organisms.[24] But in respect to their removal rates these substance groups are of interest because they will only be removed in waste water treatment plants for about 10 % to 25 % - even in secondary or tertiary treatment - and thus, increase the load of inorganic salts in waterbodies. Especially sodium carbonate and sodium metasilicate-pentahydrate matter due to their huge amount in the detergents used in the investigated laundries.

Of specific concern have to be chlorine or chlorinated products, because of their high negative effects on water organisms and their potential long-term adverse effects in the aquatic environment. In use in hygiene laundry are sodiumhypochlorite[25] and Triclosan[26] Further-

[24] Sodium silicates, sodium carbonate and methylhydroxyethylcellulose are classified in water hazard class 1 and are not classified as harmful to water organisms (http://www.hvbg.de/d/bia/fac/stoffdb/index.html).

[25] Sodiumhypochlorite is classified as very toxic to water organisms (R 50) (http://www.hvbg.de/d/bia/fac/stoffdb/index.html).

more, these substances cannot be adequately retained in sewage treatment plants and therefore reach the environmental compartments of water and air, respectively. In the past chlorine and chlorinated substances are used in laundries for bleaching and disinfection. In contrast today, chlorine free products are available and are used commonly. This survey shows that some laundries still use chlorinated products.

Having a look at the life cycle stages (Table 25, Figure 15 - Figure 18) one can see, that the main impact for the GWP derives from the laundering process (69 %); towel production contributes to the GWP with 26 %, the distribution share of cotton towels is 8 %. Concerning the AP, the shares of towel production and laundering are nearly the same: towel production contributes to the AP with 47 %, laundering with 45 %. Towel distribution accounts for 12 %. In respect to the EP the main share derives from towel production (67 %), followed by laundering (25 %) and distribution with 10 %. Regarding the POCP the picture is slightly different: the shares of laundering and distribution are in the same range (45 % resp. 41 %). For this indicator towel production is less important with 16 %.[27]

[26] Triclosan is classified as very toxic to water organisms (R 50) and may cause long-term adverse effects in the aquatic environment (R 53).

[27] Shares higher than 100 percent derive from credits given to the system for reuse of cotton towels as industrial / cleaning cloths (cf. section 3.1.6).

Table 25 Impact assessment results for the cotton roll system (weighted average) for different life cycle stages for 10,000 hand dryings (standard scenario)

parameter	unit	Cotton roll system average
Cotton towel production		
Global Warming Potential	kg CO2-eq.	24
Acidification Potential	kg SO2-eq.	0.28
Eutrophication Potential	kg PO4-eq.	0.05
Photochemical Ozone Creation Potential	kg Eth-eq.	0.01
Laundering		
Global Warming Potential	kg CO2-eq.	64
Acidification Potential	kg SO2-eq.	0.27
Eutrophication Potential	kg PO4-eq.	0.02
Photochemical Ozone Creation Potential	kg Eth-eq.	0.02
Distribution / Redistribution		
Global Warming Potential	kg CO2-eq.	7.2
Acidification Potential	kg SO2-eq.	0.08
Eutrophication Potential	kg PO4-eq.	0.01
Photochemical Ozone Creation Potential	kg Eth-eq.	0.02
End of life		
Global Warming Potential	kg CO2-eq.	-2.0
Acidification Potential	kg SO2-eq.	-0.02
Eutrophication Potential	kg PO4-eq.	-0.00
Photochemical Ozone Creation Potential	kg Eth-eq.	-0.00

4.2.2 Paper towel system

The impact assessment results show that for 10,000 hand dryings, the environmental burden for the Global Warming Potential (GWP) is 180 kg CO_2-equivalents for VLP and 184 kg CO_2-equivalents for RCF. For the acidification potential (AP) both paper options emit approx. 2.0 kg SO_2-equivalents. The Eutrophication Potential (EP) is 0.15 kg PO_4-equivalents for VLP and 0.10 kg PO_4-equivalents for RCF. Regarding the Photochemical Ozone Creation Potential (POCP) the VLP emits 0.10 kg ethylene equivalents and the RCF-option 0.09 kg ethylene equivalents (Table 26).

Table 26 Impact assessment results (net values) for the paper towel system for 10,000 hand dryings (standard scenario)

parameter	unit	Paper towel system	
		VLP average	RCF average
Global Warming Potential	kg CO2-eq.	180	184
Acidification Potential	kg SO2-eq.	2.04	2.00
Eutrophication Potential	kg PO4-eq.	0.15	0.10
Photochemical Ozone Creation Potential	kg Eth-eq.	0.10	0.09

In contrary to all the other impact categories, the Aquatic Toxicity Potential (ATP) was investigated in a verbal-argumentative way, as a commonly accepted quantitative approach does not exist yet. Within this assessment relevant substances of the paper towel manufacturing were analysed and evaluated with their correspondent removal rates in sewage treatment plants (cf. Annex, Table 44).

Data for paper towel manufacturing concerning potentially aqua toxic substances are incomplete, in particular for tissue production, where the used chemicals are not further specified in the BREF documents. For example, for chemicals like colour agents, additives, flotation agents or bleaching agents no further specification is given. Thus, an assessment of these substances is not possible within this study.

Regarding the substances specified, in particular chlorinated products – in pulp production for virgin luxury paper sodium chlorate is used – and EDTA are of particular interest concerning aqua toxicity. Sodium chlorate has high negative effects on water organisms and may cause long-term adverse effects in the aquatic environment.[28] Furthermore, these substances cannot be adequately retained in sewage treatment plants and therefore reach the environmental compartments of water and air, respectively. In the past chlorine and chlorinated substances are used commonly in paper production, mostly for bleaching. In contrast today, most processes are chlorine free, but still chlorinated products are used in pulp production (cf. BREF pulp & paper 2001). But also EDTA, which is also used in pulp production, has to be of specific concern due to its aquatic toxicity potential and its potential long-term adverse effects in the aquatic environment.[29]

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28 Sodium chlorate is classified as toxic to water organisms (R 51) and may cause long-term adverse effects in the aquatic environment (R 53) (http://www.hvbg.de/d/bia/fac/stoffdb/index.html).

29 EDTA is classified as harmful to aquatic organisms (R 52) and may cause long-term adverse effects in the aquatic environment (R 53) (http://www.hvbg.de/d/bia/fac/stoffdb/index.html).

Having a look at the life cycle stages (Table 27, Figure 15 - Figure 18) one can see, that the main impact for the GWP for both systems derives from the towel production (both systems: 104 %,); distribution contributes to the GWP in both cases with 7 %. This is nearly the same picture for the other three indicators: concerning the AP, the share of towel production is 108 % (both VLP and RCF), in respect to the EP the share deriving from towel production is 91 % (VLP) resp. 87 % (RCF); regarding the POCP the shares are 79 % (VLP) and 77 % (RCF). The share of distribution in all indicators is less important, only for the POCP the share is nearly one third (VLP: 27 %, RCF: 31 %).[30]

Table 27 Impact assessment results (net values) for the paper towel system for different life cycle stages for 10,000 hand dryings (standard scenario)

parameter	**unit**	**Paper towel system**	
		VLP average	**RCF average**
Paper towel production			
Global Warming Potential	kg CO2-eq.	190	190
Acidification Potential	kg SO2-eq.	2.20	2.15
Eutrophication Potential	kg PO4-eq.	0.13	0.09
Photochemical Ozone Creation Potential	kg Eth-eq.	0.08	0.07
Use stage (distribution / bin liner production)			
Global Warming Potential	kg CO2-eq.	13	13
Acidification Potential	kg SO2-eq.	0.12	0.12
Eutrophication Potential	kg PO4-eq.	0.01	0.01
Photochemical Ozone Creation Potential	kg Eth-eq.	0.03	0.03
End of life			
Global Warming Potential	kg CO2-eq.	-21	-21
Acidification Potential	kg SO2-eq.	-0.28	-0.28
Eutrophication Potential	kg PO4-eq.	0.00	0.00
Photochemical Ozone Creation Potential	kg Eth-eq.	-0.01	-0.01

4.2.3 Comparison of the two systems

Impact assessment results (Table 24, Table 26) show that the cotton roll system causes less environmental burdens concerning all the indicators investigated:

In respect to the GWP the cotton roll system emits half the CO_2-equivalents than both paper options. For the cotton towel system, the main impact to this indicator derives from the laundering process, for the paper towel system from towel production (Figure 15).

[30] Shares higher than 100 percent derive from the credits given to the system for electricity generation by waste incineration (cf. section 3.2.6).

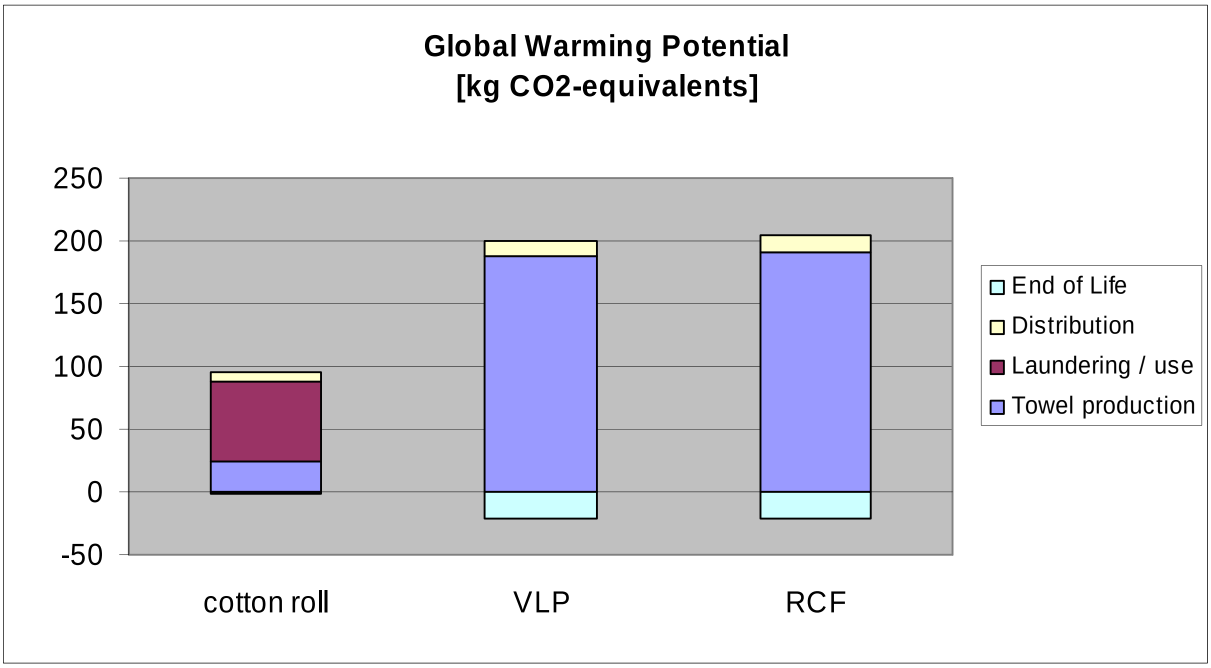

Figure 15 Comparison of the Global Warming Potential (GWP) for the cotton roll and the paper towel systems (average) for 10,000 hand dryings (standard scenario)

Concerning the AP the results are even better: the cotton roll system causes less than one third of the environmental burden for this indicator than both paper options. The main impacts to this indicator come from towel production for the paper options as well as from towel production and laundering to nearly the same extent for the cotton towel system (Figure 16).

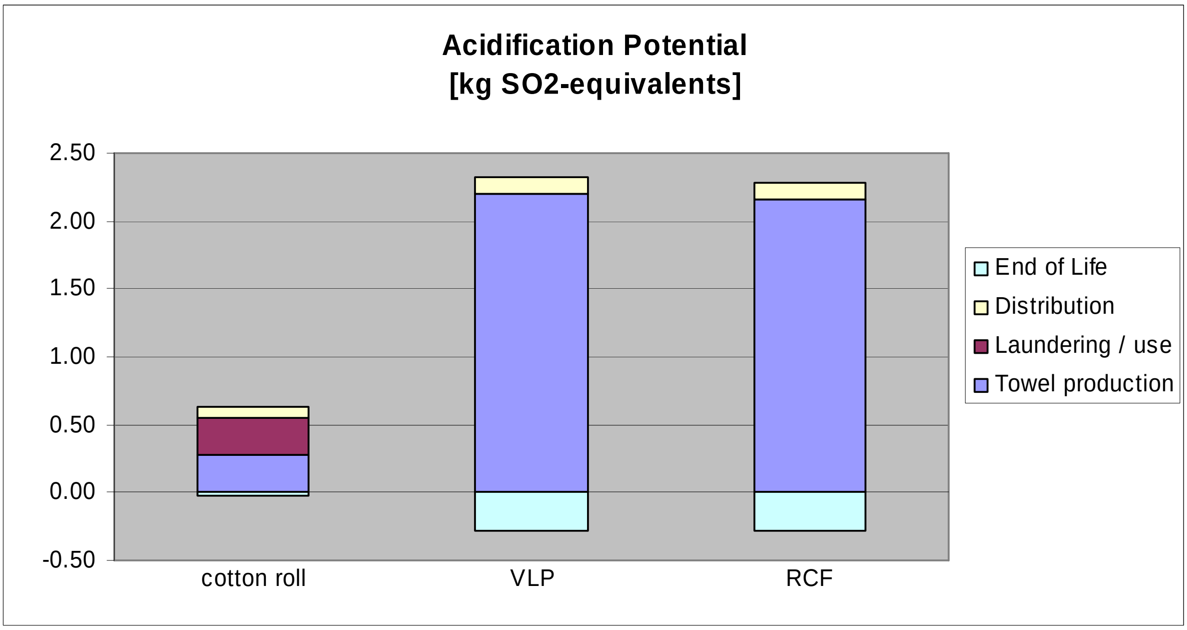

Figure 16 Comparison of the Acidification Potential (AP) for the cotton roll and the paper towel systems (average) for 10,000 hand dryings (standard scenario)

Regarding the EP the environmental impact of the cotton system is nearly halved in respect to the VLP-option and is approx. 20% lower than the one of the RCF-option. The main impacts to this indicator are caused by towel production in both systems (Figure 17).

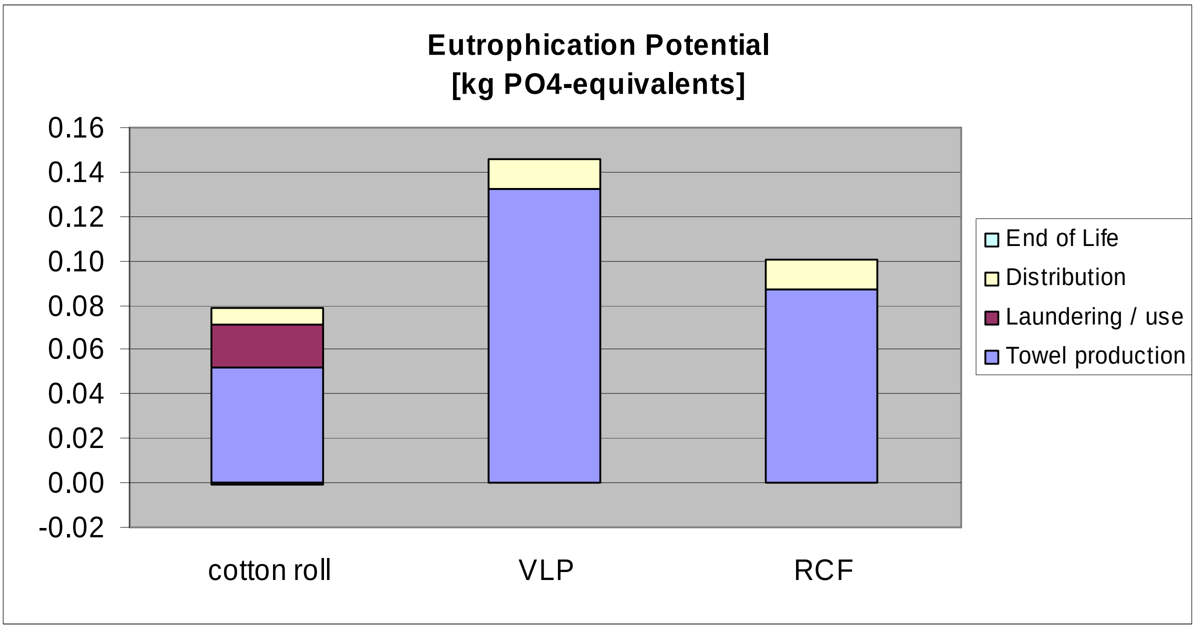

Figure 17 Comparison of the Eutrophication Potential (EP) for the cotton roll and the paper towel systems (average) for 10,000 hand dryings (standard scenario)

In respect to the POCP the environmental burden caused by the cotton roll system is 50% lower than the VLP system and 40% lower than the RCF system. To this indicator the impact of the towel distribution for both systems is quite high (compared with the other indicators); in case of the cotton roll system laundering and distribution have nearly the same impact to this indicator. In contrast, for the paper options, the towel production has the most relevant share (Figure 18).

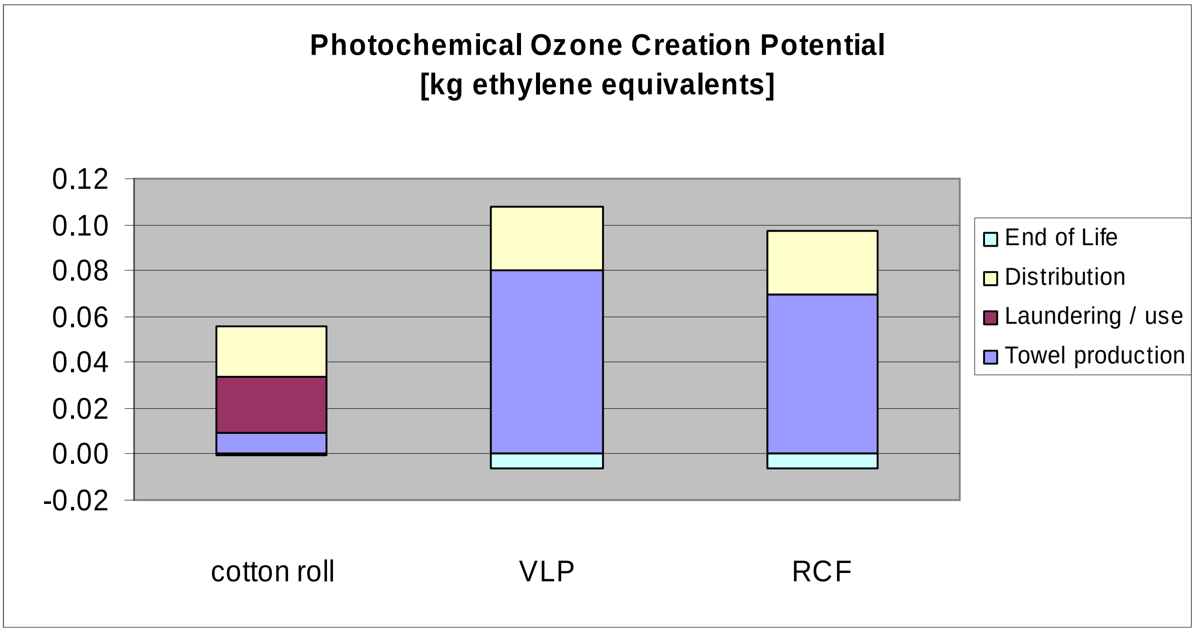

Figure 18 Comparison of the Photochemical Ozone Creation Potential (POCP) for the cotton roll and the paper towel systems (average) for 10,000 hand dryings (standard scenario)

4.3 Sensitivity analyses

With respect to the parameters which influence the results of the analysed systems significantly (cf. sections 3.1.7 and 0) following sensitivity analyses have been carried out:

- Regarding the paper towel system, scenarios with higher and lower **paper towel consumption per hand drying** were calculated (section 4.3.1.1).
- Regarding the cotton roll system, a scenario with higher **use of cotton roll towel per hand drying** was calculated (section 4.3.1.2).
- Regarding the paper towel system, a scenario for a higher **recycling paper share** in paper towels was calculated (section 4.3.1.3).
- Regarding the cotton roll system one scenario with lower and one with higher **life time of the cotton roll** (section 4.3.1.4) was calculated.

4.3.1.1 Paper towel consumption per hand drying

In order to see to what extent the paper towel consumption influences the results, two sensitivities were calculated and compared with the cotton roll system (standard use of 2 towels per hand drying):

- Minimum use scenario: halving paper towel consumption to **1 paper towel per hand drying**
- Maximum use scenario: doubling paper towel consumption to **4 paper towels per hand drying**

The results of the calculation show that for both paper qualities the environmental impact halves resp. doubles by halving resp. doubling the amount of paper towels used (Table 28).

Table 28 Sensitivity analysis results (net values) for the paper towel consumption per hand drying (for 10,000 hand dryings)

Total (net)		**Standard use**	**Minimum use**	**Maximum use**
Towels per hand drying		*2*	*1*	*4*
		VLP		
CED, total	MJ	4,040	2,020	8,070
water use	kg	12,270	6,130	24,540
waste	kg	37	19	74
Global Warming Potential	kg CO2-eq.	180	90	360
Acidification Potential	kg SO2-eq.	2.04	1.02	4.08
Eutrophication Potential	kg PO4-eq.	0.15	0.08	0.29
Photochemical Ozone Creation Potential	kg Eth-eq.	0.10	0.05	0.20
		RCF		
CED, total	MJ	3,510	1,750	8,810
water use	kg	9,600	4,800	13,800
waste	kg	30	15	60
Global Warming Potential	kg CO2-eq.	184	92	367
Acidification Potential	kg SO2-eq.	2.00	1.00	3.99
Eutrophication Potential	kg PO4-eq.	0.10	0.05	0.20
Photochemical Ozone Creation Potential	kg Eth-eq.	0.09	0.05	0.18

Compared with the environmental burden caused by the standard use of cotton towel rolls (1 pull per hand drying, Table 20, Table 24) and the results of the comparison of both systems investigated (sections 4.1.3 and 4.2.3) one can see (Figure 19, Figure 20), that

- the minimum use scenario for both paper towel options (lower end of the bar) shows higher environmental impacts than the cotton roll system for CED, waste and AP: the minimum use scenario needs about one third more energy, produces between 1.7 times (RCF) and 2.2 times (VLP) more waste and causes for both VLP and RCF approx. two thirds (VLP) more SO_2-equivalents;
- for the GWP, the EP and the POCP results change: in the minimum scenario both paper towel options are equal to the cotton roll system regarding GWP and concerning EP and and POCP slightly better than the cotton roll system: the VLP minimum use scenario is between 5 and 7 % better than the cotton roll standard use scenario for the three indicators; the RCF minimum scenario is between 17 and 33 % better;
- regarding water consumption, the maximum use scenario for both paper towel options shows higher environmental impacts than the cotton roll system: 86 % more for VLP resp. 46 % more for RCF. In contrast, in the standard and minimum use scenario both paper options are better than the cotton roll system.

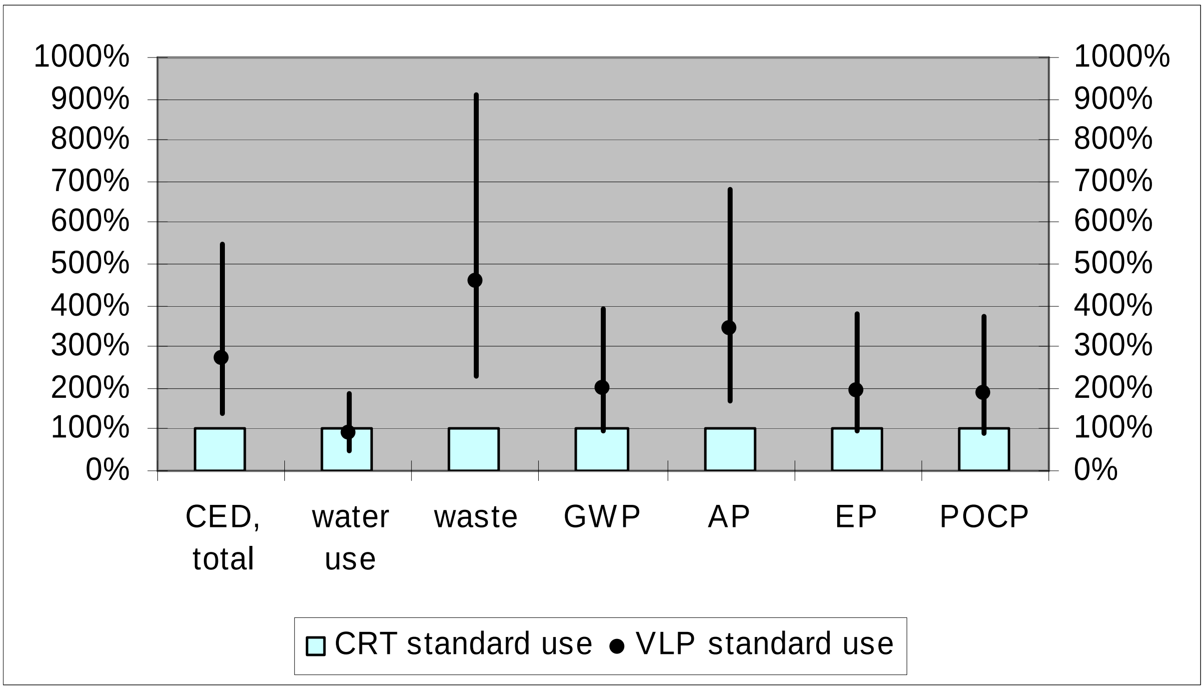

Figure 19 Different use scenarios for VLP paper towel system for 10,000 hand dryings

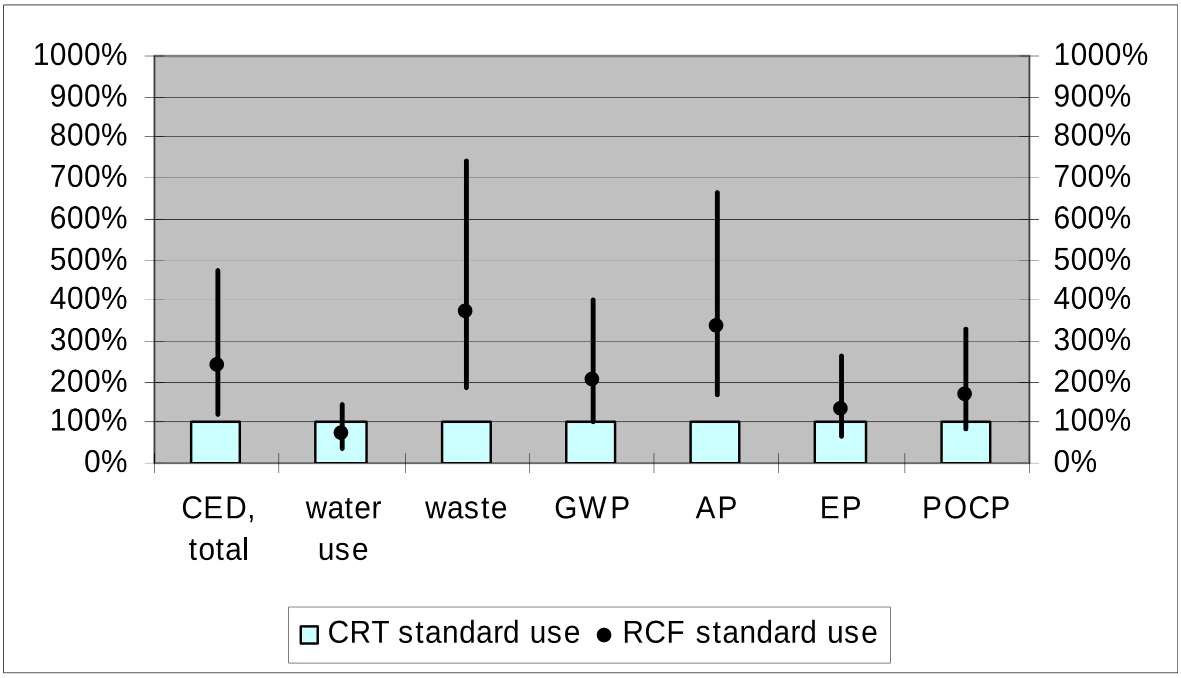

Figure 20 Different use scenarios for RCF paper towel system for 10,000 hand dryings

4.3.1.2 Use of cotton roll per hand drying

In order to get an impression to what extent the amount of cotton roll used per hand drying influences the results, one maximum use scenario with 2 pulls per hand drying was calculated and compared with the paper towel system (standard use of 2 paper towels per hand drying).

The results show that the environmental impact doubles with a doubling of the amount of cotton roll towel used per hand drying (Table 29).

Table 29 Sensitivity analysis results (net values) for different amounts of cotton roll pulls per hand drying (for 10,000 hand dryings)

Total (net)		**Standard use**	**Maximum use**
Pulls per hand drying		*1*	*2*
CED, total	MJ	1,500	3,000
water use	kg	13,300	26,600
waste	kg	8.1	16.3
Global Warming Potential	kg CO2-eq.	93	186
Acidification Potential	kg SO2-eq.	0.60	1.20
Eutrophication Potential	kg PO4-eq.	0.08	0.15
Photochemical Ozone Creation Potential	kg Eth-eq.	0.05	0.11

Compared with the both paper towel options one can see (Figure 21, Figure 22), that

- in the maximum use scenario the cotton roll towel system is even better than the standard use scenario of both paper systems concerning CED, waste and AP: for CED, cotton rolls are about one third better, for AP it is about 1.5 times and for waste it is about 2 times better than both paper towel options (standard use);
- regarding water demand, the cotton roll system gets worse than both paper towel options (about 2 times worse than the standard scenario);
- in the maximum use scenario, cotton roll towels are equal or slightly worse than the standard use of VLP regarding GWP, EP and POCP (less than 10 %) and also worse than the standard use of RCF: for GWP about 15 %, for EP about 34 % and for POCP about 17 %.

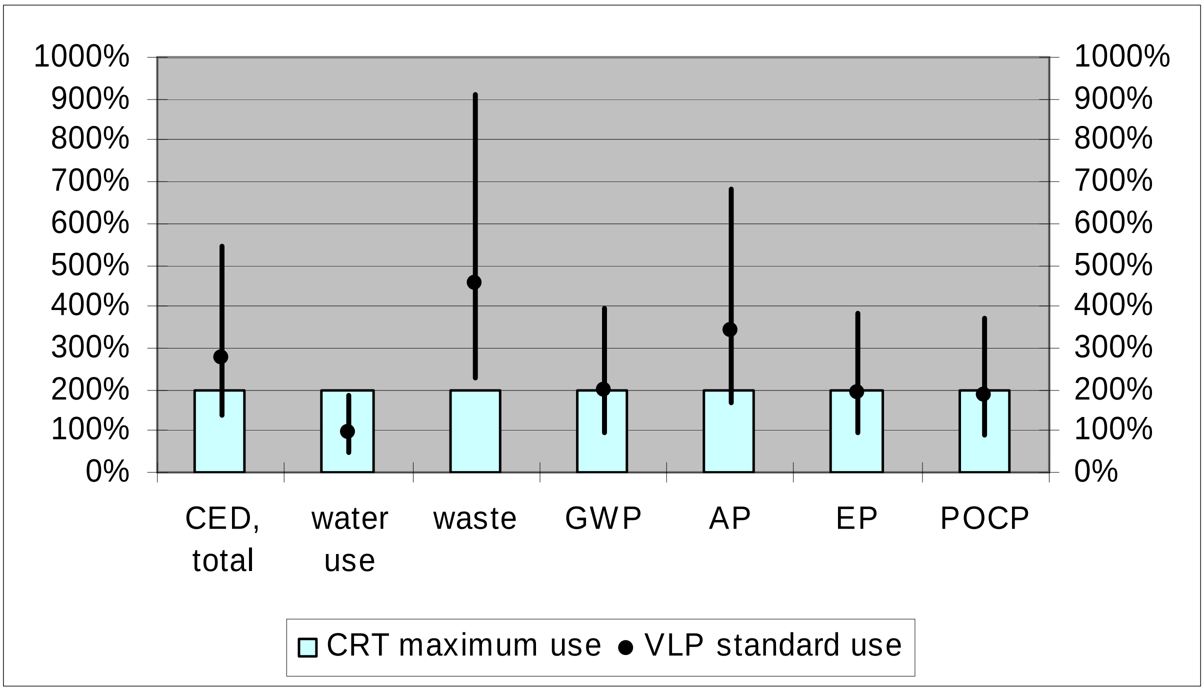

Figure 21 Maximum cotton roll towel use (2 pulls) for 10,000 hand dryings in comparison with VLP paper towel system

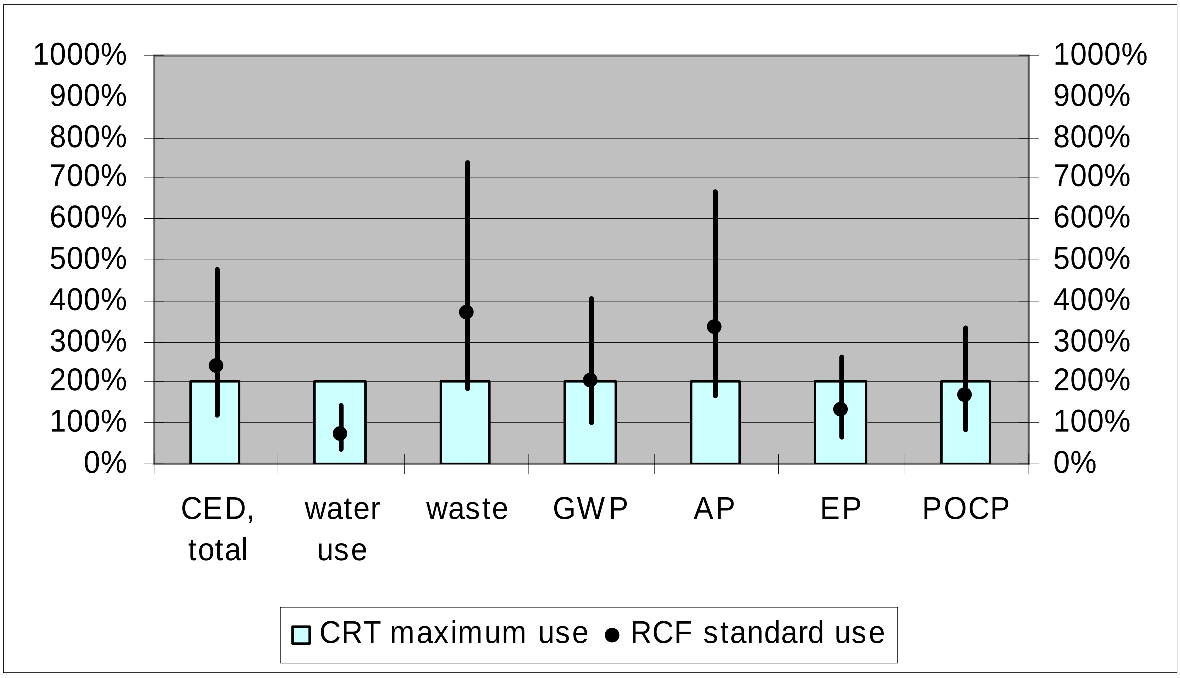

Figure 22 Maximum cotton roll towel use (2 pulls) for 10,000 hand dryings in comparison with RCF paper towel system

4.3.1.3 Recycling paper share

In order to see to what extent the share of recycling paper in paper towels influences the results, one scenario with 100 % recycling paper input for paper towel production was calculated. Restrictions due to fibre shortening were considered (cf. section 3.2.2.2). The results show (cf. Table 30), that if instead of 50 % partly recycled paper towels, 100 % recycling paper towels would be used, the environmental burden reduces significantly for all parameters and indicators except for GWP:

- CED decreases by 15 %.
- Water use decreases by 28 %,
- Waste accumulation decreases by 23 %,
- AP decreases by 2%,
- EP decreases by 45 %,
- POCP decreases by 12 %,
- GWP increases by 2 %.

Table 30 Sensitivity analysis results (net values) for recycling paper share in paper towels for 10,000 hand dryings (standard scenario)

Total (net)		**50 % recycling paper**	**100 % recycling paper**
CED	MJ	3,510	2,980
water use	kg	9,600	6,940
waste	kg	30	23
Global Warming Potential	kg CO2-eq.	184	188
Acidification Potential	kg SO2-eq.	2.00	1.96
Eutrophication Potential	kg PO4-eq.	0.10	0.06
Photochemical Ozone Creation Potential	kg Eth-eq.	0.09	0.08

4.3.1.4 Cotton roll life time

In order to have an impression to what extent the life time of the cotton rolls influences the results, two sensitivities were calculated and compared with standard life time:

- one scenario with a reduced life time (70 washing cycles instead of 103)
- and one scenario with an enlarged life time (130 washing cycles instead of 103).

The results show (Table 31), that the life time of cotton rolls influences the results to a great extent: regarding minimum life time of 70 washing cycles, the environmental burden of cotton towel production increases by nearly 50 %, for the maximum life time of 130 washing cycles the environmental impact is reduced by 20 %.

Table 31 Sensitivity analysis results (net values) for different cotton roll life times (for 10,000 hand dryings)

Cotton towel production		**Standard life time**	**Reduced life time**	**Enlarged life time**
Cotton roll life time [washing cycles]		*103*	*70*	*130*
CED	MJ	270	390	210
water use	kg	11,300	16,700	9,000
Waste	kg	2.2	3.2	1.7
Global Warming Potential	kg CO2-eq.	24	35	19
Acidification Potential	kg SO2-eq.	0.28	0.42	0.23
Eutrophication Potential	kg PO4-eq.	0.05	0.08	0.04
Photochemical Ozone Creation Potential	kg Eth-eq.	0.01	0.01	0.01

4.3.1.5 Crediting within the end-of-life stage

Regarding the influence of the crediting assumptions within the end-of-life stage two sensitivities were calculated and compared with standard assumption:

- one scenario with 100% credits from the thermal recycling of the waste paper
- and one scenario with no credits.

The results show (Table 32), that the different crediting assumptions influence the results to a certain extent. For example, concerning CED, the scenario with 100% credits shows approx. 10% less environmental burden. However, this no influence on the results of the comparison (cf. Table 22, Table 24): Except for water use, the cotton roll system remains better than the paper towel system.

Table 32 Sensitivity analysis results (net values) regarding different crediting assumptions within the end-of-life stage (for 10,000 hand dryings)

Total (net)		0% credits		50% credits (standard)		100% credits	
		VLP	RCF	VLP	RCF	VLP	RCF
CED	MJ	4,490	3,960	4,040	3,510	3,580	3,060
water use	kg	12,990	10,320	6,580	9,600	11,540	8,880
waste	kg	38	31	37	30	36	29
GWP	kg CO2-eq.	201	205	180	184	159	163
AP	kg SO2-eq.	2.33	2,29	2.04	2.00	1.74	1.70
EP	kg PO4-eq.	0.15	0.11	0.15	0.10	0.14	0.10
POCP	kg Eth-eq.	0.11	0.10	0.10	0.09	0.09	0.08

5 Conclusions

In general, for the standard scenario, the cotton towel roll system is better for all impact assessment indicators than the paper towel system (Table 33). Only the water demand of the cotton roll system higher than the one of the paper options. Figure 23 illustrates the results for the impact assessment indicators compared to the cotton roll system (100 %).

Table 33 Overview of inventory and impact assessment results (net values) for the two analysed systems for 10,000 hand dryings (standard scenario)

parameter	unit	Cotton roll system	Paper towel system	
			VLP	RCF
Total				
CED, total	MJ	1,500	4,040	3,510
water use	kg	13,300	12,270	9,600
waste	kg	8.1	37	30
Global Warming Potential	kg CO2-eq.	93	180	184
Acidification Potential	kg SO2-eq.	0.60	2.04	2.00
Eutrophication Potential	kg PO4-eq.	0.08	0.15	0.10
Photochemical Ozone Creation Potential	kg Eth-eq.	0.05	0.10	0.09
Cotton / Paper towel production				
CED	MJ	270	4,220	3,700
water use	kg	11,300	12,750	10,080
waste	kg	2.2	29	22
Global Warming Potential	kg CO2-eq.	24	190	190
Acidification Potential	kg SO2-eq.	0.28	2.20	2.15
Eutrophication Potential	kg PO4-eq.	0.05	0.13	0.9
Photochemical Ozone Creation Potential	kg Eth-eq.	0.01	0.08	0.07
Use stage (laundering / distribution / bin liner production)				
CED	MJ	1,290	260	260
water use	kg	2,080	115	115
waste	kg	6.3	0.2	0.2
Global Warming Potential	kg CO2-eq.	71	13	13
Acidification Potential	kg SO2-eq.	0.35	0.12	0.12
Eutrophication Potential	kg PO4-eq.	0.03	0.01	0.01
Photochemical Ozone Creation Potential	kg Eth-eq.	0.05	0.03	0.03
End of Life				
CED	MJ	-50	-450	-450
water use	kg	-70	-600	-600
waste	kg	-0.3	7.6	7.6
Global Warming Potential	kg CO2-eq.	-2	-21	-21
Acidification Potential	kg SO2-eq.	-0.02	-0.28	-0.28
Eutrophication Potential	kg PO4-eq.	-0.00	0.00	0.00
Photochemical Ozone Creation Potential	kg Eth-eq.	-0.00	-0.01	-0.01

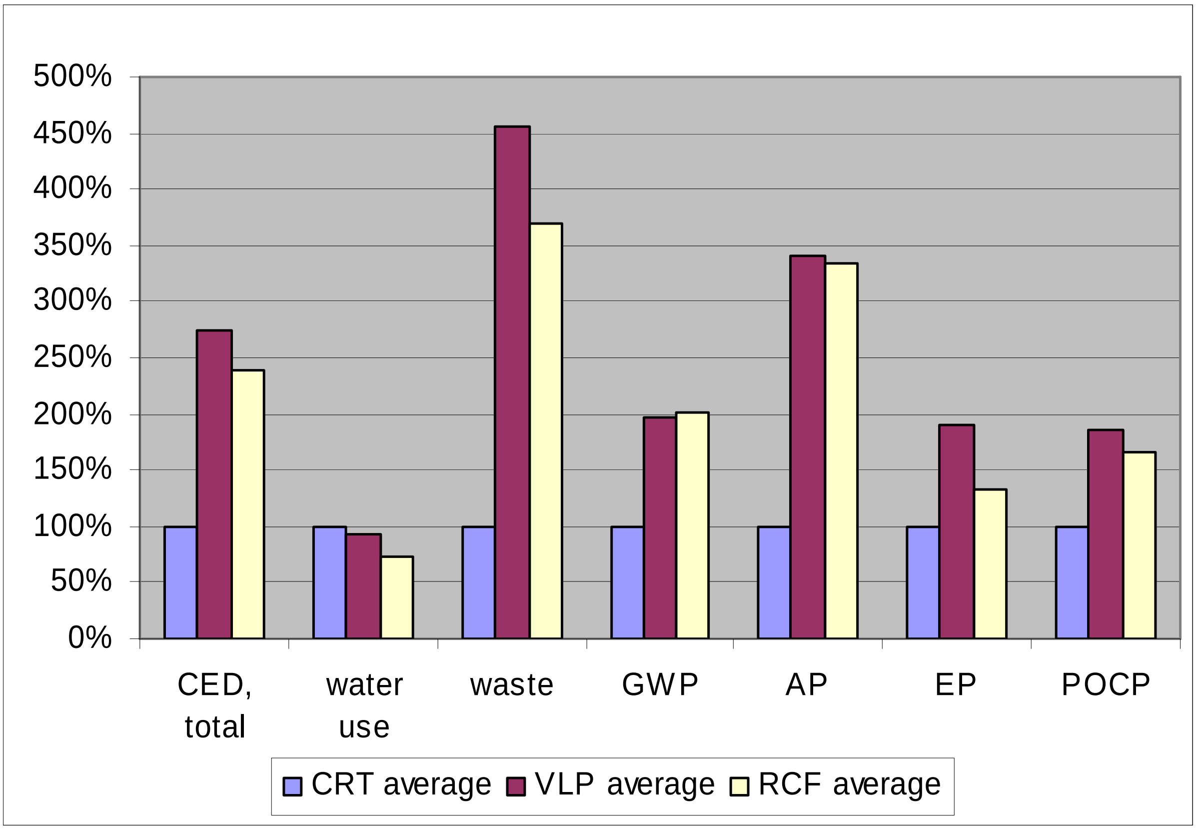

Figure 23 Comparison of the environmental impacts for the analysed hand drying systems for 10,000 hand dryings (standard scenario)

Consequently, the main environmental impact of the paper towel system derives from towel production for all indicators. In contrast, for the cotton roll system, the main impact is sometimes caused by laundering (CED, GWP) and sometimes by towel production (water, EP). Concerning AP, towel production and laundering have nearly the same impact; regarding POCP, laundering and distribution nearly have the same impact (Table 34).

Table 34 Contribution of life cycle steps to the environmental impacts for 10,000 hand dryings (standard scenario)

parameter	unit	Cotton roll system	Paper towel system	
			VLP	RCF
Cotton / Paper towel production				
CED, total	MJ	18 %	105 %	105 %
water use	kg	86 %	104 %	105 %
waste	kg	27 %	79 %	74 %
Global Warming Potential	kg CO2-eq.	26 %	104 %	104 %
Acidification Potential	kg SO2-eq.	47 %	108 %	108 %
Eutrophication Potential	kg PO4-eq.	68 %	91 %	87 %
Photochemical Ozone Creation Potential	kg Eth-eq.	16 %	79 %	77 %
Laundering				
CED	MJ	81 %	-	-
water use	kg	16 %	-	-
waste	kg	75 %	-	-
Global Warming Potential	kg CO2-eq.	70 %	-	-
Acidification Potential	kg SO2-eq.	46 %	-	-
Eutrophication Potential	kg PO4-eq.	25 %	-	-
Photochemical Ozone Creation Potential	kg Eth-eq.	45 %	-	-
Distribution				
CED	MJ	6 %	7 %	7 %
water use	kg	0 %	1 %	1 %
waste	kg	3 %	1 %	1 %
Global Warming Potential	kg CO2-eq.	8 %	7 %	7 %
Acidification Potential	kg SO2-eq.	13 %	6 %	6 %
Eutrophication Potential	kg PO4-eq.	10 %	9 %	13 %
Photochemical Ozone Creation Potential	kg Eth-eq.	41 %	27 %	31 %
End of Life				
CED	MJ	-3 %	-11 %	-13 %
water use	kg	-1 %	-5 %	-6 %
waste	kg	0 %	21 %	25 %
Global Warming Potential	kg CO2-eq.	-2 %	-12 %	-11 %
Acidification Potential	kg SO2-eq.	-4 %	-14 %	-14 %
Eutrophication Potential	kg PO4-eq.	-1 %	0 %	0 %
Photochemical Ozone Creation Potential	kg Eth-eq.	-1 %	-6 %	-7 %

These results refer to a cotton roll life time of about 100 washing cycles. If life time is shorter, being the case in some of the investigated textile service companies, the environmental burden of cotton roll towel production increases by nearly 50 % (cf. section 4.3.1.4). This would lead to a significantly higher impact – particularly for water demand, EP and AP. In contrast, a longer cotton roll life time, which was also found in the laundries investigated, leads to significantly lower impacts of about 20 %. Respectively, this is most relevant for the three above mentioned indicators.

The amount of paper towels used to dry hands resp. the cotton roll pulls for hand drying also have a great influence (cf. section 4.3.1.1, 4.3.1.2): even if only one paper towel is used for hand drying, the standard use scenario for the cotton roll system still shows better results for 3 out of 7 parameters / indicators (CED, waste, AP). For two indicators result change, and paper towels get better than the cotton roll system in a minimum scenario. Furthermore, even if more paper towels are used than in the standard scenario, result will change: in the maximum use scenario the paper towel system is worse than the cotton roll system for all investigated parameters / indicators. In contrast, continuous cotton roll towels are even better in a maximum use scenario for 3 out of 7 parameters / indicators than the paper towel system (standard use scenario): this is the case for CED, waste and AP. However, in the maximum scenario, the cotton roll system is worse than the paper system for water use, EP and POCP.

As conclusion and seeing that the use behaviour of washroom clients will influence the environmental assessment of both systems significantly, it can be stated that, with standard use, the cotton roll system causes less environmental impacts than the paper towel system.

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7 Annex

7.1 Questionnaire

Please specify the data sources and data quality as follows: 1 / 2 / 3 / 4
(1): year of reference: **199# / 200#**
(2): place of reference: in-house (**I**), literature (**L**), other (**O** and specification)
(3): single value (**S**); aggregated value (**A**)
(4): measured (**M**); calculated (**C**); estimated (**E**)
Example: 19,345 kWh_{el} (**2001/I/S/M)**

1 Address and contact person

Address of company:

Contact person(s):

2 Company

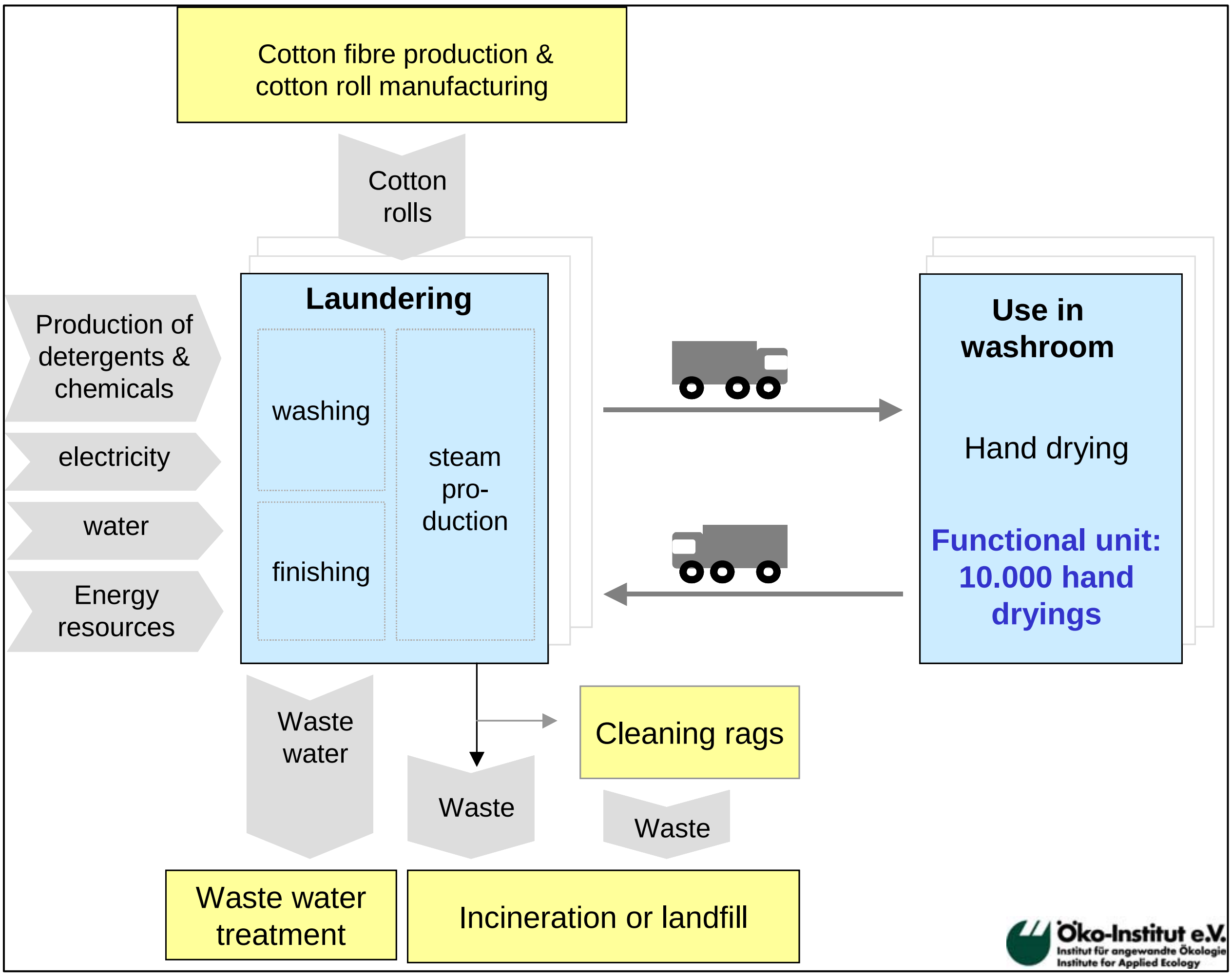
Short description of the company (sites, business areas, types and amount of laundry, amount of cotton rolls washed per year, amount of paper towels sold per year etc.), please also use the table below.

Laundry site	**Processing volume [cotton rolls / a]**	**Paper towels sold [pieces / a]**

3 Continuous cotton roll system

Life Cycle Analysis is an instrument to gain more information on environmental impacts inter alia of products and services. Within specified system boundaries the processes will be analysed from cradle to grave. As there are existing various laundering processes for continuous cotton roll towels it is important to get information as detailed as possible. Figure 1 gives you an overview of the aspects of interest for this Life Cycle Assessment.

Figure 1 Continuous cotton roll system



3.1 Description of the system

Please describe the system ('from cradle to grave') with the specifics of yours company's laundries as detailed as possible.

3.1.1 Laundering process

Please describe the laundering process (washing, finishing etc.) and the necessary peripheral processes (e.g. steam production, water conditioning, waste water treatment) as detailed as possible concerning their environmental aspects. The following list with important aspects and parameters might be of assistance.

Type(s) of washing machine(s)	
Washing temperature	
Exposure time	
Drying technology (e.g. centrifuge, press)	
Laundry transport technology in laundry (e.g. negative pressure)	
Steam production (e.g. gas / oil)	
Electricity production (e.g. grid / in-house)	
Water supply (e.g. grid / own well)	
Water conditioning (e.g. reverse osmosis)	
Wash water recycling (e.g. reuse in other process)	
Waste water treatment (e.g. in own ETP)	
Waste treatment	

3.1.2 Distribution of cotton rolls and use stage

Please describe distribution and logistics, number and place of sites where cotton rolls are delivered to by using the following table.

Number of customers (per laundry site)	
Number of cotton rolls delivered (per laundry site)	
Number of storage / distribution facilities (per laundry site)	

3.2 Input/Output data

3.2.1 Laundering process

Please specify to which **amount of washed cotton rolls** the data refer to (functional unit, e.g. annual production) and specify data references and quality (see above), e.g. 19,345 kWh_{el} (2001/I/S/M).

Input washing / finishing process	
Cotton rolls (kg)	
Energy demand	
Electricity from grid (kWh_{el})	
Electricity internal production (kWhel)	
Steam internal production (kWhth)	
Energy sources for internal energy production: e.g. coal, natural gas, light fuel oil etc. (specific unit and MJ/unit)	
Materials	
Water (m^3) (please specify origin and treatment before use)	
Detergents (kg or Liter and density)	
Other chemicals (e.g. acids etc.; kg or Liter and density, please specify)	
Packaging materials (kg), please specify materials	

Output washing / finishing process	
Waste water Total amount (m^3) (please specify treatment) pH-value temperature **Concentrations (mg/l)**: COD AOX BOD-5 Heavy metals (please specify) chemicals (please specify) other	
Waste total amount (kg) *specification*: textile waste (kg) recycled waste (kg) (please specify treatment) commercial / residential waste for incineration (kg) commercial / residential waste for landfilling (kg) hazardous waste (kg) (please specify treatment)	
***Other** (please specify)*	

3.2.2 Formulation of detergents and other chemicals

Please attach the safety data sheets of the used detergents and chemicals and give us the address(es) and contact person(s) of the manufacturer(s).

Address(es) / contact person(s):

3.2.3 Distribution

Please specify the distribution of the cotton rolls by using the following table. For the LCA we need to have data for an average tour (distance, number of customers, number of delivered cotton rolls, lorry type and utilisation ratio). If you already have this kind of data you can fill in the last line of the table, if you don't have the average data for your laundry please specify for each delivery tour. In the case you organize your delivery tours via storage / distribution centres outside your laundry, please specify in the second table. Again we need average data if you have or the data for each delivery tour to the storage / distribution centre.

Delivery tours to customer

Delivery tours	**Total distance driven [km]**	**Number of customers**	**Total number of cotton rolls delivered**	**Lorry type [max. weight]**	**Utilisation ratio of lorry [%]**
Tour 1					
Tour 2					
Tour 3					
Average tour					

Delivery tours to storage / distribution centre (if applicable)

Delivery tours to storage centre	**Total distance driven [km]**	**Number of customers**	**Total number of cotton rolls delivered**	**Lorry type [max. weight]**	**Utilisation ratio of lorry [%]**
Tour 1					
Tour 2					
Tour 3					
Average tour					

3.2.4 Use in washroom

Please describe the use of cotton rolls in the washroom by using the following table:

Average cotton roll length [m]	
Average cotton roll width [cm]	
Average weight of cotton roll [kg]	
Average number of pulls per cotton roll	
Average number of washing cycles per cotton roll ("primary life time")	

3.2.5 End-of-life usage of cotton rolls

Is there a secondary use of worn-out cotton rolls (e.g. cleaning rags)?

□ **yes,** □ **no**

Secondary use as

How many percent of worn-out cotton rolls are reused?

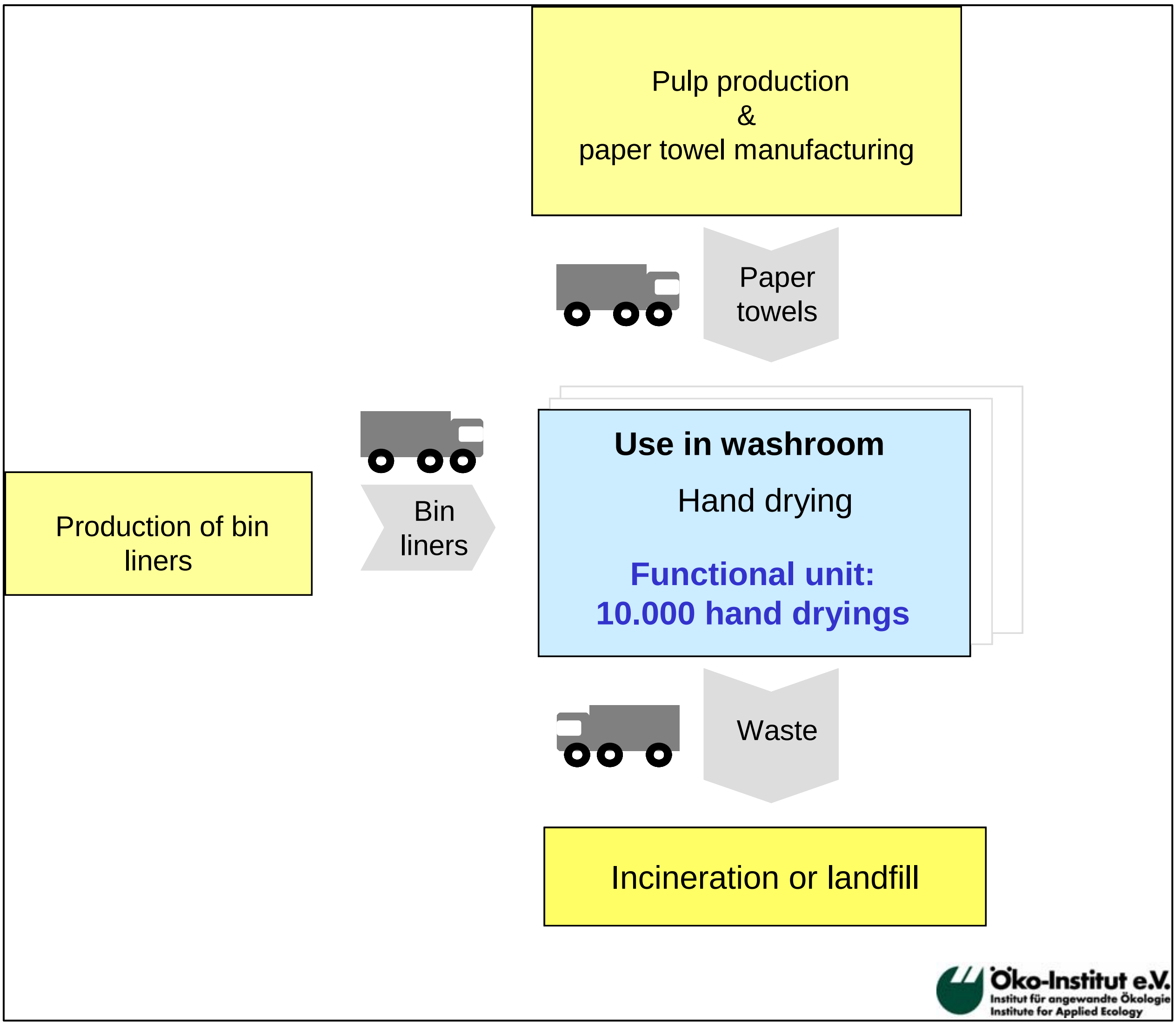
What kind of conditioning is necessary?

3.3 Other relevant information for cotton roll system

4 Paper towel system

Figure 2 gives you an overview of the aspects of interest for this Life Cycle Assessment.

Figure 2 Paper towel system



4.1 Description of the system

Please describe the system as detailed as possible.

4.1.1 Amount of paper towels distributed by the company per year (in kg)

Name of paper product	supplier	volume [kg / a]

4.1.2 Supplier(s) of paper towels (company name, address and contact person

Supplier	address	contact person

4.1.3 Distribution of paper towels and use stage

Please describe distribution and logistics, number and place of sites where paper towels are delivered to, etc.

Number of customers (per laundry site)	
Amount of paper towels delivered (per laundry site) [kg]	
Number of storage / distribution facilities (per laundry site)	

4.2 Input/Output data

Section 4.2.1 is designed to be sent out to and answered by the paper towel supplier. Section should be answered by the laundries.

Please try to provide us data as detailed as possible.

Paper towel production

Address and contact person paper towel supplier

Address of company:

Contact person(s):

Company

Short description of the company (sites, business areas, types and amount of paper towels sold per year etc.).

4.2.1 Input / Output paper towel production

Life Cycle Analysis is an instrument to gain more information on environmental impacts inter alia of products and services. Within specified system boundaries the processes will be analysed from cradle to grave. This Life Cycle Analysis focuses on paper towels made from *virgin luxury paper* and paper towels made from *medium quality 50 % recycling paper*. As there are existing various processes for manufacturing those paper towels it is important to get information as detailed as possible. If only aggregated data for the whole process are available, please provide us the aggregated data. Figure 3 gives you an overview of the aspects of interest for this Life Cycle Assessment.

Please specify the data sources and data quality as follows: 1 / 2 / 3 / 4

(1): year of reference: **199# / 200#**

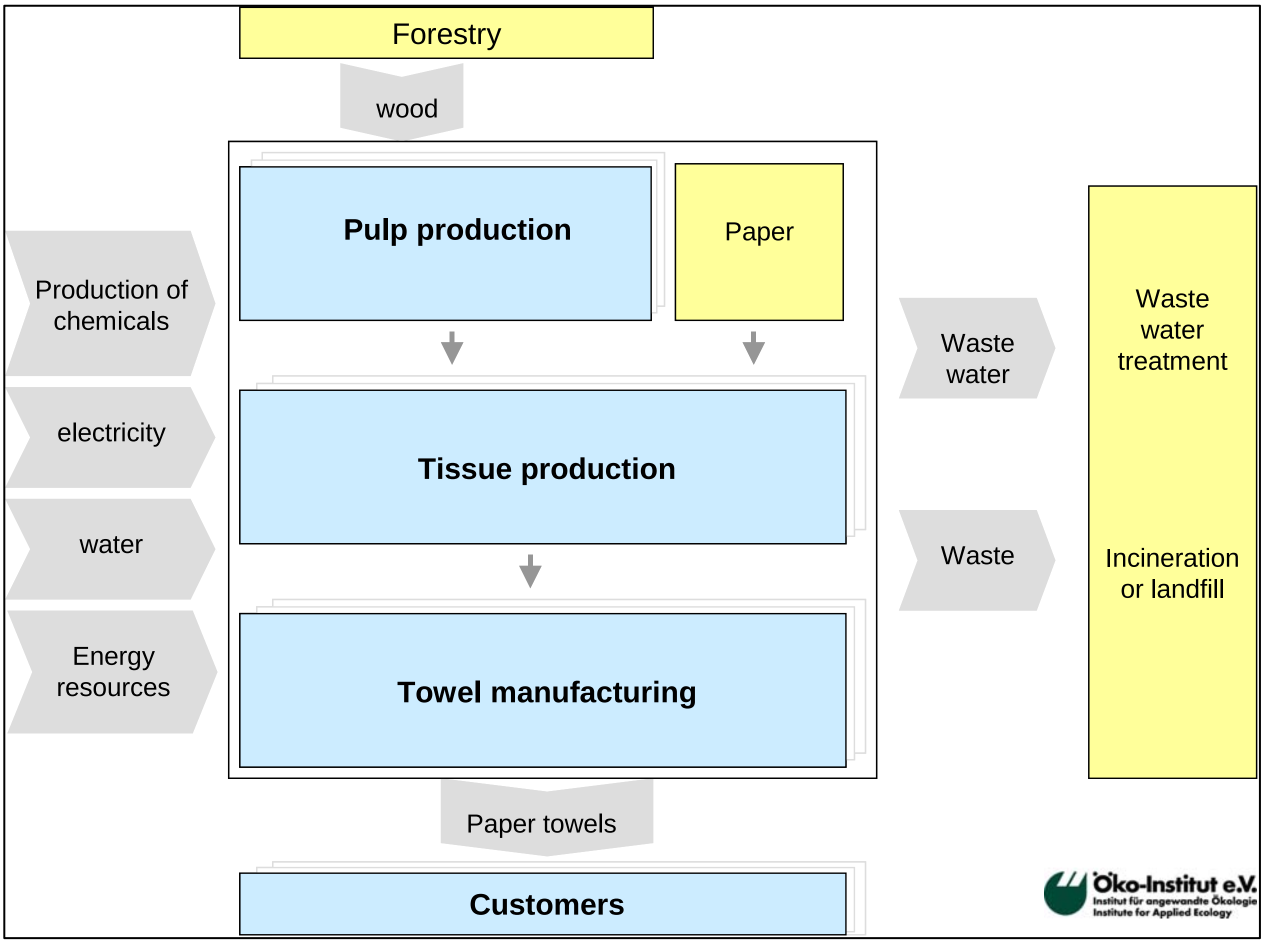
(2): place of reference: in-house (**I**), literature (**L**), other (**O** and specification)

(3): single value (**S**); aggregated value (**A**)

(4): measured (**M**); calculated (**C**); estimated (**E**)

Example: 19,345 kWh_{el} (**2001/I/S/M)**

Figure 3 Paper towel production



4.2.1.1 Pulp production

Please specify to which **amount of pulp** the data refer to and specify data references and quality (see above), e.g. 19,345 kWh_{el} (2001/I/S/M).

Please also indicate the **country / place** where the wood derives from and where the pulp is produced. If wood / pulp from different countries are used for paper towel production please specify for each country.

Input pulp production	
Wood (kg or m^3 / country)	
Energy demand	
Electricity from grid (kWhel)	
Electricity internal production (kWhel)	
Steam internal production (kWhth)	
Energy sources for internal energy production: e.g. coal, natural gas, light fuel oil etc. (specific unit and MJ/unit)	
Materials	
Water (m^3) (please specify origin and treatment before use)	
Chemicals (kg) please specify	

Output pulp production	
Waste water Total amount (m^3) pH-value temperature **Concentrations (mg/l)**: COD AOX BOD-5 Heavy metals (please specify) Chemicals (please specify) Other	
Waste total amount (kg) *specification*: recyclable waste (kg) (please specify treatment) commercial /residential waste for incineration (kg) commercial / residential waste for landfilling (kg) hazardous waste (kg) (please specify treatment)	
Pulp (kg)	

4.2.1.2 Tissue production

Please specify to which **amount of tissue** the data refer to (functional unit) and specify data references and quality (see above), e.g. 19,345 kWh_{el} (2001/I/S/M).

Please also indicate the **country / place** where the tissue production takes place. If tissue production takes place in different countries please specify for each country. Also indicate the country / place where the paper comes from.

Input tissue production	**Virgin luxury paper**	**50 % rec. paper**
Pulp (kg / country)		
Paper (kg / country)		
Energy demand		
Electricity from grid (kWhel)		
Electricity internal production (kWhel)		
Steam internal production (kWhth)		
Energy sources for internal energy production: e.g. coal, natural gas, light fuel oil etc. (specific unit and MJ/unit)		
Materials		
Water (m^3) (please specify origin and treatment before use)		
Chemicals (kg) (please specify)		

Output tissue production	Virgin luxury paper	50 % rec. paper
Waste water Total amount (m^3) (please specify treatment) pH-value temperature **Concentrations (mg/l)**: COD AOX BOD-5 Heavy metals (please specify) Chemicals (please specify) Other		
Waste total amount (kg) *specification*: recyclable waste (kg) (please specify treatment) commercial /residential waste for incineration (kg) commercial / residential waste for landfilling (kg) hazardous waste (kg) (please specify treatment)		
Tissue (kg)		

4.2.1.3 *Paper towel manufacturing*

Please specify to which **amount of paper towels** the data refer to (functional unit) and specify data references and quality (see above), e.g. 19,345 kWh_{el} (2001/I/S/M).

Please also indicate the **country / place** where the paper towel production takes place. If towel production takes place in different countries please specify for each country.

Input paper towel manufacturing	**Virgin luxury paper**	**50 % rec. paper**
Tissue (kg / country)		
Energy demand		
Electricity from grid (kWhel)		
Electricity internal production (kWhel)		
Steam internal production (kWhth)		
Energy sources for internal energy production: e.g. coal, natural gas, light fuel oil etc. (specific unit and MJ/unit)		
Materials		
Water (m^3) (please specify origin and treatment before use)		
Chemicals (kg) (please specify)		

Output paper towel manufacturing	**Virgin luxury paper**	**50 % rec. paper**
Waste water Total amount (m^3) (please specify treatment) pH-value temperature **Concentrations (mg/l)**: AOX BOD-5 COD Heavy metals (please specify) Chemicals (please specify) other		
Waste total amount (kg) *specification*: recyclable waste (kg) (please specify treatment) commercial /residential waste for incineration (kg) commercial / residential waste for landfilling (kg) hazardous waste (kg) (please specify treatment)		
Paper towels (kg and pieces per kg)		

4.2.2 Use stage

4.2.2.1 Distribution

Please specify the distribution of the paper towels by using the following table. For the LCA we need to have data for an average tour (distance, number of customers, number of delivered paper towels, lorry type and utilisation ratio). If you already have this kind of data you can fill in the last line of the table, if you don't have the average data for your laundry please specify for each delivery tour. In the case you organise your delivery tours via storage / distribution centres outside your laundry, please specify in the second table. Again we need average data if you have or the data for each delivery tour to the storage / distribution centre.

Delivery tours to customer

Delivery tours	**Total distance driven [km]**	**Number of customers**	**Total number of paper towels delivered**	**Lorry type [max. weight]**	**Utilisation ratio of lorry [%]**
Tour 1					
Tour 2					
Tour 3					
Average tour					

Delivery tours to storage / distribution centre (if applicable)

Delivery tours to storage centre	**Total distance driven [km]**	**Number of customers**	**Total number of paper towels delivered**	**Lorry type [max. weight]**	**Utilisation ratio of lorry [%]**
Tour 1					
Tour 2					
Tour 3					
Average tour					

4.2.2.2 Use in washroom

Please describe the use of paper towels in the washroom.

Weight (in kg) of one paper towel:

- Virgin luxury paper

- 50 % recycled paper

- Materials of bin liners?
-
-
- Weight of bin liners?
-
-
- How many used paper towels per bin liner?

4.2.2.3 End-of-life treatment

Please describe the treatment of spent paper towels (incineration (%) / landfilling (%) / recycling (%)).

4.3 Other relevant information for paper towel system

7.2 Life cycle inventory of cotton roll production

7.2.1 Cotton fibre production

Table 35 Input / output data of the cotton fibre production

Input				Output		
Item	**Quantity**	**Unit**		**Item**	**Quantity**	**Unit**
Cumulative energy demand (KEA)				emissions (air)		
KEA, fossil total	1.62E+04	kJ		inorganic compounds (a)		
fine chemicals				ammonia (a)	4.00E-03	kg
Fertilizers				carbon dioxide (a)		
K-fertilizer (as K2O)	5.36E-02	kg		carbon dioxide, fossil (a)	1.28E+00	kg
N-fertilizer (as N)	1.67E-01	kg		carbon monoxide (a)	2.08E-04	kg
P-fertilizer (as P2O5)	7.75E-02	kg		dinitrogen monoxide (a)	3.00E-03	kg
Pesticides				nitrogen dioxide (a)	2.46E-03	kg
Pesticides, unspec.	1.00E-02	kg		sulfur dioxide (a)	6.32E-03	kg
other materials				particles (a)	6.04E-04	kg
water, arid area	6.10E+03	kg		VOC (a)		
Resources (r)				VOC (hydrocarbons) (a)	2.92E-04	kg
energy resources (r)				emissions (water)		
crude oil (r)	3.78E-01	kg		emissions (w)		
				inorganic compounds (w)		
				nitrogen compounds (w)		
				nitrogen compounds as N (w)	4.30E-02	kg
				other materials		
				cotton fibre	1.00E+00	kg

7.2.2 Spinning

Table 36 Input / output data of the spinning process

Input			Output		
Item	**Quantity**	**Unit**	**Item**	**Quantity**	**Unit**
other materials			other materials		
cotton fibre	1.10E+00	kg	cotton yarn	1.00E+00	kg
secondary energy			waste		
electric energy	7.67E+03	kJ	waste, unspec.	1.00E-01	kg
heat energy	2.50E+03	kJ			

7.2.3 Sizing

Table 37 Input / output data of the sizing process

Input			Output		
Item	**Quantity**	**Unit**	**Item**	**Quantity**	**Unit**
other materials			other materials		
cotton yarn	1.00E+00	kg	cotton yarn	1.10E+00	kg
running materials					
corn starch	1.00E-01	kg			

7.2.4 Weaving

Table 38 Input / output data of the weaving process

Input			Output		
Item	**Quantity**	**Unit**	**Item**	**Quantity**	**Unit**
other materials			other materials		
cotton yarn	1.10E+00	kg	cotton cloth	1.10E+00	kg
secondary energy					
electric energy	1.52E+04	kJ			
heat energy	1.39E+04	kJ			

7.2.5 De-sizing / scouring /bleaching

Table 39 Input / output data of the desizing / scouring /bleaching process

Input				Output		
Item	**Quantity**	**Unit**		**Item**	**Quantity**	**Unit**
basic chemical materials				emissions (water)		
basic chemical materials, inorg.				emissions (w)		
hydrogen peroxide	4.50E-01	kg		inorganic compounds (w)		
sodium hydroxide	5.50E-02	kg		nitrogen compounds (w)		
other materials				ammonium (w)	1.60E-03	kg
cotton cloth	1.10E+00	kg		nitrogen compounds as N (w)	2.90E-03	kg
secondary energy				phosphorous compounds as P (w)	2.40E-04	kg
electric energy	3.60E+03	kJ		indicator parameter (w)		
heat energy	1.49E+04	kJ		AOX (w)	4.30E-02	kg
Water				BOD-5 (w)	1.51E-01	kg
industrial/drinking water				COD (w)	1.61E-01	kg
water, unspec.	1.62E+02	kg		other materials		
				cotton roll	1.00E+00	kg
				water		
				sewage		
				sewage, unspec.	1.62E+02	kg

7.3 Life cycle inventory of paper towel production

7.3.1 Virgin pulp production

Table 40 Input / output data virgin pulp production

Input				Output		
Item	**Quantity**	**Unit**		**Item**	**Quantity**	**Unit**
basic chemical materials				emissions (air)		
basic chemical materials, inorg.				inorganic compounds (a)		
hydrogen peroxide	1.60E-02	kg		nitrogen oxides, unspec. (a)	1.73E-03	kg
oxygen	1.50E-02	kg		sulfur (a)	2.02E-03	kg
sodium chlorate	3.50E-02	kg		particles (a)	1.63E-03	kg
sodium hydroxide	3.75E-02	kg		emissions (water)		
sulfur dioxide	6.00E-03	kg		emissions (w)		
other materials				inorganic compounds (w)		
calcium oxide	7.50E-03	kg		nitrogen compounds (w)		
secondary energy				nitrogen compounds as N (w)	4.50E-04	kg
electric energy	2.52E+03	kJ		phosphorous compounds as P (w)	4.75E-05	kg
heat energy	1.20E+04	kJ		suspended solids (w)	5.10E-03	kg
water				indicator parameter (w)		
industrial/drinking water				AOX (w)	1.00E-03	kg
water, unspec.	7.00E+01	kg		BOD-5 (w)	2.01E-02	kg
wood and woodpulp				COD (w)	4.70E-02	kg
wood				waste		
industrial wood (white fir)	2.00E+00	kg		waste for disposal (wfd)		
				hazardous waste (wfd)	2.00E-04	kg
				sewage sludge (wfd)	1.00E-02	kg
				waste for reuse (wfr)		
				ashes and slags (wfr)	2.30E-02	kg
				waste, unspec. (wfr)	1.10E-02	kg
				water		
				sewage		
				sewage, unspec.	7.00E+01	kg
				wood and woodpulp		
				wood pulp		
				pulp (softwood), unspec.	1.00E+00	kg

7.3.2 Virgin tissue production

Table 41 Input / output data virgin tissue production

Input				Output		
Item	**Quantity**	**Unit**		**Item**	**Quantity**	**Unit**
other materials				emissions (air)		
running materials				inorganic compounds (a)		
corn starch	1.50E-02	kg		carbon dioxide (a)		
UF resin	4.00E-02	kg		carbon dioxide, fossil (a)	1.05E+00	kg
secondary energy				nitrogen oxides, unspec. (a)	2.75E-03	kg
electric energy	5.40E+03	kJ		sulfur dioxide (a)	5.04E-03	kg
fuels, gaseous				water vapor (a)	1.00E+00	kg
natural gas (kJ)	1.50E+04	kJ		emissions (water)		
water				emissions (w)		
industrial/drinking water				inorganic compounds (w)		
water, unspec.	5.35E+01	kg		nitrogen compounds (w)		
wood and woodpulp				nitrogen compounds as N (w)	5.25E-05	kg
wood pulp				phosphorous compounds as P (w)	1.55E-05	kg
pulp (softwood), unspec.	1.02E+00	kg		suspended solids (w)	2.00E-03	kg
				indicator parameter (w)		
				AOX (w)	1.00E-05	kg
				BOD-5 (w)	1.50E-03	kg
				COD (w)	4.00E-03	kg
				other materials		
				tissue	1.00E+00	kg
				waste		
				waste for disposal (wfd)		
				sewage sludge (wfd)	2.50E-02	kg
				water		
				sewage		
				sewage, unspec.	5.30E+01	kg

7.3.3 Recycled tissue production

Table 42 Input / output data recycled tissue production

Input				Output		
Item	**Quantity**	**Unit**		**Item**	**Quantity**	**Unit**
basic chemical materials				emissions (air)		
basic chemical materials, inorg.				inorganic compounds (a)		
hydrogen peroxide	1.50E-02	kg		carbon dioxide (a)		
other materials				carbon dioxide, fossil (a)	1.25E+00	kg
running materials				nitrogen oxides, unspec. (a)	1.15E-03	kg
corn starch	1.50E-02	kg		sulfur dioxide (a)	5.03E-03	kg
UF resin	4.00E-02	kg		water vapor (a)	1.00E+00	kg
secondary energy				emissions (water)		
electric energy	5.76E+03	kJ		emissions (w)		
fuels, gaseous				inorganic compounds (w)		
natural gas (kJ)	1.50E+04	kJ		nitrogen compounds (w)		
water				nitrogen compounds as N (w)	5.25E-05	kg
industrial/drinking water				phosphorous compounds as P (w)	1.55E-05	kg
water, unspec.	5.25E+01	kg		suspended solids (w)	2.00E-03	kg
wood and woodpulp				indicator parameter (w)		
wood pulp				AOX (w)	1.00E-05	kg
pulp (softwood), unspec.	2.20E-01	kg		BOD-5 (w)	1.50E-03	kg
				COD (w)	4.00E-03	kg
				other materials		
				tissue	1.00E+00	kg
				waste		
				waste for disposal (wfd)		
				waste for incineration (wfd)	8.25E-02	kg
				water		
				sewage		
				sewage, unspec.	5.25E+01	kg

7.4 Life cycle inventory of the cotton roll system

7.4.1 Gross values

available on CD ROM (CRT_gross.xls)

7.4.2 Credits items

Table 43 LCI data for the credit items of the cotton roll system

available on CD ROM (CRT_credit.xls)

7.5 Life cycle inventory of the paper towel system

7.5.1 Gross values of the VLP system

available on CD ROM (VLP_gross.xls)

7.5.2 Credits items of the VLP system

available on CD ROM (VLP_credit.xls)

7.5.3 Gross values of the RCF system

available on CD ROM (RCF_gross.xls)

7.5.4 Credits items of the RCF system

available on CD ROM (RCF_ credit.xls)

7.6 Characterisation Factors

7.6.1 Global Warming Potential

available on CD ROM (Annex 7.6_CF.pdf)

7.6.2 Acidification Potential

available on CD ROM (Annex 7.6_CF.pdf)

7.6.3 Eutrophication Potential

available on CD ROM (Annex 7.6_CF.pdf)

7.6.4 Photochemical Ozone Creation Potential

available on CD ROM (Annex 7.6_CF.pdf)

7.6.5 Aquatic Toxicity Potential

In the following table (Table 44) the CML 1992 classification factors and removal rates for primary and secondary/tertiary treatment in sewage plants for different chemicals which are used in detergents and as auxiliaries in the washing process are listed. These parameters form part of the verbal-argumentative assessment of the aquatic toxicity (section 4.2).

Table 44 Aquatic eco-toxicity of chemicals through waste water treatment: CML 1992 characterisation factors and removal in standard waste water treatment (supplemented according to Eberle et al. in preparation)

Ingredient name	**Characterisation Factor (m^3 polluted water per kg)**	**Removal Rate (%) (Primary treatment)**	**Removal Rate (%) (Sec/Tert treatment)**
Alcohol (C13) ethoxylate, *EO < 5 (EO3)*	0.0056	29	97
Alcohol (C13) ethoxylate, *EO > 5 (EO7)*	0.0042	29	97
C13-15 alcohol ethoxylate-propoxylate, 14EO, 4PO	0.0028	29	95
Diethylene-triamine-pentamethylen-phosphonic acid, Na salt	0.00004	60	60
Fluorescer, distyryl-biphenyl type	0.001	55	60
Fluorescer, stilbene type	0.0001	55	60
Hexadecyltrimethylammonium chloride	0.0149	10	90
Hydroxyethylidenediphosphonic acid, sodium-salt	0.00004	60	60
Isopropanol	0.00001	0	87
Methylhydroxyethylcellulose	0.000004	10	25
Nitrilotriacetate, Na-salt	0.000016	0	87
Oleic acid	0.0001	59	95
Pentasodiumtriphosphate	0.000001	5	40-90
Peracetic acid[31] / acetic acid	0.00001	0	95
Phthalimidoperoxyhexanoic acid	0.004	0	84
Polyoxycarboxylic acid, Na-salt	0.000009	20	60
Potassium hydroxide solution	0.00001	0	0
Silicon-based antifoam	0.00021	60	60
Sodium hydroxide solution	0.00001	0	0
Sodium metasilicate-pentahydrate	0.000001	10	20
Sodiumcarbonate	0.000004	10	20
Sodiumdisilicate	0.000001	10	20
Talc soap	0.0001	59	95
Terpinolene	0.138	17.7	95.5
Zeolite P	0.0000057	50	95

[31] In waste water per acetic acid has fully reacted to acetic acid and water. For this reason the factors for acetic acid are given in the table.

7.7 Critical Review Report

Introduction

A review of the Öko-Institut Life Cycle Assessment of hand-drying systems commissioned by the European Textile Service Association (E.T.S.A.) has been carried out by an external panel of experts from FORCE Technology, Denmark and ERM, United Kingdom.

Chairperson of the review panel selected by E.T.S.A. is:

Jeppe Frydendal
M.Sc. in Engineering
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During the review process more informal contacts to the paper industry have also been used to clarify and validate certain aspects related to the paper alternatives.

The review has been carried out according to ISO 14040:1997 as a review by interested parties. The review budget constraints have limited the possibilities to include a wide range of interested parties in the review panel.

The critical review process shall ensure that:

- The methods to carry out the LCA are consistent with this 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 and scope; and
- The study report is transparent and consistent.

The following review procedure has been used:

- The Review Panel got access to the draft LCA report, the confidential annex and requested data for random checks.
- The Review Panel did screen the report and forwarded preliminary comments to the Öko-Institut.
- The Öko-Institut made the final draft LCA report and forwarded it to the review panel.
- Compliance with the ISO 14040 standards was checked and a number of random checks of the data and data quality were performed by the reviewers.
- A draft review report was prepared.
- The draft review report was discussed and Öko-Institut prepared the final LCA report.
- Finally the reviewers prepared the final review report to be included into the LCA report.

Review comments

Goal

Goal and Use

The goals and use of the LCA are clearly defined in accordance with the requirements of the ISO standards.

- To gain more information about hand drying systems (paper towels and textile towel rolls).
- To identify the system with lesser environmental impacts.
- To inform the public on environmental impacts of hand drying systems.
- To use the results for marketing purposes.
- To disclose optimisation potentials of the analysed systems.

Target audience

The intended target audience is also clearly stated.

- Washroom operators.
- Professional laundries.
- Manufactures of cotton rolls and paper towels.
- Laundry detergent manufacturers.
- Environmental policy makers/administrators.
- Interested public in general.
- Organisations representing branches of industry and trade where cotton rolls and paper towels are used.

It is stated in the report that E.T.S.A. intends to use the results of the study for marketing purposes, but that they will not actively publish the LCA report including this critical review. The reviewers recommend that E.T.S.A. in all marketing materials where the results are used includes a reference to the LCA report and furthermore makes it clear to the receiver how a copy of the LCA report including this critical review can be obtained.

Scope

Functional unit

The functional unit of 10,000 hand dryings in Europe representing 20,000 paper towels or 10,000 pulls of cotton rolls is adequate and the function of the two compared product systems is justified to be comparable.

The quantification (2 paper towels vs. 1 pull per hand drying) could be better documented and justified. For instance, one pull of the towel roll per hand drying may be considered as a minimum, and it will not represent the average consumption. Of course, the relative consumption 1 pull per 2 towels might not be too bad as many persons use more than two paper towels. A detailed measurement study would be preferred, but probably it would be too costly in comparison with the study budget. This major assumption is furthermore tested in the sensitivity analysis.

System boundaries

All main stages of the life cycle from raw material acquisition to final disposal have been included in the study. Within each stage processes and materials have been left out, and the cut off criteria to exclude a process/material is stated to be less than 1% of the total mass- and energy balance per process. However, the stated cut off criteria also defines that in total no more than of 5% of the total mass- and energy balance must be excluded.

The cut-off criteria are in line with the goal of the study but by nature it is difficult to document a quantifiable compliance, as the reason for leaving out a process often is lack of data or lack of time to include minor processes. Therefore, cut-offs in the study are not always justified quantitatively, and it is not possible for the reviewer to check compliance. However, looking at the overall picture the reviewers are not concerned by the excluded processes and materials, as they are in line with common practice for similar studies.

Some cut-offs are not clearly stated (e.g. exclusion of enzymes for desizing and spinning oils in cotton spinning). This is probably, because these are regarded as unimportant by the LCA practitioner and far below the cut-off criteria. However, this means less transparency for the target audience.

Figure 2, 3 and 4 are not very detailed and figure 3 and 4 does not in all cases reflect the chosen system boundaries caused by the use of system expansion and allocation rules.

Included data categories and impacts

Many of the impact categories used are from the CML-methodology, which is internationally recognised. Ozone depletion has not been included, which is completely understandable, as it is shown in other studies related to hand drying that this specific environmental impact is not relevant.

Concerning resource consumption and waste generation the following aspects are covered:

- The cumulative energy demand.
- Use of water.
- Generation of waste.

Energy demand is defined as primary net energy, which is in accordance with normal practice in LCA. It is stated that no characterisation steps are undertaken but conversion of e.g. one kg of coal to cumulative energy demand is 'characterisation'.

Use of water is defined as all water flows – including cooling water. Water is a renewable 'local' resource and in some regions there is plenty of water whereas in others there is heavy scarcity. This makes it difficult to aggregate. When using cooling water there is often no real consumption of water, e.g. if water is taken from a nearby river and is emitted downstream (with a higher temperature that could have a local impact on the eco-system – but not an impact on the amount of available water resources). Furthermore, experience show that datasets taken from databases do not always include water for cooling meaning that the calculated consumptions of water are not consistent.

However, in general there is often an interest in the consumption of water, when it comes to the life cycle of textiles, so it is understandable that this 'impact' is included, but it should be taken into account that an alternative with a higher water consumption does not always reflect more environmental problems related to water depletion than the alternative with a lower consumption. This is sufficiently described in the LCA Report.

Generation of waste is not adequately defined. It is not clear:

- If waste is defined as "ultimate waste" after waste handling (e.g. slags and ashes from incineration), or if waste streams for further waste management are included.
- If waste e.g. also includes mine tailings, which is typically not consistently handled in LCA databases.

Obviously, the missing definition and the different ways of including and excluding specific types of waste in the background data may have an impact on the results. The report however states that the waste impact category is dominated by slags and ashes.

Different types of waste are of different concern, when defining waste as a certain amount. One kg of nuclear waste obviously cannot be compared with one kg of cotton waste in terms of relevance, so this impact category cannot be used to support conclusions of which alternative is better environmentally. Like for water the target groups are often interested in waste issues, so including it as an 'impact category' is understandable – but it should be stressed that the figures are not necessarily comparable in respect to relevance. In other words the one with the lowest waste indicator measured as kg of waste could in fact be the worst alternative. This is sufficiently described in the report.

An important aspect concerning the two analysed systems, which is not covered, is the impacts on land use and biodiversity. Use of land in e.g. forestry and for cotton cultivation is probably significant. This exclusion is acceptable, because it is documented and explained in the limitations.

Consumptions of other resources than energy and water are not included as impacts, but anyway for both analysed systems energy related feedstocks and fuels are in similar studies shown to be the most important:

- Wood resources for paper.
- Oil and gas resources for detergents.
- Cotton resources for towel rolls.

Hence, the most important resource consumptions are covered by the cumulative energy demand (CED).

Data quality requirements

ISO 14040 states that when a study is used to support a comparative assertion that is disclosed to the public, the following data quality requirements shall be addressed:

- Time related coverage.
- Geographical coverage.
- Technology coverage.
- Precision, completeness and representativeness of the data.
- Consistency and reproducibility of the methods used throughout the LCA.
- Sources of their data and their representativeness.
- Uncertainty of the information.

This study describes all of the relevant data quality requirements are in accordance with normal practice. As described in the report, the data quality criteria are not always followed, e.g. in relation to time related coverage. However, for the processes of major importance (paper production and laundering) the criterion for time related coverage has been followed.

For all core processes a presentation of the data quality related to the parameters above are included.

The electricity used in the study does not comply with the time related coverage. More recent data for all the outdated data used in this study are available in e.g. ecoinvent and should preferably have been used. However, in the report it is documented that the use of outdated electricity data is a conservative estimate in favour of the paper alternatives. Hence, updating the data would not affect the conclusions.

System expansion and allocation

The ISO-standards allow the use of allocation as well as system expansion. In the study system expansion is as far as possible used to avoid allocation – which is preferred by ISO. However, in the report a number of very different approaches have been used, e.g.:

- Economic allocation is used in cotton cultivation
- Allocation based on physical units (mass) are used e.g. in laundering
- UBA rule on allocation of benefits (avoided production) from incineration has been used for incineration processes
- Consequential system expansion with avoided production of virgin paper towels is used in waste disposal of cotton towel roll
- Loss of fibre quality in recycling of paper fibres

A qualitatively description of the importance/sensitivity of the chosen modelling to show the importance of the allocation/system expansion procedures is preferred. This has been done for the most important situations as the comments below shows:

- The important aspects of the cotton growing process is presented to show which impact categories could be sensitive to the choice of modelling related to cotton fibres.
- The allocation based on physical units (mass) used in laundering were only necessary to use for a single laundry with a combined laundering of towel rolls and workwear. Hence, as described in the report this is not expected to influence the data used for laundering significantly.
- The sensitivity of the UBA-rule in incineration processes is presented in the sensitivity analysis.

Disposing textile towel rolls by cutting them in to pieces and subsequently used as disposable wipers is modelled by crediting the towel roll system with avoided production of virgin paper wipers. However, also the avoided disposal of the paper towels with energy recovery should be included. It the report this is shown to be below the cut-off criteria and thereby the exclusion in the modelling is not in conflict with the ISO standards. The opinion of the reviewers is however, that the modelling preferably should have been included as the data are readily available. Especially because the LCA commissioned by E.T.S.A. can loose credibility in the public every time a bias towards the towel rolls is introduced - even if it is a small bias that may not affect the conclusions.

Method for assessment and interpretation

In accordance with the ISO 14042 standard concerning comparative assertions, no explicit weighting of the impact categories has been carried out. However, the study indirectly uses the number of indicators where one product is better than the other as weighting – especially in relation to interpretation of the sensitivity analysis. This procedure is commonly used, but it can with a strict interpretation of the ISO standard be regarded as in conflict with the basic principles when comparative assertions are made to be presented to the public.

Description of the critical review process

The critical review process has been described in the LCA report as required. In the appendix of this review report a documentation of the review dialogue is furthermore shown.

Inventory

Data

<u>Data documentation</u>

As is often the case in many LCA studies only a limited amount of data is presented in the report due to confidentiality etc. This makes it impossible for the reader to check data aggregation etc. meaning low transparency.

<u>Data verification</u>

During the review process it has not been possible to verify all the data used in the study, as only a few spot checks have been made.

The missing data transparency in the report makes it very difficult to really compare a major part of the data used. Furthermore, the reviewers do not have direct access to the data models in Umberto (the reviewers do not own a licence for this specific tool), which makes it difficult for the reviewers to track down potential errors in data and modelling.

For the textile alternative data on laundering is most important, and for the paper alternative the pulp and paper production is of major importance.

Laundering

As laundering data is of major importance the practitioners were asked for verification of the data obtained. The LCA practitioner states that some verification of the data obtained from the laundries were done – e.g. by comparing the data with calculations of theoretical necessary energy demands.

In the Nordic Swan label criteria for laundry service the following criteria on energy and water have to be met. The principle is that to obtain the ecolabel, you have to be a frontrunner, and it is expected that the criteria is set stricter than the performance of the average laundry.

Laundry consumptions per kg of towel rolls	***Weighted average*** *[E.T.S.A.]*	***Range*** *[E.T.S.A.]*	***Criteria***[32] *[laundries – towel rolls]*
Electricity	0.1 kWh	0.1-0.3 kWh	< 1 kWh
Fuel	4.1 MJ	3.5-12.4 MJ	< 7.2 MJ
water	9.4 litres	6.0-14.0 litres	< 18 litres

A comparison of the reported figures with the ecolabel criteria shows that the weighted average is much lower than the ecolabel criteria. Furthermore, the average E.T.S.A. laundry would score maximum points for the consumption of electricity, fuel and water in the other criteria for the Nordic Swan related to towel roll service[33]. This could give the impression that the stated consumptions are in the low end. However, on the other hand it should be stressed that:

1) The ecolabel criteria with respect to energy and water consumption are not known to be very strict.
2) E.T.S.A. laundries are large laundries that typically have a higher efficiency compared to the average laundry.
3) In the Nordic countries that are covered by the Swan label criteria thermal disinfection at high temperatures is common practice, whereas some E.T.S.A. laundries use a lower temperature in the washing, resulting in a lower consumption of energy.

Based on the data collection and allocation procedures for the laundering processes, the reviewers have no reason to believe that the data for the laundering processes are not representative for E.T.S.A. members.

Paper production

For the present LCA study, the use of data from the BREF documents seems appropriate as they probably represent the best available industrial average data.

Data for virgin pulp production in relation to energy and water parameters seems to be in accordance with figures in the BREF document identified by the reviewers.

[32] Nordic Ecolabelling: Ecolabelling of Laundries, Criteria Document version 1.2.

[33] Nordic Ecolabelling: Swan labelling of Hand Towel Roll Services. Criteria document version 2.1.

In the data concerning virgin pulp production there is an input of wood as well as electricity and heat based on wood. In the typical pulp mill of today, the electricity and heat used at the pulp mill is produced from input of wood. Hence, there is a risk of double counting the energy input. Öko-Institut has ensured the reviewers that energy was not double counted.

Data concerning RCF tissue production has been checked for energy consumption in relation to the BREF values in Table 5.4 on page 235 in the BREF document. This seems to be in accordance with the used data. However, our contacts in the tissue paper industry estimate these values to be too high in relation to the average values of today. The data presented on page 303 of the BREF document should according to the paper industry be more representative for the energy consumption of today.

As explained in the LCA report the data for paper production were improved based on the more recent environmental reports to include the improvements in the paper industry. According to Öko-Institut these up-to-date environmental reports do not support the comment from the paper industry.

The random spot checks of the data consistency and validity carried out by the Review Panel revealed uncertainties and errors that could have had an impact on the overall results and conclusions. The errors found were corrected by Öko-Institut.

Aggregation

Checking the aggregation of data is not possible for the review panel within the time frame of this review. Using professional software like UMBERTO for aggregation is considered to guarantee for avoiding calculation errors in the aggregation step.

Impact assessment

As mentioned previously some of the impact categories are not clearly enough defined and/or covered in a consistent way by the databases and data used. See our review comments related to “Included data categories and impacts” for more details.

Normalisation and weighting

No normalisation and weighting have been carried out, which is in compliance with the ISO standards as the study presents a comparative assertion.

Interpretation

In comparative studies, the equivalency of the systems being compared shall be evaluated before interpreting the results. Systems shall be compared using the same functional unit and equivalent methodological considerations, such as performance, system boundaries, data quality, allocation procedures, decision rules on evaluation inputs and outputs and impact assessment. Any differences between systems regarding these parameters shall be identified and reported.

The reviewers find that the equivalency of the systems could have been presented in a more transparent manner by making a specific table extracting the differences in relation to the above mentioned parameters. It is always difficult to compare two product systems with different characteristics and applying different types of materials and process technologies.

Two important messages are that different allocation procedures have been used, and that the age of the core data for the two systems (laundering and paper production) as a first impression seems to vary a lot in favour of the textile alternative, i.e. new laundering data vs. older data for paper production. However, Öko-Institut has used up-to-date environmental reports to:

1) Justify the use of the average BREF values
2) Update the BREF values to reflect more recent data for paper production

Sensitivity analysis

A number of calculations are made to analyse the sensitivity of different important assumptions. However, the presented sensitivity results do not cover all major assumptions concerning for example best available technologies (BAT) for paper vs. average and worst case textile alternatives. This is only presented in a confidential annex making it not transparent to the reader and could influence the credibility of the conclusions in the public.

Furthermore, all results of the sensitivity analysis are presented separately. Making an analysis showing the combination of all major sensitivities would probably show that it is very difficult to support any a conclusion on which alternative is the best from an environmental point of view.

Conclusion

The LCA presented in the report is based on the guidelines of the ISO standards 14040 series, i.e. methodology, assumptions and limitations of the study are generally sufficiently described. It is the impression of the reviewers that the study is consistent with the reporting requirements and methodology specified in the ISO standards. However, we stress that a review, as is common practice, is not “an approval” of the conclusions of the study. Hence, this was not part of the focus of the review.

The reviewers did find errors in the random spot check procedure. These errors were corrected by Öko-Institut. However, the reviewers did only check a limited amount of the used data, but with main focus on the core processes.

A more detailed sensitivity analysis in the public part of the LCA study would be preferred to increase the transparency of the study and credibility of the results.

Appendix – Review process

In this appendix former review comments that because of corrections and amendments in the report are made obsolete are presented.

Scope

Functional unit

The functional unit of 10,000 hand dryings representing 20,000 paper towels or 10,000 pulls of cotton rolls is adequate and the function of the two compared product systems is justified to be comparable. *The reviewers suggested to include the geographical scope ("in Europe") in the functional unit, which was amended by Öko-Institut.*

Included data categories and impacts

Use of water is defined as all water flows – including cooling water. Water is a renewable 'local' resource and in some regions there is plenty of water whereas in others there is heavy scarcity. This makes it difficult to aggregate. When using cooling water there is often no real consumption of water, e.g. if water is taken from a nearby river and is emitted downstream (with a higher temperature that could have a local impact on the eco-system – but not an impact on the amount of available water resources). Furthermore, experience show that datasets taken from databases do not always include water for cooling meaning that the calculated consumptions of water are not consistent.

However, in general there is often an interest in the consumption of water, when it comes to the life cycle of textiles, so it is understandable that this 'impact' is included, but it should be taken into account that an alternative with a higher water consumption does not always reflect more environmental problems related to water depletion than the alternative with a lower consumption. A qualification would be useful.

Based on the review comment on water consumption Öko-Institut included comments in the report making the above aspects much more transparent to the reader.

Generation of waste is not adequately defined. It is not clear:

- If waste is defined as "ultimate waste" after waste handling (e.g. slags and ashes from incineration), or if waste streams for further waste management are included.
- If waste e.g. also includes mine tailings, which is typically not consistently handled in LCA databases.

Obviously, the missing definition and the different ways of including and excluding specific types of waste in the background data may have an impact on the results. Furthermore, different types of waste are of different concern, when defining waste as a certain amount. One kg of nuclear waste obviously cannot be compared with one kg of cotton waste in terms of relevance, so this impact category cannot be used to support conclusions of which alternative is better environmentally. Like for water the target groups are often interested in waste issues, so including it as an ‘impact category’ is understandable – but it should be stressed that the figures are not necessarily comparable in respect to relevance. In other words the one with the lowest waste indicator measured as kg of waste could in fact be the worst alternative. A qualitative explanation would be useful.

Based on the review comment on waste generation Öko-Institut included comments in the report making the above aspects more transparent to the reader. Furthermore, they included a comment telling the reader which waste fraction were dominating the waste generation impact category.

Data quality requirements

ISO 14040 states that when a study is used to support a comparative assertion that is disclosed to the public, the following data quality requirements shall be addressed:

- Time related coverage.
- Geographical coverage.
- Technology coverage.
- Precision, completeness and representativeness of the data.
- Consistency and reproducibility of the methods used throughout the LCA.
- Sources of their data and their representativeness.
- Uncertainty of the information.

This study only describes the first three explicitly. Excluding the others should be justified.

The data quality requirements for the first three aspects are in accordance with normal practice. As described in the report, the data quality criteria are not always followed, e.g. in relation to time related coverage. However, for the processes of major importance (paper production and laundering) the criterion for time related coverage has been followed.

Based on the comments from the reviewers, data quality requirements for the other aspects as well have been included. For the core processes a description of these aspects has furthermore been included in the report.

Early in the process the reviewers noted that the electricity used in the study does not comply with the time related coverage. Based on this a footnote was made to justify the use of UCTPE electricity instead of UCTE. More recent data for all the outdated data used in this study are available in ecoinvent and could be used even though the practitioner stated that ecoinvent is not compatible with Umberto. IFU who develops Umberto have participated in the development of the data format for ecoinvent and have implemented the databases. In the current report there is also a reference to ecoinvent (pp 70). Thus the data is available and should be used in order to facilitate a consistent methodology.

According to the LCA practitioner, in the used version 4.3 of Umberto, ecoinvent data were not matched with the Umberto materials. The practitioners' state that they consider the use of data from the Umberto database as consistent modelling.

System expansion and allocation

The ISO-standards allow the use of allocation as well as system expansion. In the study, a number of very different approaches have been used, e.g.:

- Economic allocation is used in cotton cultivation
- Allocation based on physical units (mass) are used e.g. in laundering
- UBA rule on allocation of benefits (avoided production) from incineration has been used for incineration processes
- Consequential system expansion with avoided production of virgin paper towels is used in waste disposal of cotton towel roll
- Loss of fibre quality in recycling of paper fibres

The reviewers suggested to define one preferred method more explicitly in the scope and use that as far as possible throughout the study – and furthermore, to make a qualitatively description of the importance/sensitivity of the chosen modelling to show the importance of the allocation/system expansion procedures. Hence, Öko-Institut included a more explicit definition of their preference.

Office paper is used to model the impacts from the "necessary use" of virgin fibres in production of RCF to replace the fibre loss in recycling. Virgin pulp should be used, and as this has a significantly lower impact than virgin office paper the reported results represents an overestimation of the actual impacts. In fact, the results show that partly recycled fibre towels have a higher cumulative energy demand (and contribution to energy-related impact categories) than virgin luxury fibre towels (Figure 12), a finding that is in contradiction to both common sense and generic LCA databases like BUWAL 250. If virgin pulp is used in modelling the production of RCF, the CED and related impact categories will probably decrease by 25% or more, giving a very different basis for the comparison.

Based on this comment, Öko-Institut changed the modelling and used virgin pulp instead of office paper. This changed the results for the partly recycled paper, meaning that for CED RCF has now a better environmental performance than virgin luxury paper.

Looking at the results of the study for the textile alternative, data for the laundering process is of major importance. For the laundries handling other textiles than towel rolls an allocation has been made on the basis of the mass of towel rolls compared to the mass of other products handled at the laundry. This way of allocation is inappropriate for dividing the burdens of the laundry as different types of textiles requires very different amounts of energy, water and detergents. E.g. laundering of mats typically has a very low consumption of water, energy and detergents per kg, compared to textile rolls.

For transparency, it should be stated, what volume of different products (working clothes, mats, towel rolls, linen etc.) is included in the original data for allocation. Based on the lack of transparency, it is not possible for the reviewers to estimate, if the chosen type of allocation is appropriate, but as the laundry data is of high importance for the results, the chosen allocation may have a major impact on the results and conclusions.

A suggestion for a better allocation is to use the allocation principles of the previous Nordic Swan label criteria. Those criteria are, of course, not perfect, but they include considerations in relation to the differences between different types of textiles laundered.

$$E_{rolls} = \frac{3 * KG_{rolls}}{3 * KG_{rools} + 3 * KG_{whitewash} + 2.6 * KG_{workclothe} + 1.6 * KG_{mats}} * \frac{E_{total}}{KG_{rolls}}$$

Where:

E_{rolls} = Energy consumption in kWh/kg for hand towels

KG_{rolls}= Towel process in kg washed towels

$KG_{whitewash}$= Whitewash process in kg whitewash

$KG_{workclothes}$= Work clothes through steam tunnel finish in kg

KG_{mats}= Mat process in kg washed mats

E_{total}= Total energy consumption

Allocation principles previously used in the Nordic Swan label criteria for towel rolls.

Based on this comment, Öko-Institut described the data collection and allocation procedure much more transparent. This elaboration made the above review comment obsolete as the major part of the laundry data were actually collected from either laundries or production lines in laundries only handling towel rolls. Only for a single laundry they had to do allocation *based on the production volumes, but as this laundry mainly handles work wear besides the towel rolls, the allocation is assessed to be realistic or even a conservative estimate in favour of the competing alternatives (paper towels).*

Disposing off textile towel rolls but cutting them in pieces to be used as disposable wipers is modelled by crediting the towel roll system with avoided production of virgin paper wipers. However, also the avoided disposal of the paper towels with energy recovery should be included. If not the textile alternative is favoured.

Afterwards Öko-Institut included a footnote showing that this exclusion is below the cut-off criteria. The opinion from the reviewers is that this modelling preferably should have been included as the data are readily available – and especially because the LCA commissioned by E.T.S.A. can loose credibility in the public every time a bias towards the towel rolls is introduced. However, excluding the modelling is not in conflict with the ISO standard.

Inventory

Data

Data for virgin pulp production in relation to energy parameters seems to be in accordance with figures in the BREF document identified by the reviewers. For water consumption it seems that data is missing in the input in Table 40 in the LCA report. This may influence the result for water consumption as shown later in this review report.

Öko-Institut corrected this error in the final report and results.

In the data concerning virgin pulp production there is an input of wood as well as electricity and heat based on wood. In the typical pulp mill of today, the electricity and heat used at the pulp mill is made from the input of wood. Hence, there is a risk that the energy has been double counted if energy is counted for both the input of wood and the input of power and heat. This needs to be clarified.

Öko-Institut was asked about this, and they ensured the reviewers that energy was not double counted.

Comparing the datasets for virgin tissue production and recycled tissue production presented in the LCA report in Table 41 and 42 respectively, there seems to be some inconsistency. In Table 41 airborne emissions are included e.g. CO_2, NO_x and SO_x (from all fuels – natural gas included), whereas in Table 42 no airborne emissions from fuel combustion are presented. This need to be clarified.

Öko-Institut corrected this error in the final report and results.

Data concerning RCF tissue production has been checked for energy consumption in relation to the BREF values in Table 5.4 on page 235 in the BREF document. This seems to be in accordance with the used values. However, our contacts in the tissue paper industry estimate these values to be too high in relation to the average values of today. The values presented on page 303 of the BREF document should be more representative for the energy consumption of today. Using those data would result in a significant lower consumption of heat and electricity than used in the study. This needs to be checked/verified and discussed in the report.

This has afterwards been discussed with Öko-Institut, who states that up-to-date environmental reports from leading paper manufacturers have been used to verify the average data in the BREF documents. To a large extend the environmental reports verified the data in the BREF document. However, for some aspects (as explained in the LCA report) the data for paper production already were improved based on the more recent environmental reports to include the improvements in the paper industry.

Impact assessment

As mentioned previously some of the impact categories are not clearly enough defined and/or covered in a consistent way by the databases and data used. See our review comments related to "Included data categories and impacts" for more details.

An example of that is the consumption of water, where the uncertainty and inconsistency can be shown with a simple calculation. The calculation is very uncertain and based on a use of 156 litres of water per kWh of electricity (data from Ringhals nuclear power plant in Sweden), but it shows that cooling water from electricity generation can impact the reported figures a lot.

156	Litres/kWh	Data from Ringhals
1,5	kWh/kg tissue production	Data from Table 41
80	Kg tissue/functional unit	Data from Table 2
36	% nuclear power in grid mix	Data from footnote 9
6 740	**Litres/functional unit in tissue production**	

Simple estimate of the amount of cooling water in nuclear power plants related to virgin tissue production for the functional unit.

Furthermore, use of water for virgin pulp production is missing in Table 40 for virgin pulp production. An emission of 70 litres of wastewater per kg pulp means that 70x80x1,02 = **5,700 litres** of water are missing in the production of virgin pulp for the VLP alternative.

Adding these two figures gives an estimated water consumption in the production of VLP per functional unit of more than **12 000 litres** compared to the reported consumption of **7 060 litres** per kg in the production.

Based on this very simple calculation it is the impression that the reported water consumptions are not valid for drawing any conclusions.

As mentioned previously, Öko-Institut corrected the error on water consumption in paper production. Furthermore, they state that 1kWh of electricity in the UMBERTO electricity process has a use of cooling water of only about 19 l/kWh. Taking this into account a similar rough calculation would fit much better with the (new) results. Anyway, the reviewers still believe that LCA databases are often inconsistent when it comes to information about the use of cooling water.

Interpretation

In comparative studies, the equivalency of the systems being compared shall be evaluated before interpreting the results. Systems shall be compared using the same functional unit and equivalent methodological considerations, such as performance, system boundaries, data quality, allocation procedures, decision rules on evaluation inputs and outputs and impact assessment. Any differences between systems regarding these parameters shall be identified and reported.

The reviewers find that the equivalency of the systems could have been presented in a more transparent manner by making a specific table extracting the differences in relation to the above mentioned parameters. It is always difficult to compare two product systems with different characteristics and applying different types of materials and process technologies.

Two important messages are that different allocation procedures have been used, and that the age of the core data for the two systems (laundering and paper production) varies a lot in favour of the textile alternative, i.e. new laundering data vs. older data for paper production.

As mentioned previously this was discussed with Öko-Institut, who has used up-to-date environmental reports from leading paper manufacturers to make the paper data more up-to-date – meaning less bias due to the age difference of the data.

Sensitivity analysis

A number of calculations are made to analyse the sensitivity of different important assumptions. However, the presented sensitivity results do not cover all major assumptions concerning:

- Age difference in data for core processes. (*See comment above*)
- Different allocation procedures.
- Best available technologies (BAT) for paper vs. average and worst case textile alternatives. This is only presented in a confidential annex making it not transparent to the reader and could influence the credibility of the conclusions in the public.

A description of the sensitivity of the allocation procedures was included in the report by Öko-Institut.