Life Cycle Assessment
ENVIRONMENTAL PROFILE OF COTTON AND POLYESTER-COTTON FABRICS

Eija M.Kalliala, and Pertti Nousiainen,
Tampere University of Technology, PO Box 527, 33101 Tampere, Finland, Europe

Abstract

The aim of this study was to increase the knowledge of environmental impact associated with producing fabrics for hotel textile services. The project was carried out in two parts: studies on hotel textiles and on textile services in three major Scandinavian laundering companies. This paper presents the results of the hotel textile study. The environmental impact was studied by applying the main principles of the life cycle assessment (LCA) methodology. Life-cycle assessments provide useful information on the quantities of energy and resources consumed and emissions associated with production systems. The impact assessment is still under development but some scenarios have been made to describe possible local, regional and global environmental consequences of the system under study. The inventory calculations proved that cotton fibre production consumes about 40% less energy than polyester fibre production. Cotton growing requires, however, huge amounts of water: irrigated amounts vary from 7 to 29 tons per kg of raw cotton fibres. Pesticides and fertilizers used in traditional cotton cultivation have ecotoxic effects in contrast to organic cotton cultivation, where natural alternatives to agrochemicals are used. It could also be concluded that 50/50 CO/PES sheets in hotel use have fewer environmental impacts than 100% CO sheets. This is due to the higher durability as well as lower laundering energy requirements of 50/50 CO/PES sheets.

Introduction

The background for this research was the growing ecological awareness of the hotel business in Scandinavia. Major hotel chains have established their own ecological programmes where textiles and their maintenance have an important role.

This project was carried out within two major Scandinavian textile service companies, and within a Finnish textile manufacturing company with a typical continuous wet-process for cotton and polyester-cotton fabrics, in order to increase the knowledge of the environmental impacts associated with producing hotel textiles and servicing hotels with them.

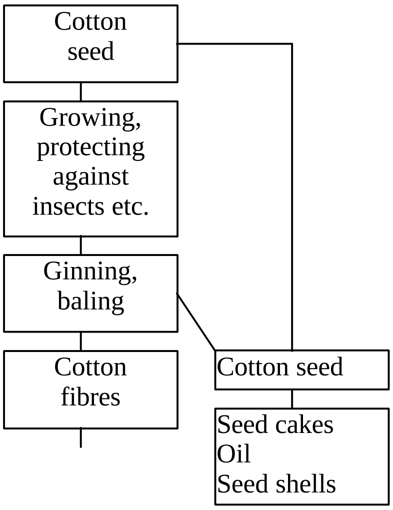
The research was carried out in two parts: studies on fabrics and on textile services (laundering and deliveries).

This paper presents the results of the study on the ecology of different fabrics used as hotel bed linen by rental companies.

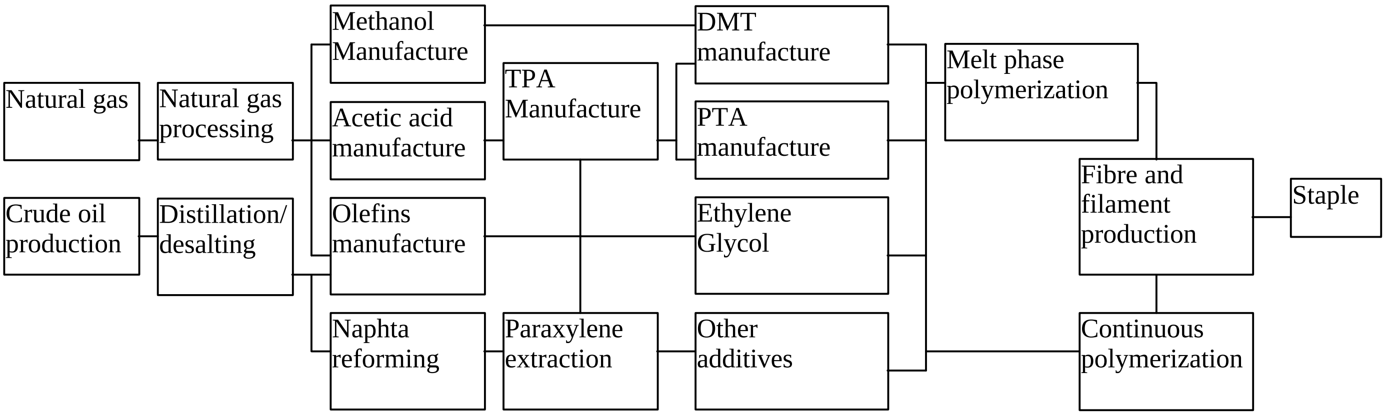
The environmental impacts of textile production and services within this research project were studied by applying the main principles of life-cycle assessment (LCA) methodology contained in the Nordic Guidelines on LCA. The textile production LCA inventory calculations were based on the production process data of one Finnish textile manufacturing company [22]. The available data covered the total manufacturing system. The restricted fibre and textile production processes under study are described in Figure 1.

The product life-time is of major importance within a life-cycle context: products with longer life times require less production energy and resources than less durable ones. The product may, however, be rejected before its physical life-time is over due to visual factors, such as the pilling effect on sheets, or due to changes in fashion trends. The fabric life-time factors were included in the LCA inventory calculations of this study.

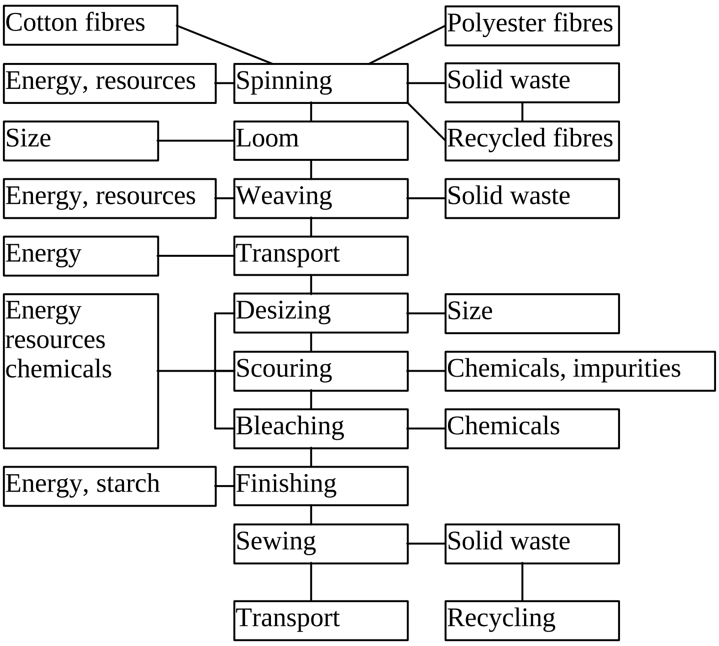
1. Cotton production



2. Polyester production



3. Fabric production



Materials and Methods of the Study

The fibre production data used in the LCA inventory calculations was based on literature from several information sources which enable cross-checking of the data [2, 3, 5, 6, 9, 11, 16, 17, 19]. The fabric production data were, however, based on the Finnish textile manufacturer´s process statistics [21]. The energy, water and process chemical consumptions were based on meter checkings and measurements converted to average values for the year 1996 [21]. Regular waste water analyses are carried out before purifications by communal waste-water plants in Scandinavia, and the values used in this study were averages for the year 1996.
The satin stripe hotel double-sheets and pillow-cases used by the laundries within this study were made of 50/50 CO/PES with a specific mass of 130 g/m^2 - 160 g/m^2. The sheets are of 100% CO plain weave with a specific mass of 155 g/m^2 and of 50/50 CO/PES plain weave with a specific mass of 130 g/m^2. The 100% CO terry-towels were made of twisted yarns with a specific mass of 400 g/m^2.
A selection of fabrics for hotel bed-sets and towel-sets were studied as well as fabrics with some eco-labelling, certificate of organic cotton manufactured and marketed for hotel use. The descriptions of the tested materials within this research project are presented in Table 1. The effects caused by the mechanical fibre quality, such as fibre length and strength, were not included in this study.

Experimental

Laundering

The hotel textiles were divided into normal size (50 kg) washing lots and treated 100 times in normal industrial laundering cycles. The 100% CO sheets, 50/50 CO/PES sheets and terry-towels were washed separately due to the differences in their absorption capacity resulting in different drying energy requirements. The drying energy represents about 70% of the total process energy requirement within hotel laundries [1, 22]. The fabric tear, caused by 100 laundering cycles, was also measured as material losses from the fabrics.

Textile durability

It can be assumed that the life times of bed linen fabrics and terry-towels are several years in hotel use, based on previous studies as well as on the laundry information [15]. It was therefore decided to test the material durability by common laboratory test methods used in fabric quality definitions for textile service companies and laundries.
The textile service companies under this study do not keep statistics on the replacement ratio of hotel textiles. It was, however, possible to use some reports of the Textile Rental Association of America (TRSA) to give a perspective on the life time of sheets and towels in US textile rental companies [20].

The mechanical stress is considerably high on textiles in the washing and ironing procedures. The fabric tensile strength tests were performed before and after 100 washing cycles. The material losses and shrinkage were also measured. The abrasion resistance was measured, as well, in order to simulate the tear and wear in hotel use.
Life times of terry-towels in hotel use appeared to be shorter than of bed-linens fabrics due to heavier soiling and high stealth rate. Terry-towel life times are, on the average, about 44% of the life time of sheets [20].

The LCA calculations

The energy database for the LCA inventory calculations is from the LCA Inventory Tool soft ware created by the Chalmers University of Technology in Sweden [10].
The environmental impacts of different processes and products were evaluated and classified according to the Nordic Guidelines on LCA studies[14]:

Data-gaps

The cotton growing data was partly based on old references due to the lack of more recent studies or information. Cotton growing practices are geographically very variable and thus estimates for average irrigation requirements or use of pesticides are inaccurate.
Complete data from textile chemical production, including raw material production, was not available.
The fabric production waste-water data was only available from the textile plant´s total production. The Finnish textile producer had, as well, not carried out regular COD value measurements of their waste water.
The ecotoxicological effects of mixtures, such as textile chemicals, are incomplete due to the present status of EU directives.

Results

The laundering energy requirements for 100% CO and 50/50 CO/PES fabrics

After pressing processes, the 100% CO materials contained on the average 65% humidity of their dry weight and the CO/PES materials 47% of their dry weight, supporting previous estimates used in waste water calculations.
The moisture content of each bed-linen sample was measured after shake out and two ironing processes. The shake out and ironing times were the same for 100% CO and 50/50 CO/PES materials.
The moisture content after the shake out of 100% CO textiles was on the average 1.2 times higher than of 50/50 CO/PES textiles within the same specific mass category.
It could thus be assumed that 100% CO textiles require on the average 29% more drying energy than 50/50 CO/PES textiles, which results in about 20% higher total laundering energy requirements for 100% CO textiles, than for 50/50 CO/PES textiles.
The test results also showed that higher specific mass and yarn density may cause higher fabric absorption capacity, resulting in significant differences in laundering energy requirements. It should also be noted that the moisture content of sample 4, which was made of non-combed yarns, was at the same level as of samples made of combed yarns with considerably higher specific mass values.
The moisture content of 50/50 CO/PES bed-linen fabrics was between 32 - 50%. The reason may be somewhat different than with 100% CO fabrics. The higher yarn density in the plain weave seemed to be the main factor towards higher humidity contents, rather than the specific mass value of the fabric

Textile durability

The material losses from 100% CO fabrics were on average 1.6% compared to 2.6% of 50/50 CO/PES fabrics. This may be due to internal friction between the hard polyester fibres against the cotton fibres, also causing the pilling effect. All bed-linen fabrics were made of intimate fibre blends.
The abrasion resistance of unwashed fabrics indicates their potential life-times in textile services for hotels. The results showed clearly that the average abrasion resistance of 50/50 CO/PES sheets was at least twice as high as 100% CO sheets within the same specific mass range. The average abrasion resistance of 50/50 CO/PES double-sheets (satin stripe weave) was, however, not significantly different from 100% CO double-sheets most likely due to their high specific mass values.
The tensile strength test results showed, as well, that the potential life-time of 50/50 CO/PES sheets can be twice as long as 100% CO sheets. It was, however, more difficult to make comparisons between the potential life-times of double-sheets, because decrease in their visual quality, such as the pilling effect, may also be a reason for rejection.
The concept “rate-of-use“ was used in this study to define the rental life-times of hotel textiles. Textile durability test results, as well as TRSA statistics, were used in rate-of-use value definitions for alternative textile materials. Hence the rate-of-use of 50/50 CO/PES sheets is 100 rentals (laundering cycles) compared to the 50 rentals of 100% CO sheet materials.
The rate-of-use of all double-sheet materials was assumed to be, on the average, 60 rentals based on the abrasion resistance test results and on the estimates made by the hotel laundries within this study.
The durability of terry-towel materials was tested by measuring the fixation strength of terry loops in the materials before and after 100 washing cycles. These test results gave no relevant indicators for terry-towel durability assessments. The TRSA statistics showed, however, that the average life-time of bath towels and mats (terry) is 44% of the life-time of sheets, including replacements due to permanent soiling or thefts.

LCA Inventory analyses

The LCA inventory calculations include s.c. mass change factors, which describe the gains and losses of process material flows.
The life-cycle inventory calculations were made for different bed-linen and terry-towel materials and for fibre production processes. Fabric life time potential and the number of sheets and towels, reserved for one hotel bed, were accounted into the inventory calculations.
The inventory calculations include energy production and consumption, chemical consumption and emissions to air and water. The emissions to air were based on energy consumption and production only. The emissions to water were based on waste-water analyses of the studied processes.
The inventory calculations for fibres showed that the production of cotton fibres consumes about 40% less energy than the production of polyester fibres, even if feedstock values of non-renewable resources, such as crude oil and natural gas used as polyester raw-materials, are included in the energy consumption. Cotton cultivation requires fossil fuel for agricultural machines, irrigation, ginning and baling as well as on the average huge amounts of water for irrigation. The energy consumption within the production of organic cotton, such as “Green Cotton" was reported to be at the same level as within the production of traditional

cotton, even if pesticides and fertilizers are not used (Table 5.3).
There were no significant differences in energy and resource consumption between 100% CO and 50/50 CO/PES fabric production since both materials were manufactured in the same continuous wet-processes. Material losses, however, in cotton spinning are almost 20% compared to the 2-3% in polyester spinning, mainly due to the better fibre length eveness of polyester fibres.

The LCA impact analyses

Table 6.1 presents LCA impact analyses for different hotel textiles including their durability factors. The production of 100% CO sheets for 100 laundering cycles, requires on average 72% more energy and over 300% more water than the production of 50/50 CO/PES sheets, since two 100% CO fabrics are required to cover the life-time of one 50/50 CO/PES fabric. The cotton growing process consumes more than 99.9% water within the total life-cycle of 100% CO or 50/50 CO/PES fabric production process. The global warming and acidification potentials from 50/50 CO/PES textile fabric production are 38% lower than for the production of two 100% CO sheets due to higher fossil energy consumption in producing two cotton sheets for 100 laundering cycles instead of one CO/PES sheet. The total emissions to water were not defined due to data-gaps in cotton fibre production. Theoretical values (in parentheses) are based on textile production processes only.

Discussion

Cotton versus polyester

The comparison of natural and synthetic fibres is hypothetical since polyester cannot be substituted by cotton and vice versa. These two materials have very different technical, physical and chemical properties and their annual production volumes are so high that it is not possible to compensate one with another. It should, however, be noted that cotton is, in some cases, cultivated in regions with scarce water supplies and, thus, with high requirements for irrigation.
Cotton textile fibres only account for one third of the total raw cotton yield. The rest consists of by-products, such as cotton seeds, lints and waste. Cotton seeds can be refined to oil or used as cattle feed, and lints are used as raw-materials for viscose fibres. The energy consumption in cotton production with associated emissions was, however, not reduced in the inventory calculations, due to the incomplete data on the rate of use of these by-products in major producer countries, such as in India and in Pakistan. An alternative scenario is presented in table 6.1 converted into a “better-case“ 100% cotton fabric, where it is assumed that one third of energy and water consumption is associated with cotton-seed-oil and linter production.
Cotton growing consumes 1.65 kg CO_2 per 1 kg cotton fibres in photosynthesis, which can be deducted from CO_2 emissions, 4.7 kg, associated with cotton fibre production. This results in 3kg net CO_2 with global warming potential within cotton fibre production.
The increase in fertilizer use in cotton growing to boost the production, causes pollution of surface water as well as of ground-water. The use of phosphate fertilizers causes accumulation of heavy metals, such as cadmium, in soil as well as surface water eutrophication in context with possible leaching [5, 6].
There are globally two disturbing trends in pesticide usage: the continued use of extremely hazardous and highly persistent organochlorine compounds in the developing countries, and the propagation of a new generation of herbicides in the industrialized countries for which current water quality monitoring is inadequate. DDT is still used in India in cotton production and in malaria control.
The total use of pesticides has increased world wide and the fastest growing market is Africa with an estimated growth of 182% between 1980 - 1984 [6]. The pesticide use grew 170% between 1964 - 1985 [6]. The severity and extent of ground water contamination cannot, however, be adequately assessed due to incomplete databases and variations in contaminant concentrations over time with needs for costly, long-time monitoring. The increasing use of pesticides results in a build-up of resistance in pests forcing growers to find new agents. Pesticides also make no distinction between pests and beneficial fauna adding to the quantities of chemicals being developed for plant protection. They may concentrate in food-chains causing poisoning of agricultural workers and wildlife. Pesticides have also been found in high concentrations in breast milk of women living near pesticide intensive cultivation [18]. People exposed to organophosphate cotton defoliants may suffer from fatigue, eye and throat irritation, nausea and diarrhea [18].

However, comprehensive systematically collected data on the residue from auxiliaries and their production resources are not available [5].
The production of organic cotton, based on principles of sustainable development, should be strongly encouraged. The production volumes are however so low at the moment that organic cotton cannot yet be regarded as a relevant substitute for basic cotton. The use of genetic manipulation has been introduced to build up natural resistance against pests and other diseases in cotton plants.
Polyester production requires non-renewable resources, such as fossil raw materials, resulting in on the

average 63% higher energy consumption than the production of cotton per 1 kg fibres (table 5.3). The processes involved are exclusively the domain of various companies and no detailed information is available. It is however known that antimony is used as a process catalyst during the production of PES from dimethyl terephtalate [5].Catalysts and stabilisers remain within the synthetic fibres. Water use in polyester production is less than 0.1% of the amount of water required in cotton growing.
Polyester is used for hotel textiles in blends to increase the fabric durability. Polyester also decreases the laundering energy requirements due to the hydrophobic nature of polyester fibres.

Product durability - rate of use

Present textile life-cycle assessments do not include the effect of product durability or rate of use. The life times of hotel textiles can be considered to be as long as their physical life times with the exception of terry-towels with high stealth rate and rejection due to permanent soiling. Total environmental impacts of durable products are lower than of less durable ones. The polyester-versus-cotton approach changed dramatically when the textile durability effect was included in the LC inventory calculations: thus the production energy consumption, with related environmental impacts, of 50/50 CO/PES sheets for 100 laundering cycles proved to be 42% lower than of 100% CO sheets. The durability and rate of use effects are recommended to be included in future life-cycle assessments (14) but no guide-lines for calculation methods are introduced within the present ISO standards on life cycle assessments.

Waste management

Rejected hotel textiles are, usually, reused or recycled. The benefits of recycling should be considered, including the impacts from transportation and laundering, as well as energy requirements of involved processes. In most cases reuse of hotel textiles as rugs, fillings etc. will minimize environmental effects as longer rates-of use.
Recycling is better for homogenous materials than for blends due to better after-treatment, such as dyeing. In all cases only mechanical recycling processes are to be considered for hotel textiles since it is not practicable to regain polyester from textile blends.

Textile incineration and associated energy regains would be a better option for non-composing material, such as polyester, than dumping into landfills. Incineration of 50/50 CO/PES produces, on the average, 19.9 MJ/kg energy based on the heat values for pure fibres. Cellulose-polyester blends produce less char when incinerated, and polyester decomposes in lower temperature than pure fibres do [13]. Cellulose, such as cotton, is decomposed when dumped into landfills. The average amount of gas from decomposing material in landfills is 5 - 6m3 / kg including mainly CH4 and CO2 gases. The energy regain of decomposed textiles is, however, considered to be insignificant compared to energy regains from textile incineration [23].
The LCA inventories for processes under study included only amounts of solid waste, such as loose fibres from textile production processes. The amounts of other wastes associated with these processes, such as packaging materials, are not accounted to this study. They should, however, be accounted to the production plant eco-balance.

LCA - characterisation and valuation scenarios

There are at present many alternatives in the characterizations for LCA impact categories. It should, however, be possible to create one aggregated value for each impact category to improve system comparisons. The importance of energy consumption should also be emphasized as a major contributor to emissions to air affecting global warming, photo-oxidant formation and acidification. A quite recent report shows that the average global temperature has risen 0.3 - 0.6 °C over the past century causing climatic variability or the frequency of extreme events [7]. Key greenhouse gases, such as CO_2 and CH_4, have lifetimes of more than a decade in the atmosphere. The present eco-labelling for textiles focuses more on emissions into water rather than to energy use. In Scandinavia process waste-water treatments are well advanced reducing for example BOD and nitrogen values by more than 90%. According also to a recent report, effective waste water purifications are the only significant ways to reduce pollution in aquatic systems. From the Scandinavian point-of-view the environmental impacts from energy consumption are more critical.
Human health impacts can be characterized within the LCA context by comparing the emitted volumes with some quality standards and aggregating them to so-called critical volumes as explained in the previous section. These quality standards, however, lack in some cases national or EU definitions, and comparisons can be made to available standards only, such as the Dutch MAC standard for polluted air.
The situation in defining ecotoxicological impacts of chemicals is very complex at present due to incomplete databases. Present EU directives or OECD guidelines are not provided for the toxicity, degradability and bioaccumulation of each component within mixtures, such as some textile auxiliaries. The chemical producers will not publish the contents of their products for very understandable reasons. There is a strong tendency, however, towards the chemical producers to supply complete data on their products. It is

suggested here that the ecotoxicology of auxiliaries should be given as total critical volumes (bioaccumulativity and eco-toxicity) per dose, with out the need to publish chemical contents.

Conclusions

The LCA's were made for cotton, organic cotton and polyester fibres, for 100% CO and for 50/50 CO/PES fabrics, as well as for terry-towel production processes in order to compare their environmental effects. The inventory calculations proved that the production of cotton fibres consumes about 40% less energy than the production of polyester fibres. Cotton growing requires, however, huge amounts of water and, in many cases, cotton is cultivated in regions where the amount of rain is not sufficient and irrigation is needed. The reported irrigation amounts vary from 7 m^3/kg to 29 m^3/kg compared to the approximately 17 l/kg of water consumption in polyester fibre production. The share of useable cotton fibres for textiles is, on the average only 1/3 of the total raw-cotton production. The rest consists of cotton seeds, which can be refined to cotton-seed oil or used as cattle feed, and of lints used for viscose raw-material. Organic cotton cultivation does not require pesticides or fertilizers as traditional cotton production. Natural alternatives are used instead for the same purposes. The ecotoxicologicology of pesticides or their impacts on human health cannot be adequately assessed since systematically collected data are not available. Environmental impacts of common pesticides, herbicides and defoliants have, however, been studied and it can be concluded that the use of such chemicals should be avoided. The long-term use of fertilizers to boost production can cause local eutrophication and nitrate contamination of drinking water as well as permanent increase in soil salinity. Transitions from heavy consumption of harmful cotton growth chemicals towards alternative solutions, such as cultivation of organic cotton or controlled use of transgenic cotton seed, should be strongly encouraged. Cotton growing should also be concentrated in regions where water resources are renewed faster than used. Production amounts of organic cotton are still very low, only 0.03% of the total annual cotton production, and cannot yet be considered as a global alternative.

The fabric LC inventory calculations show that environmental impacts of transportations are very low within a life-cycle context due to large shipment quantities.

There were no remarkable differences between continuous wet-processes for cotton and polyester-cotton fabrics, except in material losses (mostly fibres), which are 20% percent for cotton materials compared to the 2-3% for polyester. These losses include both cut shelvedges and sewing losses which, however, are in general reused or re-cycled as rugs, mats etc. Chlorinated bleaching agents have been replaced by hydrogen peroxide reducing the formation of organochlorine compounds in waste-water. In Scandinavia more than 90% of all phosphorus and BOD as well as more than 50% of total nitrogen compounds are reduced in communal water purification plants. The inventory calculations showed, that the use of fossil resources as raw-materials and in energy production causes high CO_2 emissions into the air, which rapidly increases the global warming potential.

Accurate definitions on ecotoxicological effects of wash and textile chemicals were not possible, due to incomplete data-bases. The rate of use of hotel textiles was defined according to durability tests and available statistics. It can be concluded that the potential life times of 50/50 CO/PES sheets are twice as long as of 100% CO sheets. There were, however, no differences between the potential life times of 100% CO and 50/50 CO/PES double-sheets, which may be rejected for visual reasons before their physical life times are over. The rate-of-use of double-sheets as well as of pillow-cases was assessed to be 60 rentals, compared to the 100 rentals of 50/50 CO/PES sheets and the 50 rentals of 100% CO sheets, based on the test results and on available statistics. It was estimated that the terry-towel life-times in hotel use were the same as of double-sheets and pillow-cases, based on physical test results and available statistics. The laundering and durability tests showed that the use of 50/50 CO/PES sheets has fewer environmental consequences than the use of 100% CO sheets due to their longer life-times and lower drying energy requirements.

References

1. Association of Finnish Laundries: 1996 Annual Report

2. Berger, J 'The World´s Major Fibre Crops; Their Cultivation and Manuring', Centre d´etude de L´Azofe, Suisse, 1969

3. Eco-label Criteria for Textile Products, Phase 2, A Report for the Danish Environmental Protection Agency, 1993, p161

4. Ekholm, R 'Tekokuitu päihittää luonnonkuidun', Tekniikka & Talous, 30.5.1995

5. Enquete Commission of the German Bundestag on the Protection of Humanity and the Environment: Responsibility of the Future, Options for Sustainable Management of Substance Chains and Material Flows; Economica Verlag, p49.

6. Gleick, P H *Water in Crisis*, Oxford University Press, New York - Oxford, 1993

7. Hileman, B 'Climate Observations Substantiate Global warming Models', Environment, C & EN, Nov. 27, 1995

8. Kallіala, E M 'The Ecology of Textiles and Textile Services - A LCA Assessment Study on Best Available Applications and Technologies for Hotel Textile Production and Services', Tampere University Technology Publications 214, 1997, Finland, p117.

9. Kummerer, 'Comparison of Reusable and Disposable Laparatomy Pads', Albert-Ludwigs-Universität Freiburg / Institut fur Umweltsmädizin und Krankenhaushygiene, 1996, p6

10. LCA Inventory Tool 2.0: Chalmers industriteknik, 1996, Sweden

11. Luck, G Von der 'Stoffstromanalyse zum Stoffstrommanagement in der textilen Kette - Ergebnisse der Enquete-Kommission Schutz des Menschen und der Umwelt', *37th International Detergency Conference*, 1996, p 5

12. Noergaard, L 'Green Cotton - LCA' Novotex A/S, 7430 Ikast, Denmark

13. Nousiainen, P 'Chemical flame retardation mechanisms of viscose-polyester fabrics', Technical research centre of Finland (VTT), *Espoo* 1988

14. Nordic Guidelines on Life-cycle Assessment, *Nord* 1995, vol 20, 222 p

15. Salomaa, K Laitostekstiilien pesuominaisuudet ja menetelmät, *TTKK*, 1980, 28 p

16. Sauer, Hildebrandt, Franklin and Hunt 'Resource and Environmental Profile Analysis of Childrens' Diaper systems', *SETAC*, 1994, 6 p.

17. Swedish Society for Nature Conservation, Environmental Criteria for Textiles, 13 p.

18. Swedish Standards Institution: *Textiles and Clothing - Environmental impact of production and criteria for environmental labelling*; report, 1994, 56 p.

19. Thayer, A M 'Betting the transgenic farm', *Chemical & Engineering News*, April 28, 1997; 9 p.

20. 1994 Textile Life Survey; Textile Rental Ass. of America, Hallandale, FL

Interviews and information:

21. Oy Finlayson Ab, Finland - textile production / process data

22. Lindström Oy: - Ms. Kirsti Leisio and Ms. Marjo Mäntylä on textile services

23. VTT, The Technical Research Centre in Finland, Energy Dept Mr. Lassi Hietanen on textile waste management in Finland and Sweden.

Table 1: The fabric qualities
Note! : material weight by measurements - other values by producer information

	Sample nr	Warp	Weft	Warp density	Weft density	Weight	Weave	Quality
		NE/Tex	NE/Tex	1"/10cm	1"/10cm	g/m^2		
100% Cotton sheets	1	18/33	18/33	57/220	52/220	160	plain	combed/bleached
	2	20/30	20/30	60/235	60/235	160	plain	combed/bleached
	3	21/28	21/28	60/235	60/235	155	plain	combed/bleached
	4	24/25	24/25	76/300	62/240	140	plain	organic/not combed/unbl.
	5	30/20	30/20	85/330	74/290	130	plain	organic/not combed/unbl.
100% Cotton double sheets								
	6	30/20	20/30	136/530	65/255	210	satin stripe	combed/bleached
	7	30/20	30/20	85/330	74/290	130	plain	organic/not combed/unbl.
50/50 Cotton/Polyester sheets								
	8	30/20	30/20	80/315	80/315	160	plain	combed/bleached
	9	24/25	24/25	70/270	60/240	130	plain	combed/bleached
50/50 Cotton/Polyester double sheets	11	30/20	15/40	95/362	55/220	160	satin stripe	combed/bleached
	12	30/20	30/20	110/430	70/275	155	satin stripe	combed/bleached
	13	30/20	27/22	81/316	74/291	140	satin stripe	combed/bleached

Table 2
Abrasion resistance and changes in tensile strength values after 100 laundering cycles

		Strength change/ warp	Strength change/ weft	Nr of rubbing cycles	Loss of weigth	Shrinkage warp	Shrinkage weft
100% Cotton sheets							
	1	-10,50%	6,90%	14380	-0,30%	-8,00%	0%
	2	-23,00%	-12,30%	11450	-2,60%	-7,60%	0%
	3	-19,60%	-5,60%	13500	0%	-7,80%	0%
	4	-11,80%	-3,90%	9515	0%	-4,00%	0%
	5	-21,70%	-15,80%	11475	-3,70%	-6%	-1,40%
100% Cotton double sheets							
	6	-10,90%	10,50%	17985	-0,70%	-4,60%	-2,10%
	7	-21,70%	-15,80%	11475	-3,70%	-6,00%	-1,40%
50/50 Cotton/polyester sheets							
	8	-1,20%	-2,70%	>30000	-1,40%	-4,40%	0%
	9	-11,30%	-11,70%	>30000	-1,80%	-5,90%	0%
	10	-15,20%		>30000			
50/50 Cotton/polyester double sheets							
	11	9,10%	5,90%	16750	-2,10%	-2,80%	-3,60%
	12	2,80%	-30,70%	14380	-2,90%	-4,60%	-2,50%
	13	0,30%	0%	19100	-4,60%	-4,10%	0%

Table 3: LCA Inventory Analysis on Fibre Production

	Unit / kg	Polyester	Cotton	Organic
Parameter				
Energy consumption:	**MJ**	**97,4**	**59,8**	**53,6**
Electricity	MJ	15,2	12,1	13
Fossil fuel	MJ	82,2	47,7	40,6
Non-renewable resources:	**kg**	**2,4**	**1,4**	**1,3**
Natural gas	kg	0,36	0,35	0,14
Natural gas, feedstock*	kg	0,29		
Crude oil	kg	0,41	0,53	0,57
Crude oil, feedstock*	kg	0,87		
Coal	kg	0,14	0,52	0,56
Coal, feedstock*	kg	0,37		
LP gas	kg		0,03	0,03
Hydro power (MJel)	**MJ**	**0,4**	**1**	**1**
Natural uranium	**mg**		**14**	**15**
Fertilizers	**g**		**457**	
Pesticides	**g**		**16**	
Water	**kg**	**17,2**	**22200**	**24000**
Emissions to air:				
CO_2	g	2310	4265	3913
CH_4	g	0,1	7,6	6,1
SO_2	g	0,2	4	4
NO_x	g	19,4	22,7	22,7
CH	g	39,5	5	5
CO	g	18,2	16,1	17,2
Emissions to water:			**NK**	**NK**
COD	g	3,2		
BOD	g	1		
Tot-P	g	0		
Tot-N	g	0		
*feedstock values included to the energy consumption values				
NK = not known				

Table 4: LCA Inventory Analysis on fabric production processes, incl. fibre production

		Terry towels	**100% Cotton**	**50/50 CO/PES**
Parameter	**Unit / kg**		**bleached**	**bleached**
Energy consumption:	**MJ**	**98,1**	**99,3**	**115,5**
Electricity	MJ	33,9	34,6	34,6
Fossil fuel	MJ	57,2	59,8	76
Others	MJ	7	4,9	4,9
Non-renewble resources:	**kg**	**2,2**	**2,2**	**2,7**
Natural gas	kg	0,58	0,62	0,59
Natural gas, feedstock*	kg	0	0	0,16
Crude oil	kg	0,65	0,67	0,57
Crude oil, feedstock*	kg	0	0	0,48
Coal	kg	0,9	0,92	0,66
Coal, feedstock*	kg	0	0	0,21
LP gas	kg	0,04	0,04	0,02
Hydro power (MJel)	**MJ**	**5,7**	**5,8**	**5,2**
Natural uranium	**mg**	**54,3**	**55,4**	**45,7**
Fertilizers	**g**	**526**	**537**	**254**
Pesticides	**g**	**18,5**	**18,9**	**8,9**
Water	**kg**	**25600**	**26100**	**12400**
Emissions to air:				
CO2	g	6336	6548	5132
CH4	g	12,4	13	8,2
SO2	g	6,2	6,3	3,9
NOx	g	29,4	30,2	26,8
CH	g	6,8	6,9	25,8
CO	g	27,6	28,2	28
Emissions to water:**				
COD Mn	g	13,4	13,3	13,3
BOD	g	5,1	5,1	5,7
Tot-P	g	0,053	0,052	0,052
Tot-N	g	0,004	0,004	0,002
*Feedstock values included to the energy consumption values				
**100% Cotton values based on fabric production waste water analyses only!				

Table 5: LCA Impact Analyses of alternative textile materials

Impact Category	Unit / kg	Weighting Factor	100% CO terry towels	50/50 CO/PES sheet	50/50 CO/PES double sheet	100% CO sheet	100% CO double sheet	100% CO non-bleached	100% CO organic non-bleac.	Better case of 100% CO sheet	Standard fabric values
Durability Factor			**1**	**1**	**1,67**	**2**	**1,67**	**2**	**2**	**2**	**1**
Energy consumption	**MJ**		**98,1**	**115,5**	**165,8**	**198,6**	**165,8**	**195,2**	**195,2**	**152**	**157**
Non-renewable resources	**kg**		**2,2**	**2,7**	**4,5**	**4,4**	**3,7**	**4,4**	**4,4**	**3,3**	**3,6**
Water consumption	**kg**		**25600**	**12400**	**20780**	**52200**	**43587**	**52200**	**52200**	**34970**	**32300**
Gobal warming potential (CO2)	**kg**		**7,1**	**5,6**	**9,3**	**14,6**	**12,3**	**14,6**	**14,6**	**11**	**10,1**
CO2	kg	1	6,4	5,1	8,5	13	10,9	13	13	9,8	
CH4	kg	62	0,7	0,5	0,8	1,6	1,4	1,6	1,6	1,2	
Acidification potential (SO2)	**g**		**26,8**	**22,3**	**37,9**	**54,9**	**45,8**	**54,9**	**54,9**	**39,5**	**38,8**
SO2	g	1	6,2	3,9	6,5	12,6	10,5	12,6	12,6	9,6	
Nox	g	0,7	20,6	18,8	31,4	42,3	35,3	42,3	42,3	29,9	
Eutrophication:											
BOD	g		5,1	5,7	9,5	10,2	8,5	10,2	10,2	10,2	8
Tot-N	g		0,004	0,002	0,003	0,008	0,007	0,008	0,008	0,008	0,005
Tot-P	g		0,053	0,052	0,087	0,1	0,087	0,1	0,1	0,1	0,08
Oxidant formation:											
Nox	g		29,4	26,8	44,8	60,4	50,4	60,4	60,4	42,8	43,6
CH	g		6,8	25,8	43,1	13,8	11,5	13,8	13,8	10	19,8
CO	g		27,6	28	46,8	56,4	47,1	56,2	56,2	44,2	42,2
Human health impacts:											
CO	g	34,5	952	966	1615	1946	1625	1946	1946	1525	
Nox	g	250	7350	6700	11200	15100	12600	15100	15100	10700	
SO2	g	200	120	780	1300	2520	2100	2520	2520	1912	
CH	g	2	14	52	86	28	23	28	28	20	
Total polluted air m3	**g**		**8439**	**8499**	**14204**	**19599**	**16348**	**19599**	**19599**	**14157**	**14049**
Tot-P	g	5000	265	260	435	500	400	500	500	520	
Phenols	g	200000	22	11	19	44	36	44	44	15	
BOD	g	143	734	815	1359	1459	1216	1459	1459	1459	
COD	g	NK	NK	NK	NK	NK	NK	NK	NK	NK	
Oil	g	5000	40	21	35	80	65	80	80	60	
Total polluted water l	**l**	**?**	**?**	**?**	**?**	**?**	**?**	**?**	**?**	**?**	
Pesticides	**g**		**19**	**9**	**15**	**38**	**32**	**38**	**0**	**25**	**23**
Fertilizers	**g**		**526**	**254**	**424**	**1074**	**897**	**1074**	**0**	**720**	**664**
Ecotoxic volumes of water	**l**		**NK**	**NK**	**NK**	**NK**	**NK**	**NK**	**NK**	**NK**	**NK**
Bioaccumulative substances	**g**		**NK**	**NK**	**NK**	**NK**	**NK**	**NK**	**NK**	**NK**	**NK**

NK = not known