Swerea IVF Report
22194-8

Life cycle assessment of Life Wear® bamboo garments

Sandra Roos

swerea IVF

About Swerea IVF AB

Swerea IVF is a leading Swedish industrial research institute with materials, processes and production systems within manufacturing and product development as key areas. Our aim is to create commercial advantages and strengthen the competitiveness and innovation capacity of our members and customers. Swerea IVF performs research and development work in close cooperation with industry and universities, nationally and internationally.

Our highly qualified personnel (about 150 people) based in Mölndal and Stockholm work in the fields of:

- Working life, environment and energy
- Industrial production methods
- Materials and technology development
- Polymers and textiles
- Business development and efficiency (streamlining).

We work with applied solutions to real industrial needs. Our industry-experienced researchers and consultants are able to deliver the fast and robust results that companies require in order to secure their competitiveness on the market.

Swerea IVF is a member of the Swerea Group, which comprises the Swerea parent company and five research companies with materials science and engineering technology as core activities: Swerea IVF, Swerea KIMAB, Swerea MEFOS, Swerea SICOMP and Swerea SWECAST. Swerea is jointly owned by industry through associations of owners and the Swedish state through RISE Holding AB.

Swerea IVF AB
Box 104
431 22 Mölndal
Telefon 031-706 60 00
Telefax 031-27 61 30
http://www.swereaivf.se

Swerea IVF Report 22194-8

Preface

This report contains the results of a life cycle assessment (LCA) of Life Wear® bamboo garments from Wiges AB. Life Wear® bamboo is a registered trade mark of a bamboo viscose fibre owned by Wiges AB. The studied garments are socks and men's underwear of Life Wear® bamboo, whose environmental performance has been compared with the equivalent cotton garments.

The result and the discussion can only be considered as guidance because of uncertainties and data gaps. The report and the conclusions are not intended for comparisons with competing products, instead the comparison is made of two products from the same supplier.

The life cycle assessment has undergone a critical review by an independent third party. The review report is attached to this report as an appendix.

Table of Content

Summary **4**

1. Introduction **5**
1.1 Background 5
1.2 Objective 6
1.3 General description of life cycle assessment 6
1.3.1 Principles of life cycle assessment 6

2. Method **9**
2.1 Functional unit 9
2.1.1 Functional unit for the socks 9
2.1.2 Functional unit for underwear 10
2.2 System boundaries 11
2.2.1 System boundaries for the life cycle phases 11
2.2.2 System boundaries for environmental aspects 11
2.2.3 Other system boundaries 12
2.3 Data collection and modelling 12
2.3.1 Fibre production 12
2.3.2 Yarn production 16
2.3.3 Knitting 16
2.3.4 Wet treatment 18
2.3.5 Sewing and printing 18
2.3.6 Transports 19
2.3.7 Use and end-of-life 19

3. Results **20**
3.1 Life cycle environmental impact 20
3.1.1 Life cycle environmental impact of socks 22
3.1.2 Life cycle environmental impact of socks 23
3.1.3 Production phase compared to use phase 24
3.1.4 Energy use 25
3.1.5 Toxicity 25

3.2 Environmental impact from fibre production 27
3.3 Sensitivity analysis 27

4. Discussion 30
4.1 Differences in the modelling between the bamboo viscose garments and the cotton garments 30
4.2 Environmental impact in relation to life length 31
4.3 Requirements for environmental labelling 31

5. Conclusion 32

References 33

Appendix 1. Impact assessment categories 36

Appendix 2. Detailed LCA results 38
Global warming potential (CO_2-eq), bamboo viscose socks, per kg 39
Global warming potential (CO_2-eq), cotton socks, per kg 40
Global warming potential (CO_2-eq), bamboo viscose underwear, per kg 41
Global warming potential (CO_2-eq), cotton underwear, per kg 42
Euthrophication (P-eq), bamboo viscose socks, per kg 43
Euthrophication (P-eq), cotton socks, per kg 44
Land use (m^2a), bamboo viscose socks, per kg 45
Land use (m^2a), cotton socks, per kg 46
Water consumption (m^3), bamboo viscose socks, per kg 47
Water consumption (m^3), cotton socks, per kg 48
Primary energy consumption (MJ), bamboo viscose socks, per kg 49
Primary energy consumption (MJ), cotton socks, per kg 50
Ecotoxicity (CTUe), bamboo yarn and cotton yarn, per kg 51

Appendix 3. Environmental label's requirements on regenerated cellulose fibres (in Swedish) 52
Bra Miljövals krav på regenererade fibrer av cellulosa 53
MSRs/EU ecolabels krav på regenererade cellulosafibrer 53
GOTS 54

Appendix 4. Extract about the viscose process from IPPC's Best reference document 56

Appendix 5. Modelling of the processes in the bamboo garment production chain 57

Appendix 6. Review report from Bureau Veritas 58

Summary

The objective of the life cycle assessment reported in this document has been to compare Life Wear® bamboo garments with cotton garments. Life Wear® bamboo is a registered trade mark of a bamboo viscose fibre owned by Wiges AB. The study has been performed partly through an on-site inventory of the Wiges' supply chain, at the different production sites in China. The different production steps in the Life Wear® bamboo life cycle; the bamboo forestry, the pulp production, the viscose production, the yarn spinning, the knitting, the wet treatment and the sewing were visited and inventoried on-site.

It is unusual to be granted access by Chinese companies to perform on-site visits and inventory work, as they did for this case study, so the journey was only enabled through careful preparation. Good relations and trust between suppliers combined with a clear explanation of the objective of the detailed questions about processes were, we think, the key success factors for this case study.

The results from the life cycle assessment give an unambiguous answer to the posed question – the Life Wear® bamboo garments have equal or better environmental performance than the equivalent cotton garments for all the investigated environmental impact categories; global warming potential (GWP), water consumption, land use, toxicity, euthrophication and energy consumption. A comparison was also made between all the different materials that were used in the socks and men's underwear; polyamide, elastane, cotton and bamboo viscose. The synthetic fibres polyamide and elastane dominate the climate, energy and euthrophication impact, while the cotton fibres dominate the toxicity, the water consumption and the land use. The Life Wear® bamboo is a good alternative in all these six categories.

1. Introduction

The total annual turnover of the European textile industry (EU-27) amounts to around 200 billion Euro [EURATEX, 2004]. In 2011, the Swedish consumption of textiles amounted to 80 billion Swedish crowns (around 9 billion Euro), or in average 15-20 kilograms per capita [SNF, 2012].

Today cotton is the dominating material on the Swedish clothes market, while polyester is more common in other parts of Europe. The cultivation of conventional cotton is conjunct to large amounts of water used for irrigation, heavy application of fertilizers and pesticides [Kooistra, 2006] and several ethical concerns are raised of forced labour and child labour around the harvesting [Ander, 2010]. The access to organic cotton is low; in 2009 it constituted only 0.76 % of the total cotton market [Organic Exchange, 2009]. Synthetic fibres such as polyester are being questioned due to the fact that they are in most cases fossil and have a large climate impact [Boustead, 2005]. Previous life cycle assessments performed by Swerea IVF has shown that the fibre choice is the single most important factor for climate change and water consumption [Roos, 2011]. The fibre choice will be important for the future sustainable society, also taking into account the possible competition for arable land between food and fibre production. Thus, the whole textile industry stands before a challenge to find sustainable materials for their products.

According to the Swedish business organisation TEKO, the forecast for 2020 points to that cellulose based textile material will be a fast growing market. Today, cellulose based textile material has a relatively small market share of five million tons per year [TEKO, 2012].

1.1 Background

Life Wear® bamboo is a registered trade mark of a bamboo viscose fibre owned by Wiges AB. All products marketed under the trade name Life Wear® bamboo are certified according to the OEKO-TEX® Standard 100 to ensure that the products do not contain chemical substances that are hazardous for the consumer.

Figure 1. The Life Wear® bamboo trade mark.

This study is performed partly through an on-site inventory of the Wiges' supply chain, at the different production sites in China. The different production steps in the life cycle; the bamboo forestry, the pulp production, the viscose production, the yarn spinning, the knitting, the wet treatment and the sewing were visited and inventoried on-site.

It is unusual to be granted access by Chinese companies as they did for this case study, to perform on-site visits and inventory work, so the journey was only enabled through careful preparation. Good relations and trust between suppliers combined with a clear explanation of the objective of the detailed questions about processes were, we think, the key success factors for this case study. In the study, only relevant environmental aspects are considered.

The study has been made of a specific supply chain and is not intended to be valid as average environmental performance for bamboo viscose products.

1.2 Objective

The objective of the study is to compare the environmental performance of bamboo viscose garments by Wiges with cotton garments by Wiges. The life cycle assessment has thus been performed for the specific supply chain that Wiges represents.

1.3 General description of life cycle assessment

1.3.1 Principles of life cycle assessment

Life cycle assessment (LCA) is a technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave, i.e. from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, to disposal or recycling, see Figure 2. Environmental impacts include emissions to air, water and soil as well as consumption of resources in the form of both energy and material, in the different stages of the life cycle.

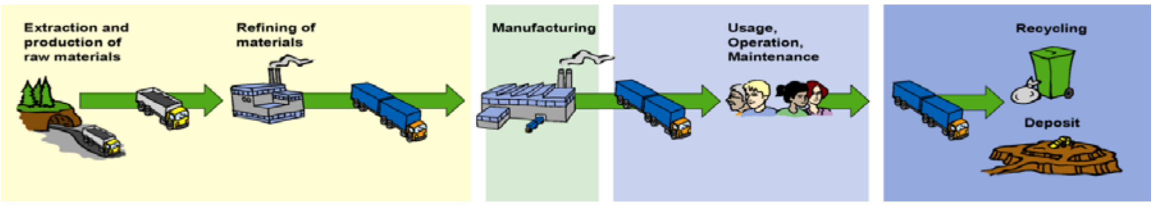


Figure 2. Schematic picture of a product’s different life cycle phases.

The purpose of performing an LCA is to get a fair and comparable evaluation of the environmental performance of a product (both services and goods can be assessed). The life cycle perspective is essential in order to avoid sub-optimization, i.e. that a certain process step or component is optimized, however the whole life cycle of the product does not reach its optimal environmental performance. Sub-optimization can occur when only parts of the life cycle are studied and the overall performance is not evaluated.

To facilitate the comparability of the results of a study, a clear definition of the functional unit used should be made. The functional unit describes the basis for the calculation, e.g. ”transporting one person one km“, or “one year use of a vehicle”.

Another important LCA concept that facilitates comparability is system boundaries. The system boundary describes what has been included in the assessment and not. The study of a transport of one person one km can e.g.

include or not include: the production of the vehicle, the tools used during production of the vehicle, the transports of goods and employees during the production of the vehicle, the production of the fuel, the combustion of the fuel, the infrastructure i.e. roads, gas stations etc., the waste management of the vehicle etc. depending on what is relevant for the specific study. It is important that the setting of the system boundaries follows the same principle when two products are compared with each other.

This life cycle assessment is performed in accordance with International Organisation for Standardization (ISO) 14044 [ISO, 2006] and the International Reference Life Cycle Data System (ILCD) Handbook [EC, 2010]. The ISO 14040 standard implies that the following steps shall be performed when performing an LCA:

1. Goal and scope definition. The goal and scope definition is the first stage of an LCA, where the purpose of the study is described. Also the boundaries of the product system are defined according to factors such as time constraints, data available and depth of study required. At this point a ‘‘functional unit’’ is defined, which provides a reference to which the inputs and outputs of the analysis are related.
2. Inventory analysis. Inventory analysis involves data collection related to the inputs and outputs of the system described in the ‘‘goal scope and definition’’. It inventories quantities of raw materials, waste flows and emissions attributed to the products life cycle.
3. Life cycle impact assessment. Life cycle impact assessment involves associating inventory data with specific environmental impact categories and category indicators, thereby attempting to understand these impacts.
4. Interpretation. Here results are interpreted, summarised and discussed, conclusions are drawn and recommendations made against the initial goals.

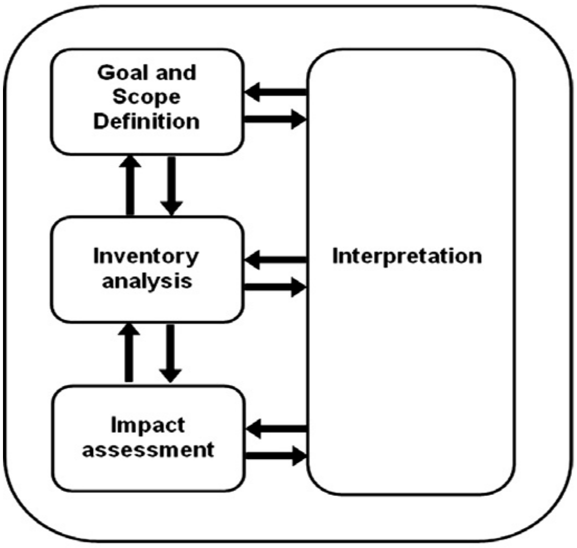


Figure 3. Phases of an LCA.

Figure 3 shows that that there are interactions between interpretation and the other stages as the study is constantly measured against its initial goals and scope and refined during its duration.

2. Method

This life cycle assessment is focused on comparing cotton fibres with bamboo viscose fibres. Data for production of bamboo viscose fibres have been inventoried in the supply chain in China, and then partly been complemented with literature data. Data for production of cotton, polyamide and elastane fibres have been taken from literature.

The processes from yarn spinning to finished garments have been inventoried in the supply chain for bamboo viscose garments. The same processes from yarn spinning to finished garments have then been applied for cotton garments.

Simplified life cycle assessment has been applied, which in principle means that only data from the own manufacturing is inventoried for the study. The remaining data, e.g. the processes performed at subsuppliers, energy sources etc. are not inventoried but instead generic data has been used. Generic data has been taken from existing databases for LCA or in literature and represent European or global averages in general. Data has mainly been drawn from the commonly used commercial LCA database Ecoinvent 2.2 and from Swerea IVF's own database. The LCA software SimaPro 7.3.3.2 has been used for the calculations.

General Programme Instructions for Environmental Product Declarations [EPD, 2008] published by the Swedish Environmental Management Council in 2008 as part of the EPD® system, was used as general guidance for the study.

2.1 Functional unit

2.1.1 Functional unit for the socks

The functional unit used in the study is "one use of one pair of socks". The life length of a pair of socks is assumed to 50 washes for both the bamboo viscose and the cotton version. The real life length is probably much longer and could be more than 150 washes.

The studied bamboo viscose sock is a black tricot sock in 72 % Life Wear® bamboo (bamboo viscose), 27 % polyamide and 1 % elastane, with a weight of 43 grams/pair.

The bamboo viscose sock is compared with an equivalent cotton sock. For the sake of simplicity the same fibre combination is assumed for the cotton sock, that is 72 % cotton, 27 % polyamide and 1 % elastane, with the same weight.

Figure 4. Socks from Wiges.

2.1.2 Functional unit for underwear

The functional unit used in the study is “one use of one pair of underwear”. The life length of a pair of underwear is assumed to 50 washes for both the bamboo viscose and the cotton version. In parallel with the case for the socks above, the real life length is probably much longer and could be more than 150 washes.

The studied bamboo viscose underwear is a black tricot underwear in 93 % Life Wear® bamboo (bamboo viscose) and 7 % elastane, with a weight of 80 grams/pair.

The bamboo viscose underwear is compared with the equivalent underwear in cotton. For the sake of simplicity the same fibre combination is assumed for the cotton sock, that is 93 % cotton and 7 % elastane, with the same weight.

Figure 5. Underwear from Wiges.

2.2 System boundaries

2.2.1 System boundaries for the life cycle phases

The life cycle assessment includes the phases that can differ between the cases where cotton fibres or bamboo viscose fibres are used. Today almost all textiles are incinerated in Sweden [Carlsson et al., 2011], therefore the waste management was excluded. The other life cycle phases are included as Figure 6 illustrates below.

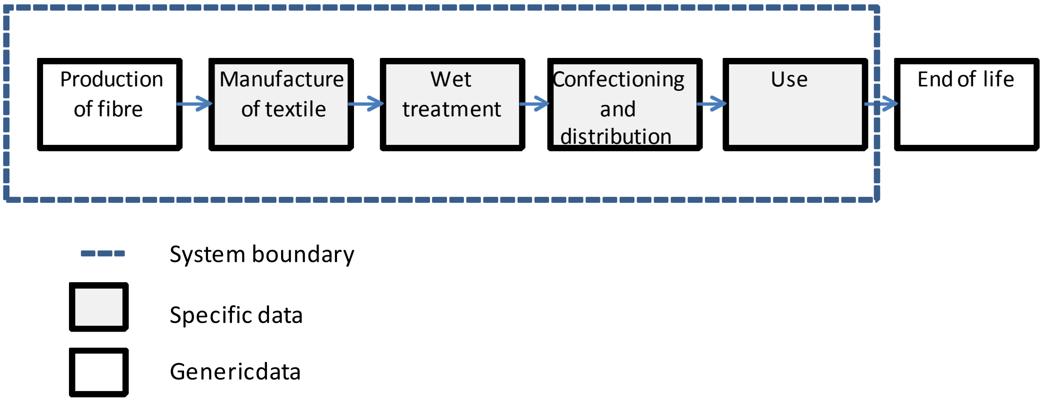


Figure 6. Schematic picture of the system boundaries.

2.2.2 System boundaries for environmental aspects

Textiles are generally associated with environmental impact in terms of energy, water and chemical aspects. For bamboo viscose there are also issues about land use, thus the following aspects were selected for calculations(?):

- Energy:
  - Primary energy consumption (MJ)
  - Global warming potential (CO_2 equivalents)

- Chemicals
    - Euthrophication (phosphor equivalents)
    - Toxicity (CTU[1])
- Land use[2] (m^2a)
- Water consumption (litres)

For the life cycle impact assessment the method ReCiPe Midpoint (H) and world ReCiPe H/H has mainly been used. For primary energy, we followed the Cumulative Energy Demand method as published by Pré Consultants in SimaPro[Hischier, 2009]. For toxicity the UNEP/SETAC consensus model UseTox™ (recommended + interim) [Rosenbaum et al., 2008] was used.

2.2.3 Other system boundaries

In general, neither personnel related impacts, such as travel to and from work, nor infrastructure for the agriculture or textile industry is included. In the case of transports, data from databases where transport infrastructure is included in terms of vehicles and vehicle manufacturing has been used. Transport infrastructure in terms of roads or maintenance is not included.

2.3 Data collection and modelling

The detailed modelling of the bamboo viscose socks and underwear is found in Appendix 5 (only internal).

2.3.1 Fibre production

2.3.1.1 Bamboo forestry

Bamboo is a generic name for around 1250 different species [Scurlock, 2000]. The bamboo used in Wiges’ products, so called Life Wear® bamboo, is cultivated in the Yunnan and Szechuan provinces in China. The inventory in this study was made in the Szechuan province [Supplier A, 2012]. The pulp plant in the Szechuan province buys bamboo from local farmers on an average distance of 50 – 60 kilometres from the factory. Three different bamboo species are cultivated here:

- Dendrocalamus membranaceus munro – “yellow bamboo"
- Neosinocalamus affinis – no English name found
- Sinobambusa intermedia – “cotton bamboo”

Below follows a brief description of the environmental aspects commonly discussed about production of natural fibres, i.e. use of pesticides, synthetic fertilizers, irrigation and biodiversity.

No irrigation, pesticides or fertilizers are applied. The three bamboo species named above have a hard bark that often contains substances that are natural

[1] The result on toxicity is reported as CTU = Comparative Toxic Unit
[2] The result on land use is reported as m^2a, that is square metres times year

toxins and thus protects the bamboo from insects and other plants, for example chlorogenic acid that is also a constituent of the coffee plant [Kweon, 2001]. The bamboo plants also protect themselves by defoliation so their leaves cover the ground to hinder competitive species. These circumstances lead to that very few insects and animals feeding on insects can live in bamboo forests. The bamboo plants grow fast and the stems reach their full height after three years, and after five years a bamboo stem will die by itself if not harvested [Scurlock, 2000]. The fallen leaves and stems will turn into nourishment for new plants, and nutrients are also supplied by the erosion of the forest hillside. Another asset of the bamboo is its ability to bind soil particles and thus prevent further erosion.

Concerning the biodiversity, bamboo forests can be a retreat for the great panda which is currently threatened by extinction. Pandas do however not eat the species present in the inventoried areas but prefer e.g. Bashania fangiana or Fargesia robusta [Reid, 1989].

When the bamboo stem is cut, new sprouts will grow from the cut, and the bamboo forestry process does therefore not contain any planting of new sprouts etc. The crop yield per hectare and year varies between species and the intended use of the material. In scientific literature there is data which states that bamboo forestry will yield around 20 ton material per hectare and year without the use of fertilizers for the edible species Phyllostachys edulis (Moso) [Feng, 2012]. To this could be added a fraction of non edible material of 10 – 15 ton material per hectare and year [Birkeland, 2002]. In other sources data suggests that yields as high as 60 ton material per hectare and year can be expected, but it is not clear if fertilizers were used [De Flander, 2009]. In this study, a value of 30 ton material per hectare and year has been assumed. In addition it is assumed that the land area is a natural forest area and not an agriculture or forest plantation area.

In the specific forest in Szechuan where the bamboo for the Wiges products is grown, the harvesting is alternated from year to year to different parts of the forest. The harvesting is manual and the farmers carry bundles of bamboo stems by hand up to the nearest road. The bundles are picked up by small three or four wheel vehicles and driven to the pulp plant [Supplier A, 2012].

The modelling of the bamboo forestry is found in Appendix 5 (only internal).

2.3.1.2 Pulp production

The bamboo stems are debarked and cooked into pulp (often called paper pulp or dissolving pulp) that is dried before it is transported to the viscose factory. The pulp is produced through the sulphate process, which is cooking in sodium hydroxide and sodium sulphide. This step in the supply chain was not visited on-site but inventoried only through an interview with the general manager of the pulp plant [Supplier A, 2012]. The interview information was then complemented with data from the Ecoinvent database for ”Sulphate pulp, ECF bleached, at plant/RER U” [Hischier, 2007]. ECF is short for Elementary Chlorine Free, which means that the fibre mass has been assumed to be bleached with chlorine dioxide. The process yield of pulp from bamboo material was reported to 35 percent.

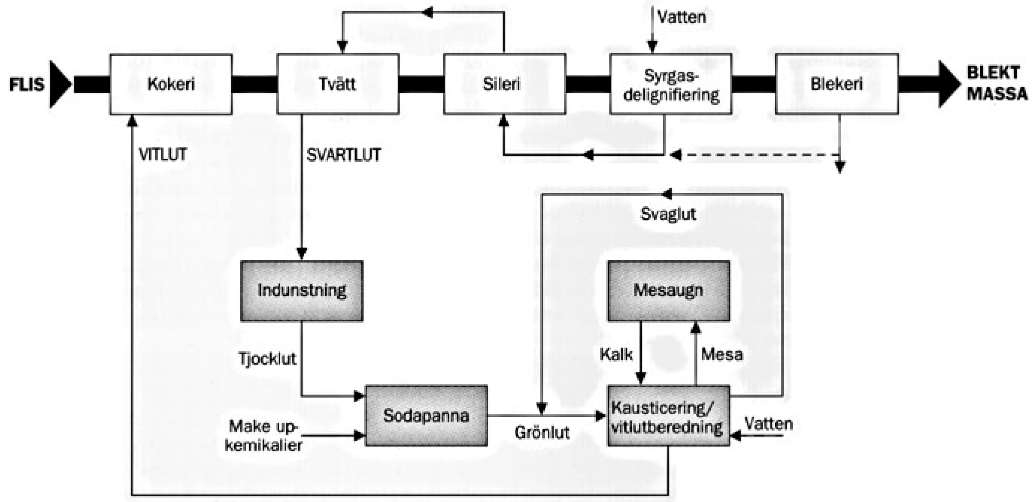


Figure 7. Pulp process, in Swedish, figure from SkogsSverige

2.3.1.3 Viscose production

The Wiges bamboo viscose fibres are produced in a closed process that is mainly identical to a closed viscose process for fibres of spruce or beech. The same apparatus and chemicals are used, but there is one extra mechanical step compared to a general closed viscose process. At the on-site visit the pulp dissolving step, the fibre spinning, the bleach and the fibre drying process were seen. During the visit it was cotton lint viscose that was produced and not bamboo viscose but the processes for cotton lint, bamboo and also hemp were reported to be identical.

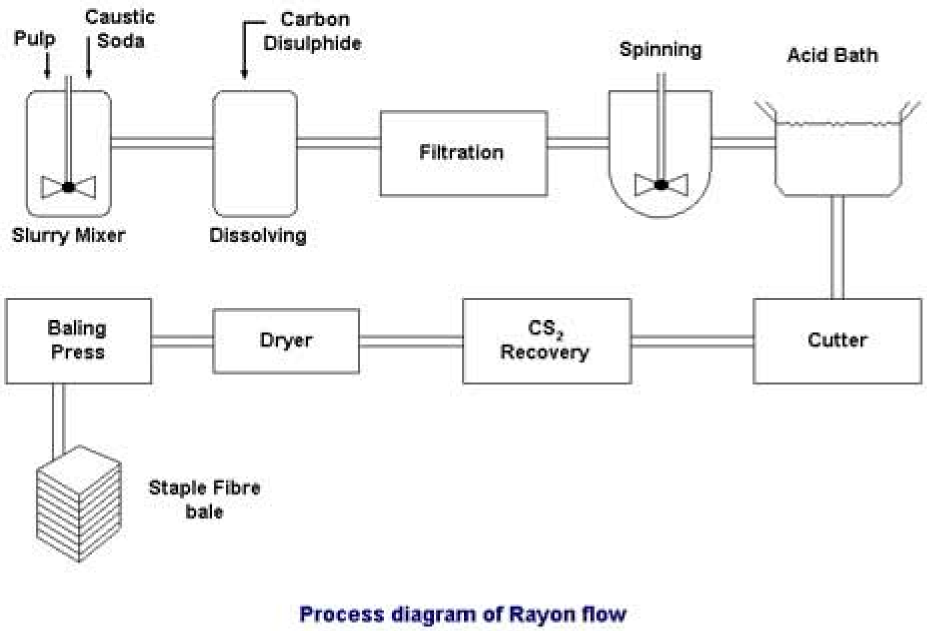


Figure 8. The viscose process, figure from Solvay Plastics.

The most questioned environmental aspects of the viscose process are the use of sodium hydroxide and carbon disulphide. Sodium hydroxide is a strongly basic and corrosive chemical that is used in large amounts and can be a working environment problem. Carbon disulphide is a sulphur containing chemical that is toxic for humans and acidifying for the environment. Wiges' supplier operates the spinning frames in houses and the sulphuric air emissions are oxidised to sulphuric acid, which is regarded as Best Available Technology (BAT) according to the IPPC BREF document [European IPPC Bureau, 2007] (marked in bold letters in Appendix 4). The supplier further adds a flocculent agent (to clump emissions together) to the waste water to precipitate the metals, the translated Chinese name is ”liquid rubber”. Any match with the BREF document processes for waste water treatment could not be made. A notable deviation from what is currently known as BAT was the use of chlorinated substances for the bleach process, which however is still regarded as average technology.

The output from the viscose process is a staple fibre, as can be seen in Figure 8. These are (?) the long filament fibres that are produced from the wet spinning that have been dried and cut into 4 cm long staple fibres and then baled.

2.3.1.4 Bamboo viscose fibres

Table 1 below shows how waste from the different processes described above is modelled.

Table 1. Modelling of bamboo viscose staple fibres, including the process wastes.

Process	**Process name**	**Amount**	**Unit**
Fibre production	Bamboo viscose fibre process	1	kg
Pulp production	Sulphate pulp from bamboo, ECF bleached	1*1.05 = 1.05	kg
Bamboo forestry	Bamboo, harvested manually	1/0.35*1.05 = 3.0	kg

2.3.1.5 Cotton fibres

Conventional cotton cultivation is water and chemical intensive. Cotton cultivation uses just under 2.5 % of the total global agriculture land area and around 11 % of total global agriculture chemicals (an excess factor of 4.4), mostly insecticides and pesticides. Of the insecticides, the cotton farmers represent 25 % of the total global consumption [WWF, 2005]. According to WHO, thousands of deaths and poisoning accidents occur each year as a result of the use of pesticides [Thundiyil, 2008].

The harvesting is often manual [Kooistra, 2006] and in that case the most energy intensive activities in the agriculture are the irrigation and the production of fertilizers. In the ginning process where cotton fibres are separated from the lint, there is also substantial energy consumption [Fimreite, 2009].

Organic cotton cultivation renders around 25-50 % harvest compared to conventional cultivation, which means that around three times larger land use is needed to produce the same amount of cotton [Fibre2Fashion, 2008]. Organic cotton on the other hand does not accept any artificial fertilizers or pesticides. Data from the Ecoinvent database ”Cotton fibres, ginned, at farm/CN S” [Althaus et al., 2007] that represents Chinese cotton cultivation from 2000 is used in the study.

2.3.1.6 Polyamide fibres

Polyamide is a synthetic material also known as nylon. There are two types of polyamide; PA 6 and PA 66. For the Wiges socks PA 6 is used, which is produced from caprolactam and spun to fibres through melt spinning. Data from the IPPC BREF document [European IPPC Bureau, 2003] is used in the study together with complementary data [Fimreite, 2009, EDIPTEX, 2007].

2.3.1.7 Elastane fibres

Elastane is a synthetic material also known as spandex. Elastane is a polyurethane blend, spun to fibres through dry spinning (solvent based spinning). In the study it has been assumed that elastane is 100 % polyurethane, spun with dimethyl acetamide. Data from the IPPC BREF document [European IPPC Bureau, 2003] is used in the study together with complementary data [Fimreite, 2009].

2.3.2 Yarn production

The processes included in the yarn production from staple fibres of the different materials are 1) opening, 2) carding, 3) yarn spinning and 4) twisting.

The yarn production begins with opening of the bales with staple fibres. The fibres are sent into the carding machine where around 0.5 % of synthetic fibres (viscose, elastane, polyamide) and around 8 % of natural fibres (cotton) are sorted out. The waste is probably recycled into isolation etc, but such by-products are excluded from this study as it is not assumed to affect the results.

The bamboo viscose yarn is spun with a technique called “ring spinning” which gives a smooth yarn with good pilling resistance and high strength. Wiges’ supplier has further invested in air extractors for each spin machine to collect the dust. No spinning oils are reported to be used. The data from the supplier of bamboo viscose yarn has been used for both cotton and bamboo viscose yarn [Supplier B, 2012].

For polyamide and elastane yarn, ring spinning is also assumed and for them data from Swerea IVF’s database has been used.

2.3.3 Knitting

2.3.3.1 Knitting tricot for underwear

Knitting of the tricot for the underwear is performed in a knitting machine in the same premises as the sewing factory. The energy consumption for both knitting and sewing (including all auxiliary processes such as lighting, ventilation etc.) were reported as an aggregated figure to on average 30 000 kWh per month [Supplier C, 2012]. Knitting is generally an energy intensive process with an energy consumption of on average 1-2 kWh/kg tricot [Fimreite, 2009].

The factory produces 2-3 million garments per year, i.e. around 200 000 garments per months or around 20 000 kg per month if an average weight of 100 gram per garment is assumed. One third of the total energy consumption was allocated to the knitting machines, i.e. 10 000 kWh per month. This gives an energy consumption of 0.5 kWh/kg, which is on level with literature data.

The consumption of knitting oil is, according to the instruction for the machine, 850 ml per kg tricot. A maximum of 200 drops per minute is assumed to give 200 ml per minute, which gives 200*60/14 = 857 ml per kg tricot. An assumption of 500 ml per kg tricot is assumed based on data from the IPPC BREF document, which states that as much knitting oil as 4-8 % of the tricot's weight is left on the tricot [European IPPC Bureau, 2003]. The knitting oil used at Wiges' supplier is a synthetic and water soluble product based on white oil (paraffin oil).

Table 2 below shows the modelling of the tricot production for the bamboo viscose underwear. For the cotton underwear modelling, the same processes for spinning and knitting are used.

Table 2. Modelling of the tricot underwear production including the process wastes.

Process	**Process name**	**Amount**	**Unit**
Bamboo viscose fibres	Bamboo viscose staple fibres	1.04	kg
Elastane fibres	Elastane staple fibres	0.08	kg
Yarn spinning	Spinning to yarn, bamboo	1.02	kg
Yarn spinning	Spinning to yarn, PES/PA IVF 2012	0.08	kg
Knitting	Knitting bamboo/elastane	1.0	kg

2.3.3.2 Knitting the socks

The socks are knitted in a sock knitting machine and the only sewing is a stitch at the toe. The knitting machine consumes 30 kWh per 24 hours and produces 0.3 kg socks per hour. This gives an energy consumption of 4.15 kWh per kg socks. This is around the double energy consumption compared to general tricot knitting that consumes 1-2 kWh per kg [Fimreite, 2009] but is considered reasonable as the sock knitting is a more complicated process. The sock knitting machine has the positive effect that it avoids waste material in the cutting process.

Table 2 below shows the modelling of the tricot production for the bamboo viscose socks. For the cotton socks modelling, the same processes for spinning and knitting are used.

Table 3. Modelling of the tricot socks production including the process wastes.

Process	**Process name**	**Amount**	**Unit**
Bamboo viscose fibres	Bamboo yarn, black	0.81	kg

Elastane fibres	Elastane yarn, black	0.011	kg
Polyamide fibres	Nylon yarn, black	0.30	kg
Knitting	Knitting bamboo/nylon/elastane	1.0	kg

2.3.4 Wet treatment

The wet treatment is performed in a jet dyeing machine, see Figure 9 below.

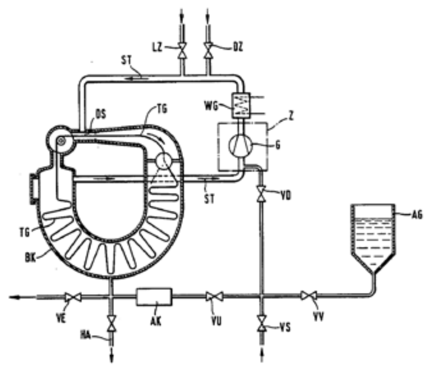


Figure 9. The jet dyeing machine. Picture from United States Patent US4862546

The jet dyeing machine performs pre-treatment, bleaching, dyeing, after-treatment and finishing. The tricot is inserted as a long roll and pushed along inside the tube by a jet of air or water while the liquid flows in the opposite direction. The wet treatment of the black tricot for Wiges' products involves filling up the machine with liquid five times [Supplier D, 2012].

The bamboo viscose is dyed using reactive dyestuffs that are common for cellulose based materials, such as cotton and viscose. Reactive dyeing uses salt (NaCl) as electrolyte to fix the dyestuff on the textile. A dye recipe is commonly based on three different dyestuffs to get a stable result, and in the finishing a softener is added. No other chemicals were reported to be used. For the waste water treatment 99 % efficiency is assumed, i.e. 1 % of the original content in the dye liquor will reach the environment.

For the socks yarn dyeing is assumed, i.e. the wet treatment occurs before the knitting, but in this report all wet treatment is collected in one section for the sake of simplicity. The same assumptions are made for yarn dyeing as for tricot dyeing. For the cotton tricot the same modelling as for bamboo viscose has been used for the dyeing.

2.3.5 Sewing and printing

The confectioning is performed in China and the data is collected from the supplier. In the confectioning the cutting, sewing, printing, ironing, packaging are included as well as all supplementary processes such as personnel premises, lighting, air conditioning, ventilation etc.. An important environmental aspect is the waste material from the cutting, which normally is around 15-20 %. In this study a cutting waste of 15 % has been assumed for the underwear and 1 % for the socks.

The factory produces 2-3 million garments per year, i.e. around 200 000 garments per months or around 20 000 kg per month if an average weight of 100 gram per garment is assumed. The energy consumption for both knitting and sewing (including all auxiliary processes such as lighting, ventilation etc.) were reported as an aggregated figure to on average 30 000 kWh per month [Supplier C, 2012]. One third of the total energy consumption was allocated to the knitting machines which leaves the confectioning with an energy consumption of 20 000 kWh per month. The energy consumption per garment is thus 0.1 kWh per garment. The literature data regarding energy consumption for sewing garments is usually reported in kWh per minute since different garments take very different time to sew, and the average consumption lies around 0.029-0.047 kWh/min. The Wiges underwear takes 10 minutes to sew which gives 0.010 kWh/min including auxiliary processes.

The printing is manually performed by “rubber prints”, blended on-site from printing paste and pigments. No energy consumption is allocated to this process except the general energy consumption for the auxiliary processes, such as light, ventilation etc.

No waste from printing is assumed for other materials such as tricot, thread etc. The garments have no extra washing label, instead the washing instructions are printed directly on the tricot with transfer prints. The paper labels are applied on the garments, which are then packed into cardboard boxes. For the cotton tricot the same modelling as for bamboo viscose has been used for the confectioning.

2.3.6 Transports

The garments are transported from China to Europe by boat. For the transports some rough assumptions have been made about ports, vehicles and distances. As the results show that transports are not an important environmental aspects, these assumptions have not been refined.

No drying agents or biocides to protect against e.g. mould are assumed to be used.

2.3.7 Use and end-of-life

The life length for both the bamboo viscose and the cotton garments are assumed to be 50 washes. This means that the garments are washed in 60 °C after every use and tumbled dry. Data for laundry has been taken from a Swedish study on laundry [Jelse, 2011]. Data for the drying has been taken from the preparatory study for the Ecodesign directive [PricewaterhouseCoopers, 2009]. For bamboo viscose two thirds of the drying energy compared with cotton is assumed in accordance with the findings in a study made by Lenzing AG [Steger, 2012].

After 50 uses the garments are assumed to be worn out and thrown away with the household waste. It is further assumed that the textile fraction will be incinerated together with other household waste in a municipal waste incineration plant.

A sensitivity analysis has also been performed when no tumble dry of the garments is assumed.

3. Results

This chapter reports and interprets the results from the life cycle impact assessment which has been performed in the LCA software SimaPro.

The LCA method ReCiPe, Midpoint (H) V1.06/World ReCiPe H [Goedkoop, 2009] was used to calculate the potential environmental impact in the four categories global warming potential (kg CO_2-equivalents), euthrophication (kg phosphorous equivalents), land use[3] (m^2a) and water consumption (litre).

For toxicity the LCA method UseTox (recommended + interim) [Rosenbaum et al., 2008] was used to calculate human toxicity and ecotoxicity (CTU[4]). For primary energy (MJ), the Cumulative Energy Demand method as published by Pré Consultants in SimaPro was followed [Hischier, 2009].

3.1 Life cycle environmental impact

This section reports the results from the comparison of Wiges' garments of bamboo viscose, so called Life Wear® bamboo, and cotton. Table 4 below summarises the results for the socks for the functional unit of "one use of one pair of socks". One pair of socks weighs 43 grams.

Table 4. Results for socks.

	Bamboo socks (1 use of 1 pair)	Cotton socks (1 use of 1 pair)
Energy (MJ)	0,66	0,81
Global warming potential (gram CO_2-equivalents)	38	46
Euthrophication (gram phosphorous equivalents)	0,024	0,032
Land use[5] (m^2a)	0,0014	0,0073
Water consumption (litre)	0,86	6,7
Toxicity[6] (CTUe), only yarn	0,0019	9,1

[3] The result is reported as m^2a, i.e. square metres and year
[4] The result is reported as CTU = Comparative Toxic Unit
[5] The result is reported as m^2a, i.e. square metres and year
[6] The result is reported as CTU = Comparative Toxic Unit

Table 5 below summarises the results for the underwear for the functional unit of "one use of one pair of underwear". One pair of socks weighs 80 grams.

Table 5. Results for underwear.

	Bamboo underwear (1 use of 1 pair)	Cotton underwear (1 use of 1 pair)
Energy (MJ)	1,2	1,5
Global warming potential (gram CO_2-equivalents)	68	79
Euthrophication (gram phosphorous equivalents)	0,044	0,058
Land use[7] (m^2a)	3,4	17
Water consumption (litre)	1,6	15,6
Toxicity[8] (CTUe), only yarn	0,0007	3,64

[7] The result is reported as m^2a, i.e. square metres and year
[8] The result is reported as CTU = Comparative Toxic Unit

3.1.1 Life cycle environmental impact of socks

The figure below shows the results for potential life cycle environmental impact from the bamboo viscose socks (green bars) compared to the cotton socks (blue bars).

It is clear that the bamboo viscose socks have a lower potential environmental impact in all four categories: global warming potential/climate change (16 %), euthrophication (24 %), land use (80 %) and water consumption (87 %).

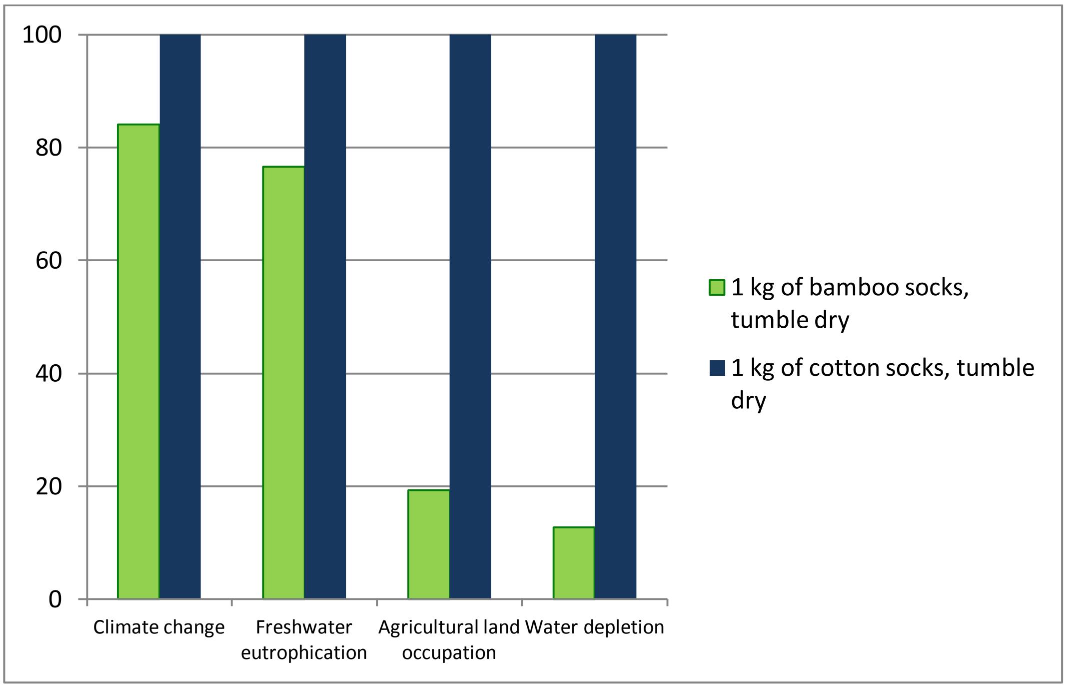


Figure 10. Potential life cycle environmental impact from the bamboo viscose socks (green bars) compared to the cotton socks (blue bars). The numbers are normalised against the maximum value for each category.

3.1.2 Life cycle environmental impact of socks

A very similar picture is received for the underwear, where the bamboo viscose garments have a lower environmental impact in all four categories: global warming potential/climate change (17 %), euthrophication (26 %), land use (81 %) and water consumption (87 %). The figure below illustrates the potential environmental impact for the bamboo viscose underwear (green bars) compared to the cotton underwear (blue bars).

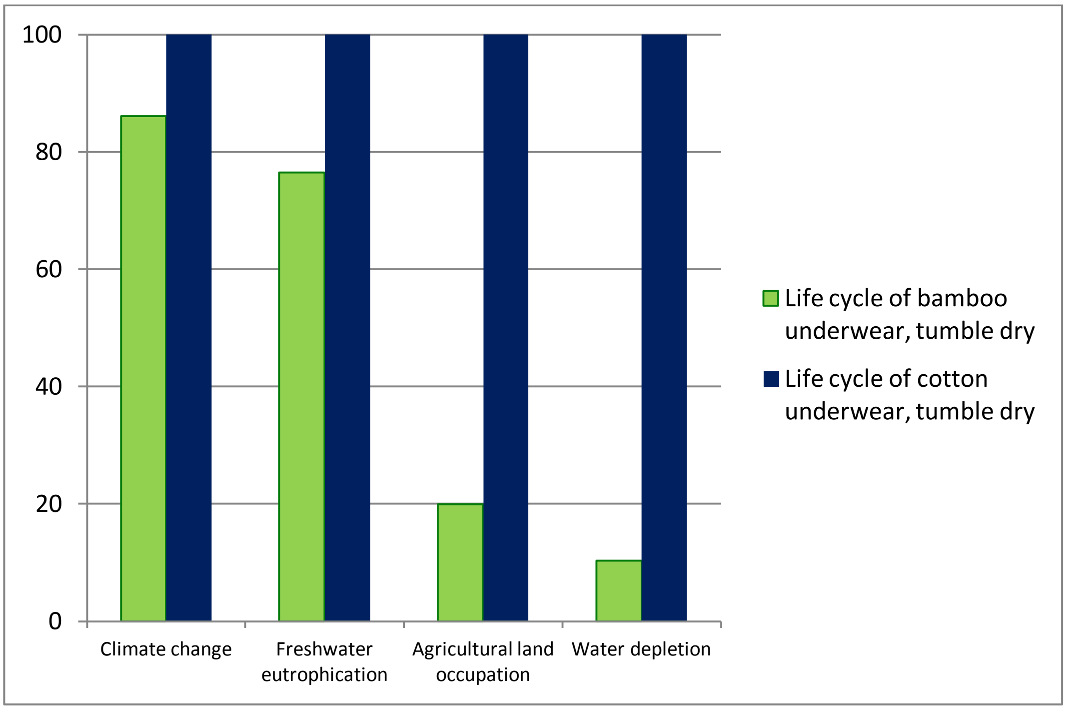


Figure 11. Potential life cycle environmental impact from the bamboo viscose underwear (green bars) compared to the cotton underwear (blue bars). The numbers are normalised against the maximum value for each category.

3.1.3 Production phase compared to use phase

The figure below compares the production phase of the socks with the use phase for both bamboo viscose socks and cotton socks. The global warming potential, euthrophication, land use and water consumption are shown. The global warming potential/climate change, land use and water consumption are largest for the production of the cotton socks (dark blue bars), while the euthrophication is largest for the use phase of the cotton socks (light blue bars).

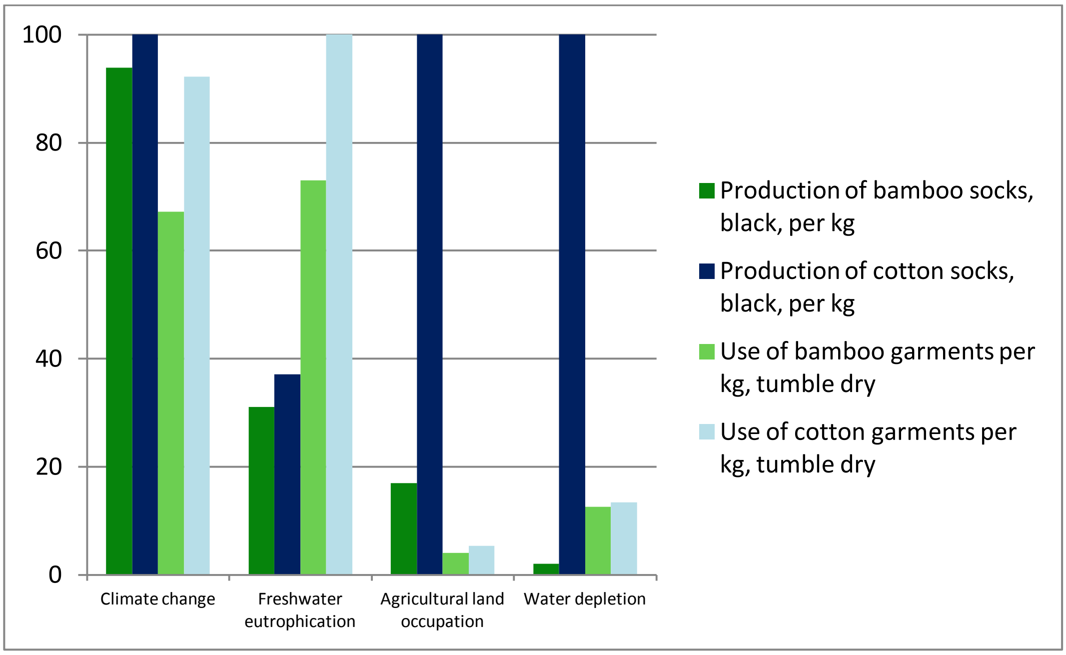


Figure 12. Potential life cycle environmental impact from the production of the bamboo viscose socks (dark green bars), the production of the cotton socks (dark blue bars), the use phase of the bamboo viscose socks (light green bars) and the use phase of the cotton socks (light blue bars). The numbers are normalised against the maximum value for each category.

Please note that the results for the use phase are dependent on the assumption of the difference in the energy consumption for tumble dry for cotton and viscose, see section 2.3.7.

3.1.4 Energy use

For primary energy, the Cumulative Energy Demand method as published by Pré Consultants in SimaPro was followed [Hischier, 2009]. The primary energy is a measure of the total amount of energy retrieved from the nature in the form of different energy carriers (see Appendix 1).

The figure below shows the use of primary energy for the functional unit of "one use of one pair of socks/underwear". The energy is divided into primary energy from renewable resources (green bars) and energy from non renewable resources (red bars) in the diagram. The higher result for the underwear compared to the socks is mainly caused by the higher weight of the underwear.

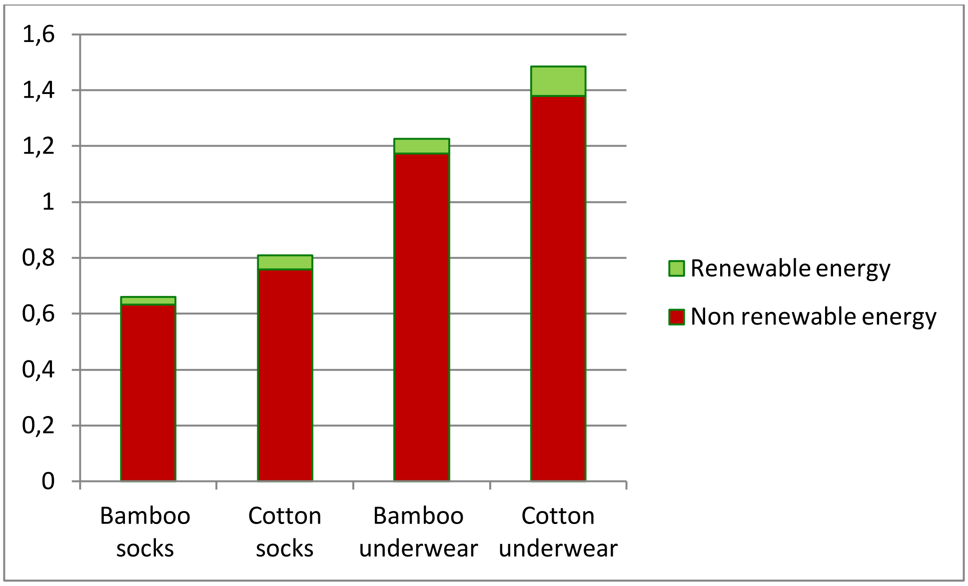


Figure 13. Primary energy use (MJ) for from left to right socks of bamboo viscose, socks of cotton, underwear of bamboo viscose and underwear of cotton.

3.1.5 Toxicity

The impact on health and environment from chemicals in terms of toxicity is difficult to assess with traditional life cycle assessment, see Appendix 1. In brief, to be able to analyse the direct environmental load caused by toxicity in different processes, without indirect load caused by previous choices of e.g. energy sources for the process, these steps need to be analysed separately, thus excluding the impact from the energy consumption. This is done in figure 14 below, where the toxicity impact from the production of dyed yarn (energy use excluded) is shown for black bamboo viscose yarn (green bars) and black cotton yarn (blue bars). The other parts of the life cycle are excluded since they are either the same for both garments of bamboo viscose and garments of cotton, or that the energy consumption is the main environmental aspect.

The result below show a much lower toxicity potential for the three categories human toxicity - carcinogenic, human toxicity - non carcinogenic and ecotoxicity, calculated with the LCA method USEtox (recommended + interim) [Rosenbaum et al., 2008]. The exact numbers are not reported here since they should be used with care due to very large uncertainty in the method. Still, it shows that the toxicity potential from the cotton yarn is much larger than the toxicity potential from the bamboo viscose yarn.

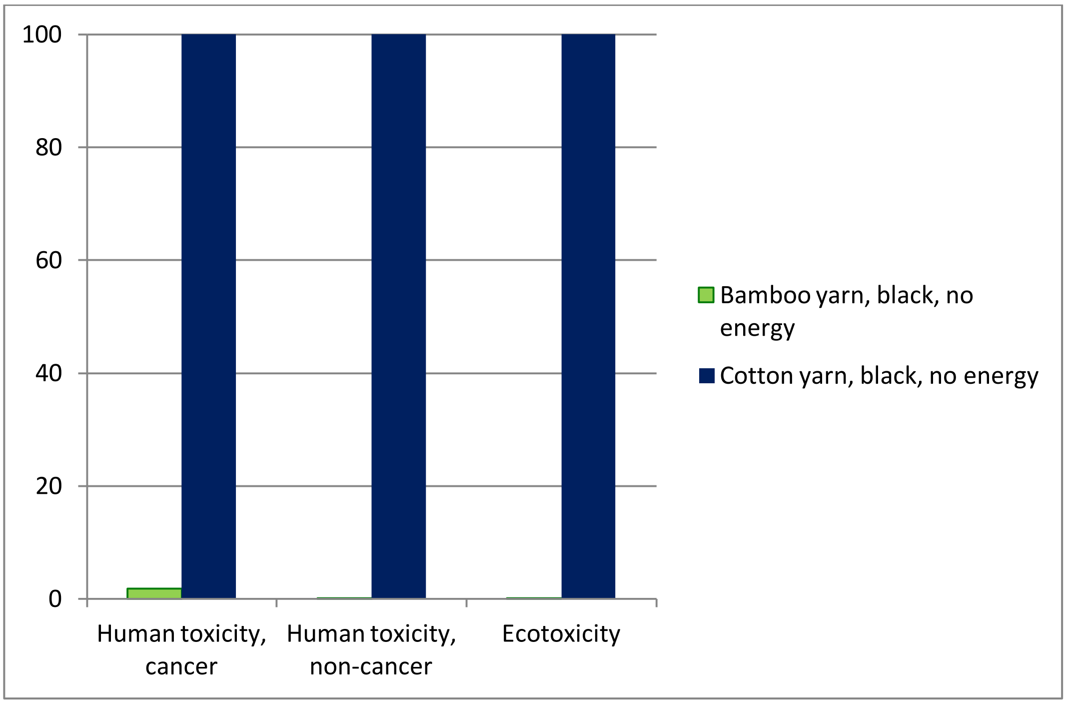


Figure 14. Potential toxicity for dyed yarn of bamboo viscose (green bars) and cotton (blue bars) calculated with USEtox [Rosenbaum et al., 2008]. The numbers are normalised against the maximum value for each category.

In the toxicity scores exposure to chemical substances of the consumer are not included. During the use phase, socks and underwear are worn with direct skin contact, and there is also an exposure to chemicals that are inhaled via textile dust. The release of short fibres and debris from textiles is generally larger for natural fibres such as cotton than for regenerated and synthetic fibres such as viscose and polyester. It is important that substances which pose unacceptable risks for people or the environment do not remain in the finished product; neither consciously added functional chemicals (softeners, dyestuff etc.), remains of process chemicals nor other pollutants.

3.2 Environmental impact from fibre production

Below the potential environmental impact is shown for the different types of fibre (fibre production cradle to gate) for the four categories global warming potential/climate change, euthrophication, land use and water consumption calculated with the LCA method ReCiPe, Midpoint (H) V1.06/World ReCiPe H [Goedkoop, 2009].

It shows that the synthetic fibres elastane (yellow) and polyamide (orange) dominates the global warming potential/climate change and euthrophication while the cotton fibres from China (dark blue) and USA (light blue) dominate the land use and water consumption. The bamboo viscose fibre constitutes a good alternative for all these categories.

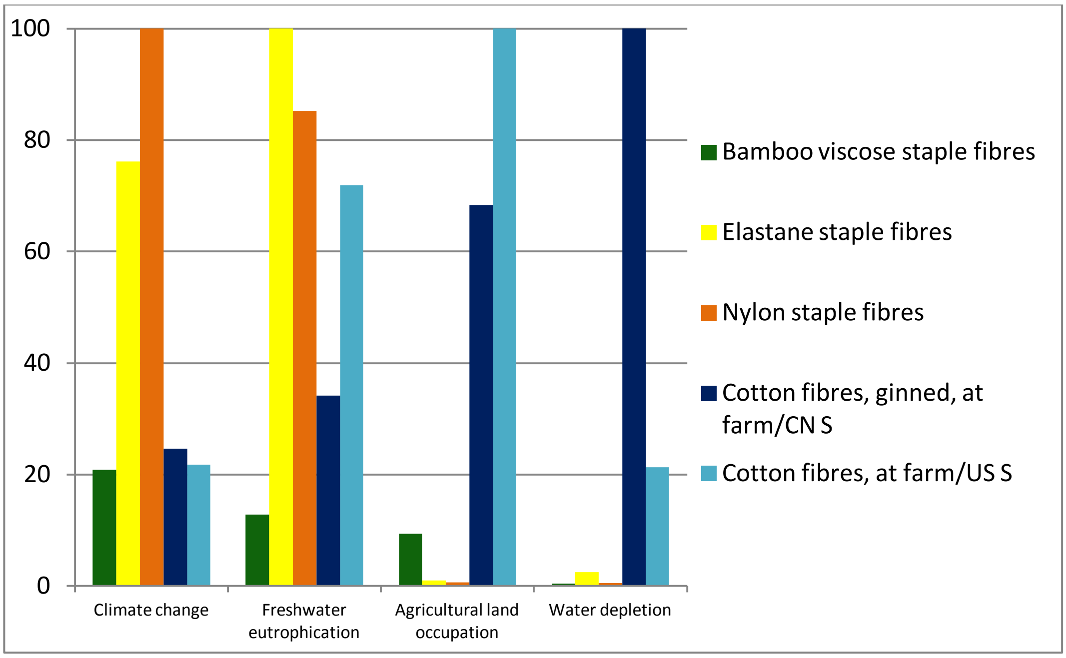


Figure 15. Potential environmental impact from the different fibre types. The numbers are normalised against the maximum value for each category.

The introduction to this report described how the world's demand for textile fibres in the future will not be able to be met by cotton. Figure 15 above shows that bamboo viscose could be a part of the solution for the future fibre shortage.

3.3 Sensitivity analysis

The results above hold a certain amount of uncertainty, due to uncertainties in the data and data gaps. A sensitivity analysis was performed to increase the confidence in the results for the environmental performance of bamboo viscose and cotton garments. The main difference in environmental performance between bamboo viscose and cotton is partly dependent on the processes involved in the fibre production and partly dependent on the energy consumption for the tumble drying, where bamboo viscose presumably demands less energy for drying. All other processes are identical in this modelling.

- **No tumble dry in the use phase**
  In the base scenarios above it is assumed that the garments are tumbled dried after each wash during the use phase. In the first sensitivity scenario it is instead assumed that the garments will be hung to dry to see if this will alter the conclusions.
- **Increased impact from the viscose production**
  The data for the production of the dissolving pulp and the viscose fibre production are the two main processes that differ the bamboo viscose fibre from the cotton fibre. Hence, underestimating the environmental impact from these processes could lead to erroneous conclusions about the environmental performance of garments of bamboo viscose compared to garments of cotton. In the second sensitivity scenario, the environmental impact of the pulp process and the viscose process has been doubled, to show the consequences this will have.

Figure 16 below shows the base scenarios with tumble drying, where the difference in environmental potential between socks of bamboo viscose (dark green bars) and cotton (dark blue bars) is 16 % just as shown before in Figure 10. In the case with hung drying the bamboo viscose sock (light green bars), it has a global warming potential more equal to the global warming potential of the cotton sock (light blue bars); the difference is now only 3 %. In the case with doubling the environmental impact from the bamboo viscose fibre production, the bamboo viscose sock has a slightly higher global warming potential than the cotton sock (around 2 %).

Furthermore, figure 16 shows that the difference between socks of bamboo viscose and cotton in potential contribution to euthrophication has decreased from 13 % to 9 % when no tumble drying is assumed in the use phase. The bamboo viscose socks have a much lower potential impact on land use (81 %) and water consumption (87 %) in both sensitivity scenarios.

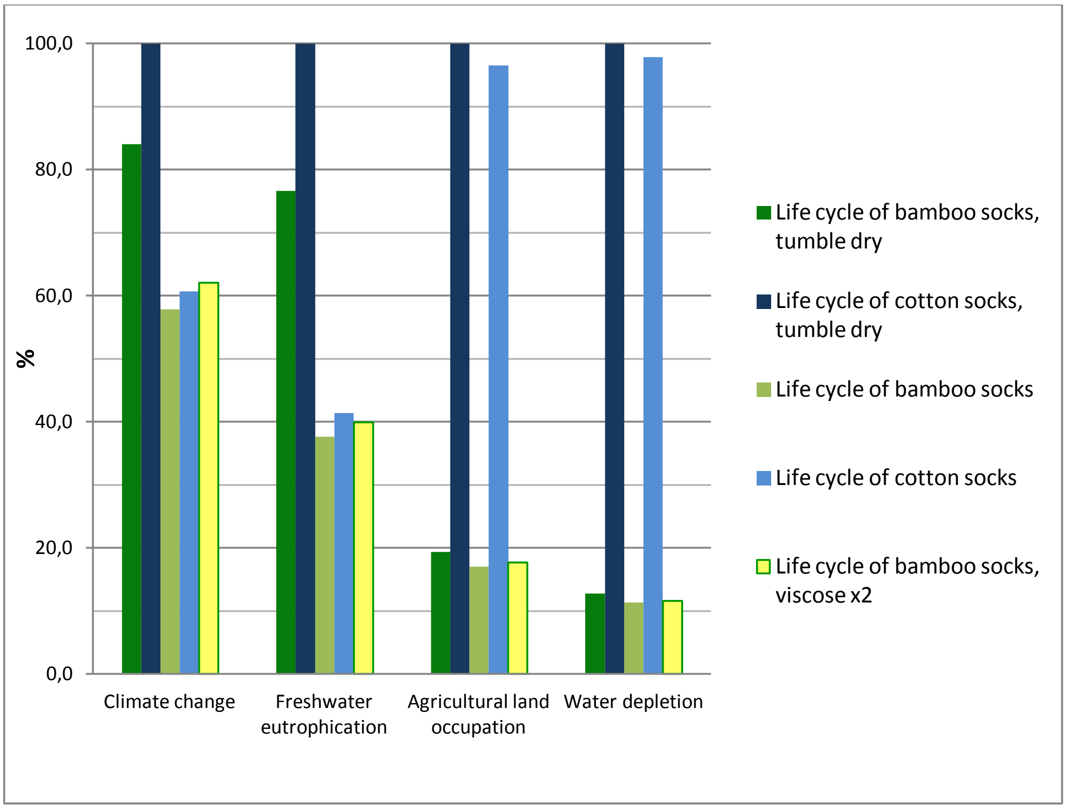


Figure 16. Potential environmental impact for the bamboo viscose socks (dark green bars – tumble dry, light green bars – hung dry, yellow bars – doubled impact from viscose production) compared to cotton socks (dark blue bars – tumble dry, light blue bars – hung dry). The numbers are normalised against the maximum value for each category.

4. Discussion

The objective with the life cycle assessment reported in this document has been to compare garments of cotton with garments of bamboo viscose from Wiges, so called Life Wear® bamboo. The diagrams in chapter 3 give an unambiguous answer; that the bamboo viscose garments have equal or lower environmental impact compared to the cotton garments for all the analysed environmental impact categories. In the calculations, the bamboo viscose garments show, with one exception, more than 10% better environmental performance (and sometimes as high as 90 % better performance) compared with the cotton garments.

The difference in environmental performance between bamboo viscose and cotton is partly depending on the processes involved in the fibre production and partly depending on the energy consumption for the tumble drying. When a sensitivity analysis was performed (see 3.3) and no tumble dry in the use phase was assumed, the global warming potential of the bamboo viscose socks was only 3 percent lower than for the cotton socks. These alternatives can then be regarded as equal from the climate perspective due to the uncertainties of the analysis. For the other environmental impact categories the bamboo viscose garments clearly still have better environmental performance compared to cotton garments.

The second case in the sensitivity analysis compared the case with doubling the environmental impact from the bamboo viscose fibre production. The bamboo viscose sock has a slightly higher global warming potential than the cotton sock (around 2 %) and only a slightly lower euthrophication potential (bamboo viscose 3 % lower). For the other environmental impact categories the bamboo viscose garments had a continued much better environmental performance compared to cotton garments.

Below follows a discussion about the assumptions that have been made in the study and what consequences they will have for the results.

4.1 Differences in the modelling between the bamboo viscose garments and the cotton garments

A factor that can contribute negatively to the environmental performance of the cotton garments is that the database data used for the production of cotton fibres describes the average Chinese cotton production from the year 2000. As this data is relatively old this could mean that the cotton fibre production could score better if newer inventory data was used. Data for the production of bamboo viscose fibre was instead collected on-site in China for the study during 2012. In addition, the cotton cultivation data represents a general average for several suppliers, while the bamboo viscose data represents a specific supply chain. The cotton cultivation on the other hand constitutes 10 % of the total contribution to the global warming potential. A heavy decrease in the environmental performance of the cotton cultivation would thus be needed to have an impact on the total life cycle performance. For the processes from the yarn spinning to the finished product the same processes have been used for cotton as for bamboo viscose so no such difference can be found there. The same limitations in the modelling are present in the comparison with polyamide and elastane in section 3.2. Also for these synthetic fibres, database data describing average production values are used.

4.2 Environmental impact in relation to life length

The life length of the garments is assumed to be 50 washes in the study for both bamboo viscose and cotton garments. The real life length is probably much longer and could be over 150 washes. With more uses of the same garment the environmental impact per use is consequently reduced, as the environmental load is spread over more occasions of use. The environmental impact of the use phase is constant and does not depend on the number of uses. In a scenario with 150 uses the environmental impact per use of one pair of bamboo socks is thus reduced from 38 gram CO_2-equivalents to 28 gram CO_2-equivalents.

This shows that it is the use phase that dominates the climate impact. The use phase is also important for the total environmental impact when the garment is not used (that is washed and dried) many times before it is thrown away. Then the production phase will constitute the major environmental impact, and the impact per use will increase.

4.3 Requirements for environmental labelling

Appendix 3 reports the requirements that a selection of different environmental labels put on viscose fibres. In general, these requirements consists of limits for emissions to air and water, which is data that cannot be produced in an LCA, which in contrast to physical measurements is a method built on voluntary passing of information.

However, the requirements have a limited relevance, as for example the limit on emissions of potassium sulphate set by Bra Miljöval, as it is rather the emissions of sodium sulphate that are relevant. The requirements are also generally concerning emissions to the outer environment, while indoor air emissions can be a larger problem for the factory workers' health.

The GOTS label is not applicable for viscose as GOTS can only certify organic products according to the definition from IFOAM[9] which only comprises agricultural products while bamboo is considered a forestry product.

Appendix 4 reports the requirements that IPCC sets out in order to consider a viscose process to be Best Available Technology (BAT). Wige's supplier fulfils the requirements for emissions to indoor air and to the outer environment. The waste water treatment method used could not be matched against any of the described methods by the IPPC but could still be a good alternative. The fourth requirement concerning energy recovery of combustible waste was not studied as this was considered of minor importance.

In conclusion, the requirements put on viscose by the different environmental labels should probably be able to be fulfilled by Wiges' supplier, but this can of course only be proven by performing a labelling in practice.

[9] International Federation of Organic Agriculture Movements (IFOAM) is a global cooperation for organisations and people working with products from organic agriculture.

5. Conclusion

The life cycle assessment shows that garments of Life Wear® bamboo have equal or better environmental performance than the equivalent cotton garments for all the investigated environmental impact categories; global warming potential (GWP), water consumption, land use, toxicity, euthrophication and energy consumption.

The production of one pair of socks of bamboo viscose from Wiges, so called Life Wear® bamboo, has a potential climate impact of around 1.1 kg CO_2-equivalents. During the entire life cycle, the socks will cause a climate impact of around 2.0 kg CO_2-equivalents, if the socks are used and washed 50 times. The result for the socks expressed in the functional unit "one use of one pair of socks" is 38 gram CO_2-equivalents for the bamboo sock compared to the cotton sock's 46 gram CO_2-equivalents.

The production of one pair of underwear of Life Wear® bamboo, has a potential climate impact of around 1.9 kg CO_2-equivalents. During the entire life cycle, the underwear will cause a climate impact of around 3.4 kg CO_2-equivalents, if the underwear are used and washed 50 times. The result for the underwear expressed in the functional unit "one use of one pair of underwear" is 68 gram CO_2-equivalents for the bamboo viscose underwear compared to the cotton underwear's 79 gram CO_2-equivalents.

These results can be better understood if compared with the fact that 1 kg CO_2-equivalents corresponds to around 50 grams of beef meat or an 8 kilometers' drive with a green car.

For the other environmental aspects that have been analysed; water consumption, land use, energy consumption and chemicals, the bamboo viscose garments have a lower or much lower environmental impact than the cotton garments. A comparison was also made between all the different materials that were used in the socks and men's underwear; polyamide, elastane, cotton and bamboo viscose. The synthetic fibres polyamide and elastane dominate the climate, energy and euthrophication impact, while the cotton fibres dominate the toxicity, the water consumption and the land use. The Life Wear® bamboo is a good alternative in all these six categories.

In the introduction the growing demand for textile fibres was discussed and that the sustainability of both cotton and synthetic fibres is questioned. The capacity for growing cotton is close to its maximum limit at the same time as the use of chemicals and irrigation also make it an unsustainable commodity. Synthetic fibres such as polyester, polyamide and elastane have a generally high climate impact and are also based on non renewable resources. The conclusion of the study is thus that garments of Life Wear® bamboo is a generally sustainable alternative for the future.

References

Personal references

Supplier A, 2012

Supplier B, 2012

Supplier C, 2012

Supplier D, 2012

Ms. Alexandra Steger, Lenzing AG, 2012.

Literature

Althaus H.J., Dinkel F., Werner F., "Life Cycle Inventories of Renewable Materials." Final report ecoinvent Data v2.0. Editors: 0. 0. Volume: 21. Issue: 0. Swiss Centre for LCI, Empa - TSL. Duebendorf, CH, 2007

Ander G., Bomull: en solkig historia, Ordfront Förlag, 2010

Birkeland, Janis, Design for Sustainability - A Sourcebook of Integrated Ecological Solutions, © 2002 Earthscan Publications Ltd

Boustead, I., Eco-profiles of the European plastics industry. Association of Plastics Manufacturers in Europe (PlasticsEurope), Brussels, Belgium, 2005

Carlsson A.et. al., "Kartläggning av mängder och flöden av textilavfall", SMED Rapport Nr 46 2011, ISSN: 1653-8102, 2011

Cherrett N et.al., "Ecological footprint and water analysis of cotton, hemp and polyester", Stockholm Environmental Institute, 2005

De Flander K., Rovers R., One laminated bamboo-frame house per hectare per year, Construction and Building Materials 23 (2009) 210–218

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

EPD – Environmental Product Declaration: General Programme instructions for an international EPD® system for environmental product declarations, and Supporting annexes. Version 1.0, 2008, http://www.environdec.com/

EURATEX, European Technology Platform for the Future of Textiles and Clothing – A vision for 2020, 2004

European IPPC Bureau, "Reference Document on Best Available Techniques for the Textiles Industry", 2003

European IPPC Bureau, "Reference Document on Best Available Techniques in the Production of Polymers", 2007

Eutrophication in Europe's coastal waters. Topic report 7/2001. EEA, Copenhagen, 2001

Feng, H.-Y., Fan, S.-H., Su, W.-H., Yu, L., Liu, G.-L., Effect of special slag fertilizer on the growth of Phyllostachys edulis bamboo shoot 2012 Forest Research 25 (3) , pp. 407-410

Ferrigno S., Lizzaraga A., Nagarajan P., Tovignan S., Farm and Fiber Report, Organic Exchange, 2009

Fibre2Fashion, "Addressing Eco Concerns of the Apparel Industry", 2008

Fimreite L, Blomstrand K, "Beräkning av textila produkters CO2-avtryck", Examensarbete i samarbete med Klättermusen AB, Textilhögskolan, Högskolan i Borås, 2009

FSC – Forest Stewardship Council, Revised P&C (FSC-STD-01-001 V5-0), http://www.fsc.org/the-revised-pc.191.htm accessed 2012-08-09

Goedkoop M.J., Heijungs R, Huijbregts M., De Schryver A.;Struijs J., Van Zelm R, ReCiPe 2008, A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level; First edition Report I: Characterisation, 2009
http://www.lcia-recipe.net

Hischier R., "Life Cycle Inventories of Packaging and Graphical Paper", Final report ecoinvent Data v2.0. Editors: 0. 0. Volume: 11. Issue: 0. Swiss Centre for LCI, Empa - TSL. Duebendorf, CH, 2007

Hischier and Weidema, Implementation of Life Cycle Impact Assessment Methods, Swiss Ecoivent Centre, 2009

ISO – International Organization for Standardization. Environmental management – life cycle assessment – requirements and guidelines. International Standard ISO 14044, Geneva; 2006

Jelse K, Fridell E, Zackrisson M; "Life cycle assessment of the prototype S'wash laundry machine and detergent", Preliminary report for the S'wash project, IVL Swedish Environmental Research Institute, 2011

Kooistra K J, Pyburn R, Termorshuizen A J, "The sustainability of cotton - Consequences for man and environment", Wagening University, 2006

Kweon, M.-H., Hwang, H.-J., Sung, H.-C., Identification and antioxidant activity of novel chlorogenic acid derivatives from bamboo (Phyllostachys edulis), 2001, Journal of Agricultural and Food Chemistry 49 (10) , pp. 4646-4655

Laursen S E, Hansen J, "EDIPTEX – Environmental assessment of textiles", Danish Environmental Protection Agency, 2007

Lenzing, Sustainability in the Lenzing Group 2008, Focus Sustainability, Lenzing Aktiengesellschaft, 2008, available at http://www.lenzing.com/sites/nh08/english/images/pdf/Focus_Sustainability_2008.pdf

Organic Exchange:"Organic Cotton Farm and Fiber Report 2009, www.organiccotton.org, 2009

PricewaterhouseCoopers, "Ecodesign of Laundry Dryers Preparatory studies for Ecodesign requirements of Energy-using-Products (EuP) – Lot 16", Final report

2009, found at
http://www.ecodryers.org/documents/doc_V8/EuP_Laundry_Dryer_final_report_2009-04-06.pdf

Reid D.G., Jinchu H., Sai D., Wei W., Yan H., Giant Panda Ailuropoda melanoleuca behaviour and carrying capacity following a bamboo die-off, Biological Conservation, Volume 49, Issue 2, 1989, Pages 85–104

Roos, S., Posner, S. Rekommendationer för hållbar upphandling av textilier, Swerea IVF-rapport 11001. 2011, Mölndal

Rosenbaum RK, Bachmann TK, Gold LS, Huijbregts MAJ, Jolliet O, Juraske R, Koehler A, Larsen HF, MacLeod M, Margni M, McKone TE, Payet J, Schuhmacher M, Van de Meent D and Hauschild MZ, USEtox - The UNEP/SETAC-consensus model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in Life Cycle Impact Assessment. International Journal of Life Cycle Assessment 13(7): 532-546, 2008

Scurlock J.M.O., Dayton D.C., Hames B., Bamboo: an overlooked biomass resource?, Biomass and Bioenergy 19 (2000) 229-244

Shen L., Patel M. K., Life cycle assessment of man-made cellulose fibres, Lenzinger Berichte 88 (2010) 1-59, 2010

SNF, Köp inte nya kläder – för miljöns skull!, SVT Debatt från http://debatt.svt.se/2012/04/21/naturskyddsforeningen/, 2012

Swedish Environmental Agency, ”Konsumtionens klimatpåverkan”, ISBN 978-91-620-5903-3.pdf, ISSN 0282-7298, Naturvårdsverket 2008

TEKO, Skogen stor framtida råvarukälla för textilindustrin, http://www.teko.se/Press/Nyheter1/2012/Skogen-framtida-ravaukalla-for-textilindistrin/, 2012

Thundiyil J. G. et al., Acute pesticide poisoning: a proposed classification tool, Bulletin of the World Health Organization, Volume 86, Number 3, March 2008, 161-240, 2008

Werner, F., Althaus, H.J., Künniger, T., Richter, K., “Life Cycle Inventories of Wood as Fuel and Construction Material”. Final report ecoinvent 2000. Volume: 9, Swiss Centre for LCI, EMPA-DU, Dübendorf, CH, 2003

Woodings C. ed., Regenerated Cellulose fibres, The Textile Institute, Woodhead Publishing Ltd, 2001

WWF, ”Bomull - En ren naturprodukt?”, Världsnaturfonden WWF 2005

Appendix 1. Impact assessment categories

Global warming potential

Global warming is measured as kilogram CO_2-equivalents. Global warming is the gradual increase, over time, of the average temperature of earth's atmosphere and oceans sufficient to induce changes on the earth's climate. This increase on earth's temperature is related to the increase of the emission of gases, such as, CO_2, methane, water vapour, nitrous oxide and CFCs, among others, from anthropogenic (manmade) sources, mainly from the burn of fossil fuels. The carbon footprint [Swedish Environmental Agency, 2008] of the average Swedish person is 10 ton CO_2 equivalents per year. Burning 1000 litres of petrol in a modern car generates around 2500 kg CO_2 equivalents as a comparison. The limit for emissions from cars classified as green cars is today 120 gram CO_2/km.

Primary energy consumption

Primary energy is measured in MJ. It measures the amount of energy withdrawn from nature associated with different energy carriers and sums up as different resources as e.g. MJ of oil in ground and MJ of potential hydropower. The summing up method used follows the Cumulative Energy Demand method as described by Hischier and Weidema [Hischier, 2009].

Eutrophication

Eutrophication is measured as equivalents of PO_4. Nutrients like phosphor or nitrogen released in a lake leads to an increased production of planktonic algae. The algae sink to the bottom and are broken down with consumption of oxygen in the bottom layers, causing a dead environment at the bottom. The most significant sources of nutrient enrichment are the agricultural use of fertilizers, the emissions of oxides of nitrogen from energy production and wastewater from households and industry. In 1995 the Baltic Sea received 761 000 t nitrogen and 38 000 t phosphorus from land [EEA, 2001]. The anthropogenic part of the nitrogen was assumed to be 79%, for phosphorus no assumption could be made.

Toxicity

The toxicity has been evaluated with the LCA method USEtox [Rosenbaum, 2008], which is the recommended method by the ILCD platform. USEtox uses the unit CTU (Comparative Toxic Unit) which is an indirect measure of the number of cases per year caused by toxic effects. USEtox discriminates between human toxicity CTUh and ecotoxicity CTUe. When only one of these measures is shown in the report, ecotoxicity was chosen.

The difficulties of a relevant result for toxicity in LCA are partly caused by the fact that toxic emissions are seldom inventoried in the database data, which has a main focus on energy use. An exception is the production of energy and transports, where toxic emissions are inventoried in such detail that these processes tend to dominate all toxicity calculations.

The second problem with toxicity calculations in LCA is that the LCA methods are lacking characterisation factors for many chemicals. USEtox is today the method that covers most chemicals. The ILCD handbook [EC, 2010] recommends that the LCA practitioner should complement the methods with missing characterisation factors if they can have impact on the results.

Water consumption

There is currently no general consensus method for how to calculate the environmental impact of water consumption. There are many different aspects of water consumption, such as depletion of groundwater, freshwater scarcity, pollution of waste water etc. In this study, the water consumption has been inventoried and reported as “water consumption” without any concerns taken to whether this consumption has high or low environmental (and social) impact.
There is currently ongoing work at ISO in the workgroup TC 207/SC 5/WG 8 Water Footprint that develops the draft ISO/PWI 14046 "Water footprint: Requirements and guidelines".

Land use

Land use is in similarity with water consumption an environmental impact category for which there is no existing consensus method. The LCA method recipe has been used which does only discriminate between use of agricultural land, use of industrial land and transformation of natural land to industrial land. In this study it is agricultural land that has been chosen as indicator for this study.

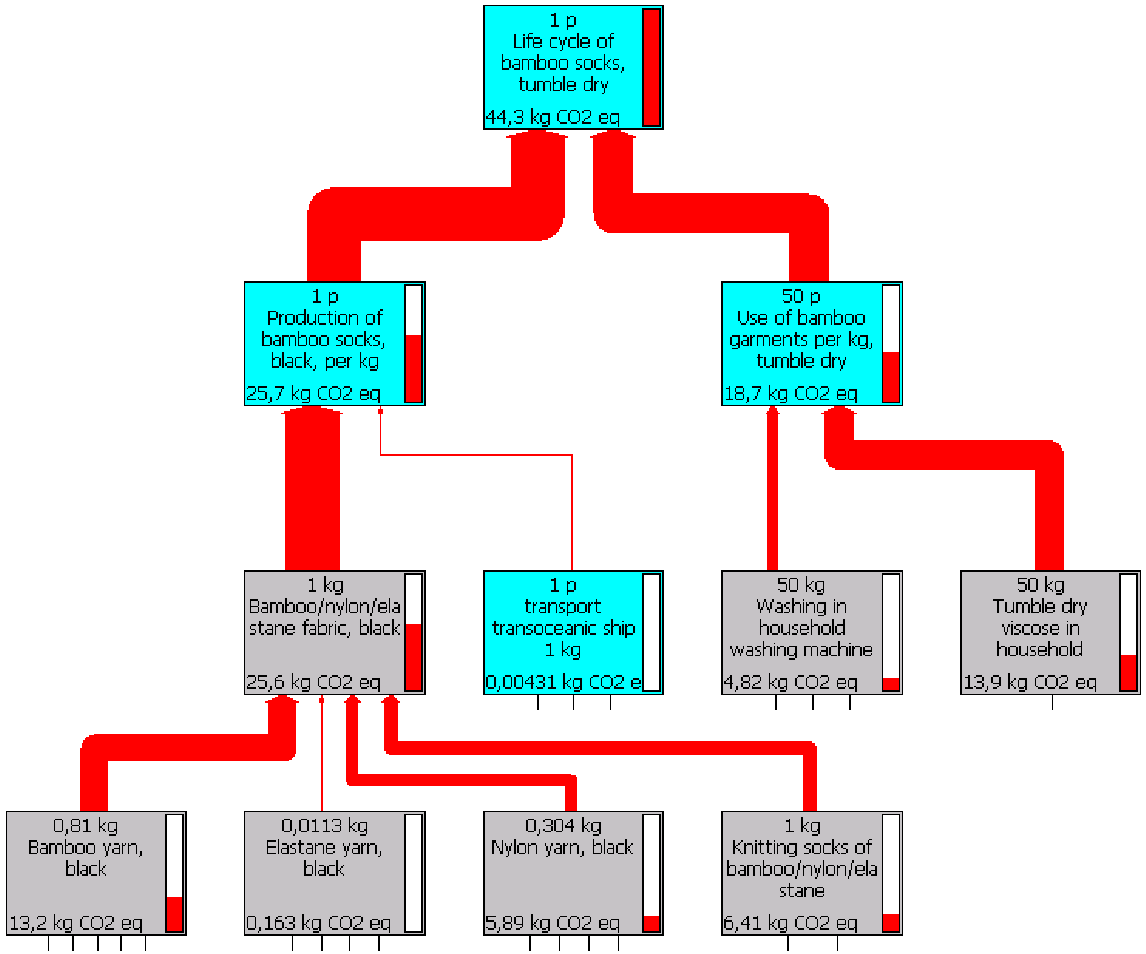
Appendix 2. Detailed LCA results

This appendix shows in detail the environmental impact from bamboo viscose socks and cotton socks for the six impact categories global warming potential (kg CO_2-equivalents), euthrophication (kg phosphorous equivalents), land use[10] (m^2a) and water consumption (litre) and primary energy consumption (MJ). Ecotoxicity (CTUe[11]) is reported on yarn level. Global warming potential is also reported for the underwear.

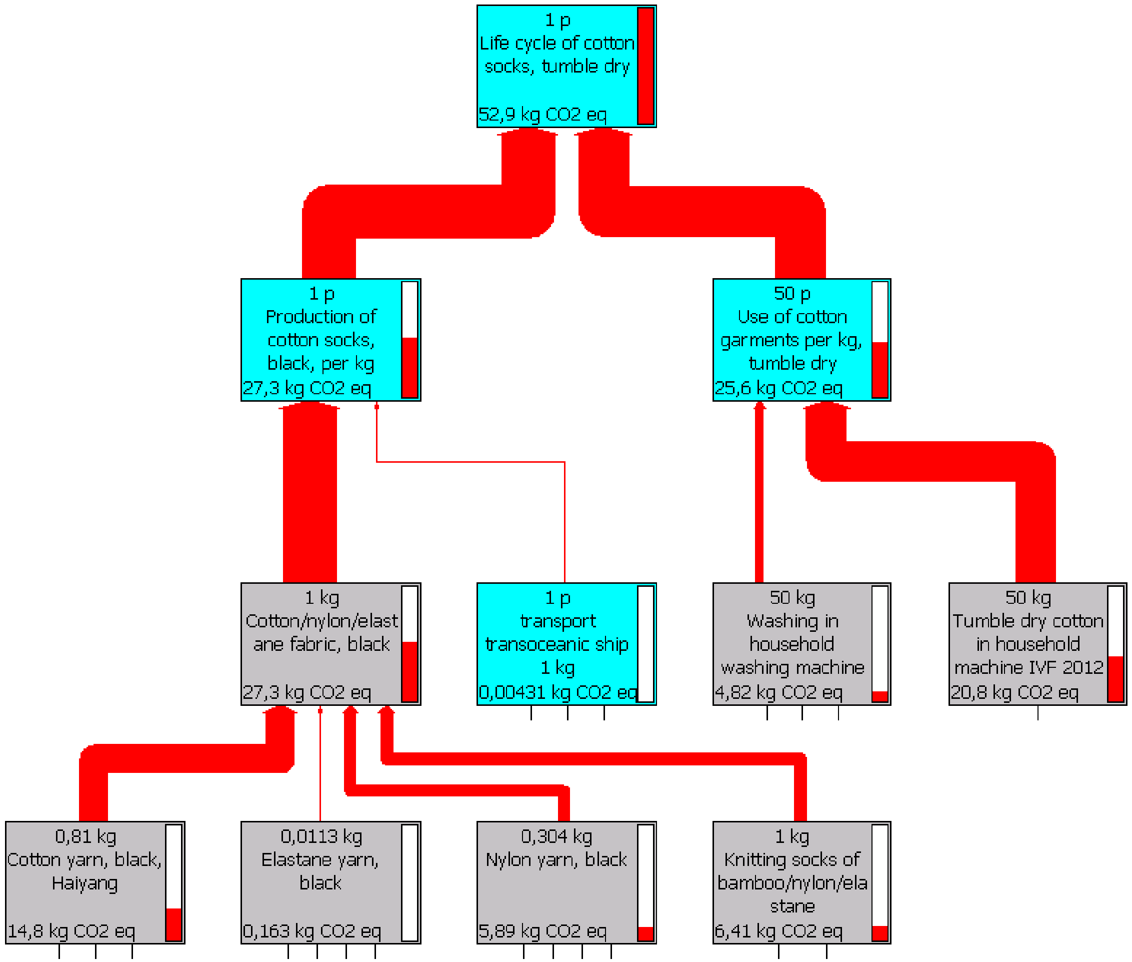
The figures below show the life cycle impact for the different impact categories. The thickness of the arrows corresponds to the environmental impact measured from respective process. The amount of environmental impact in the respective unit for the impact category is shown in the lower left corner of each box.

[10] The result is reported as m^2a, i.e. square metres and year
[11] CTU = Comparative Toxic Unit

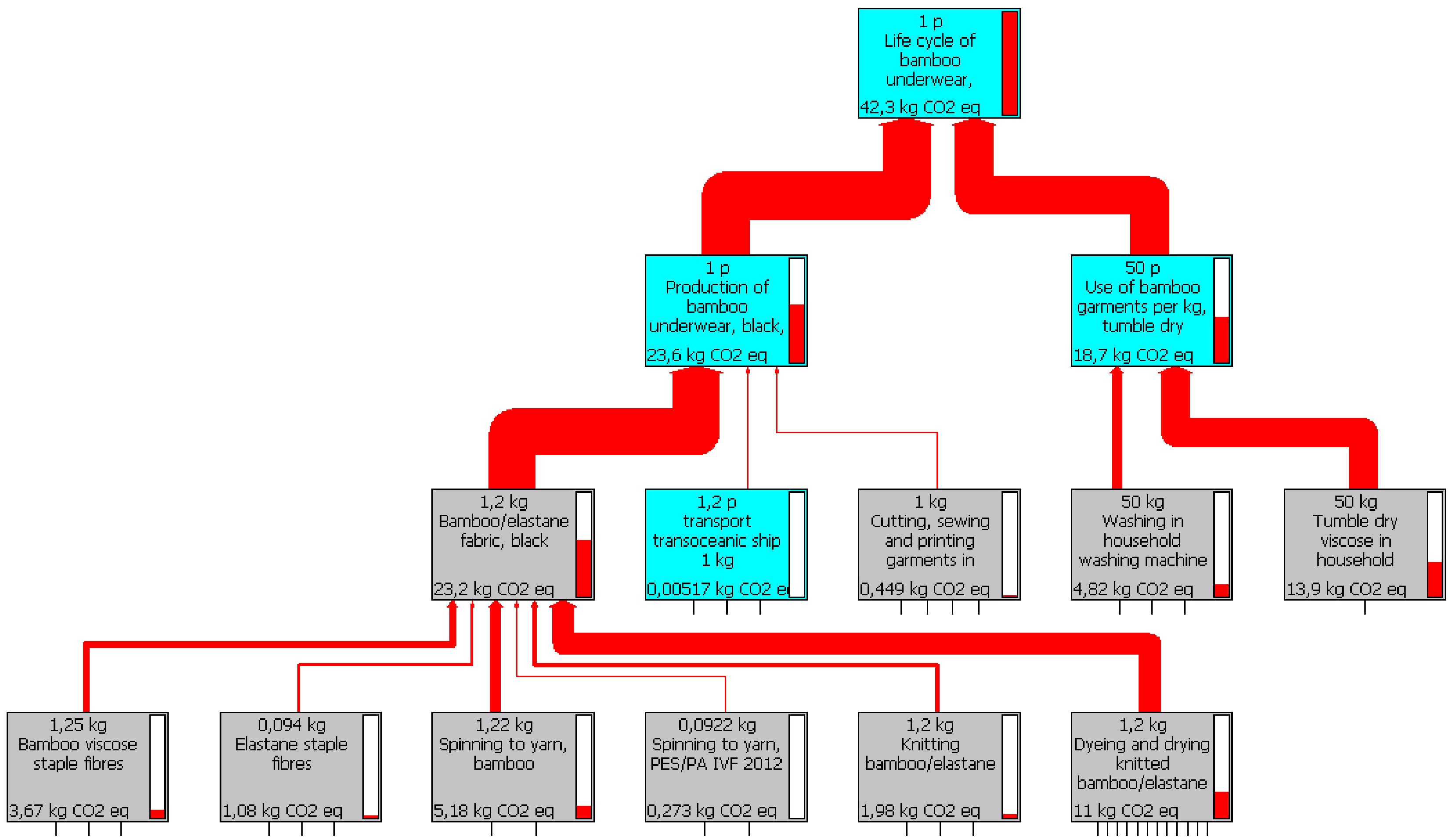
Global warming potential (CO_2-eq), bamboo viscose socks, per kg



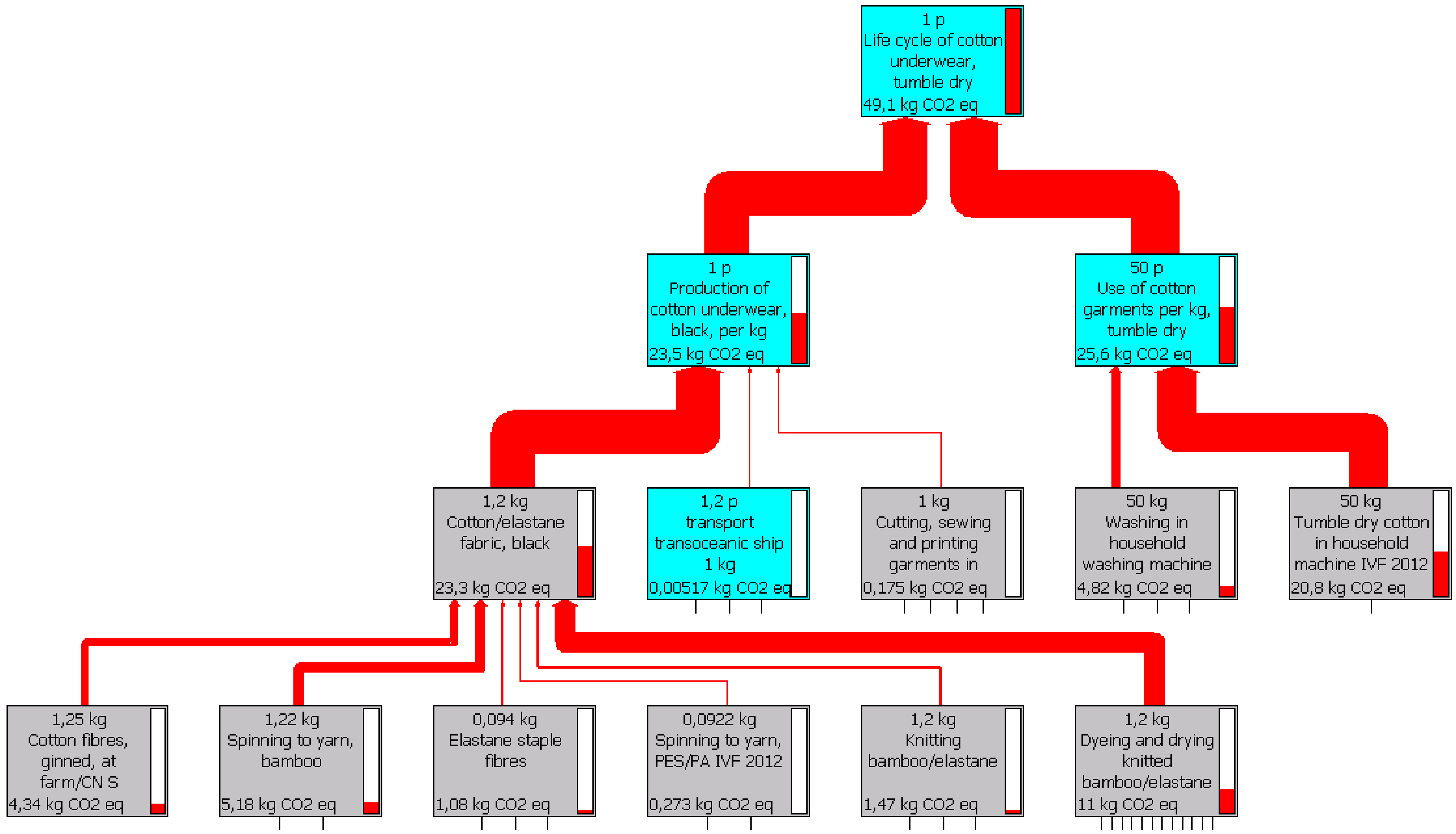
Global warming potential (CO_2-eq), cotton socks, per kg



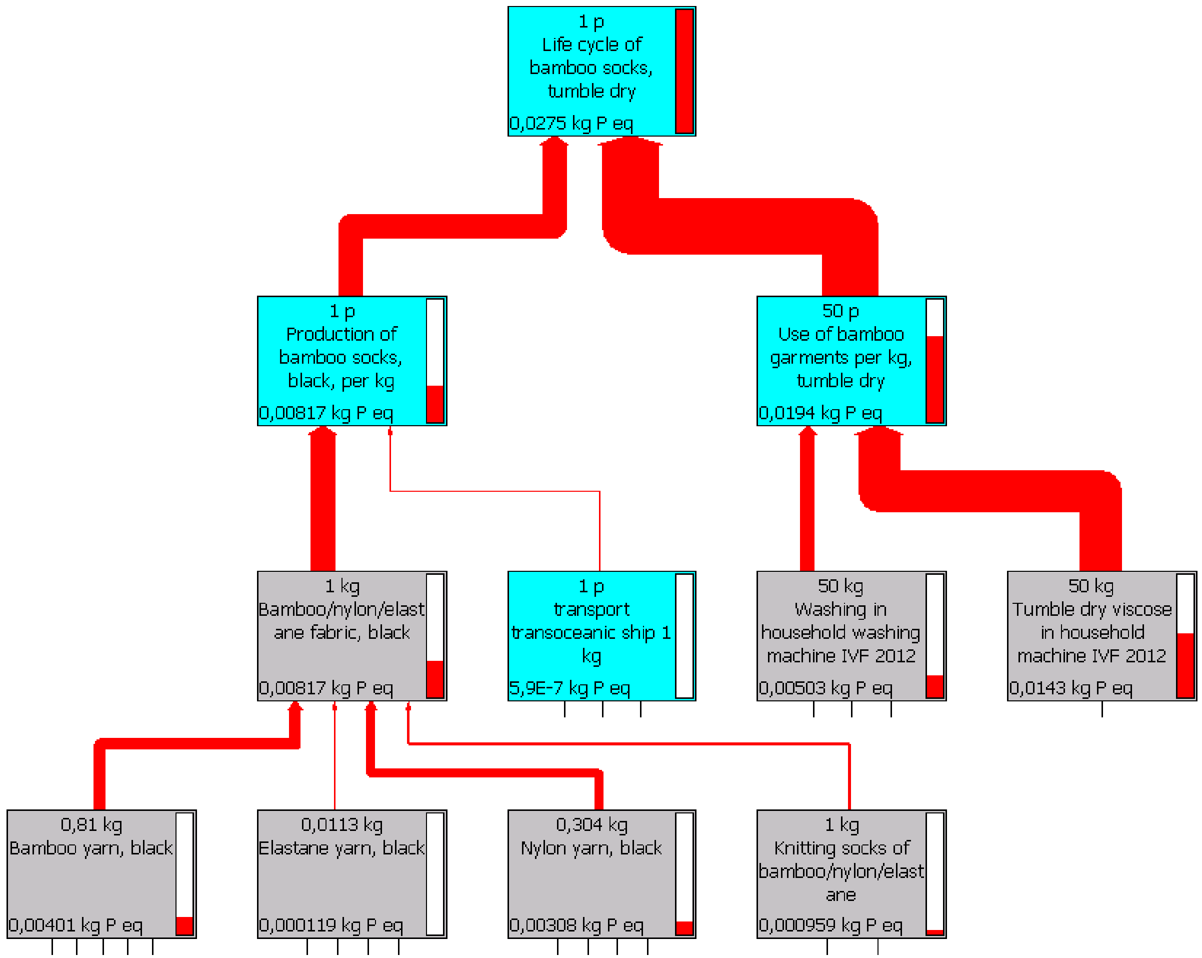
Global warming potential (CO_2-eq), bamboo viscose underwear, per kg



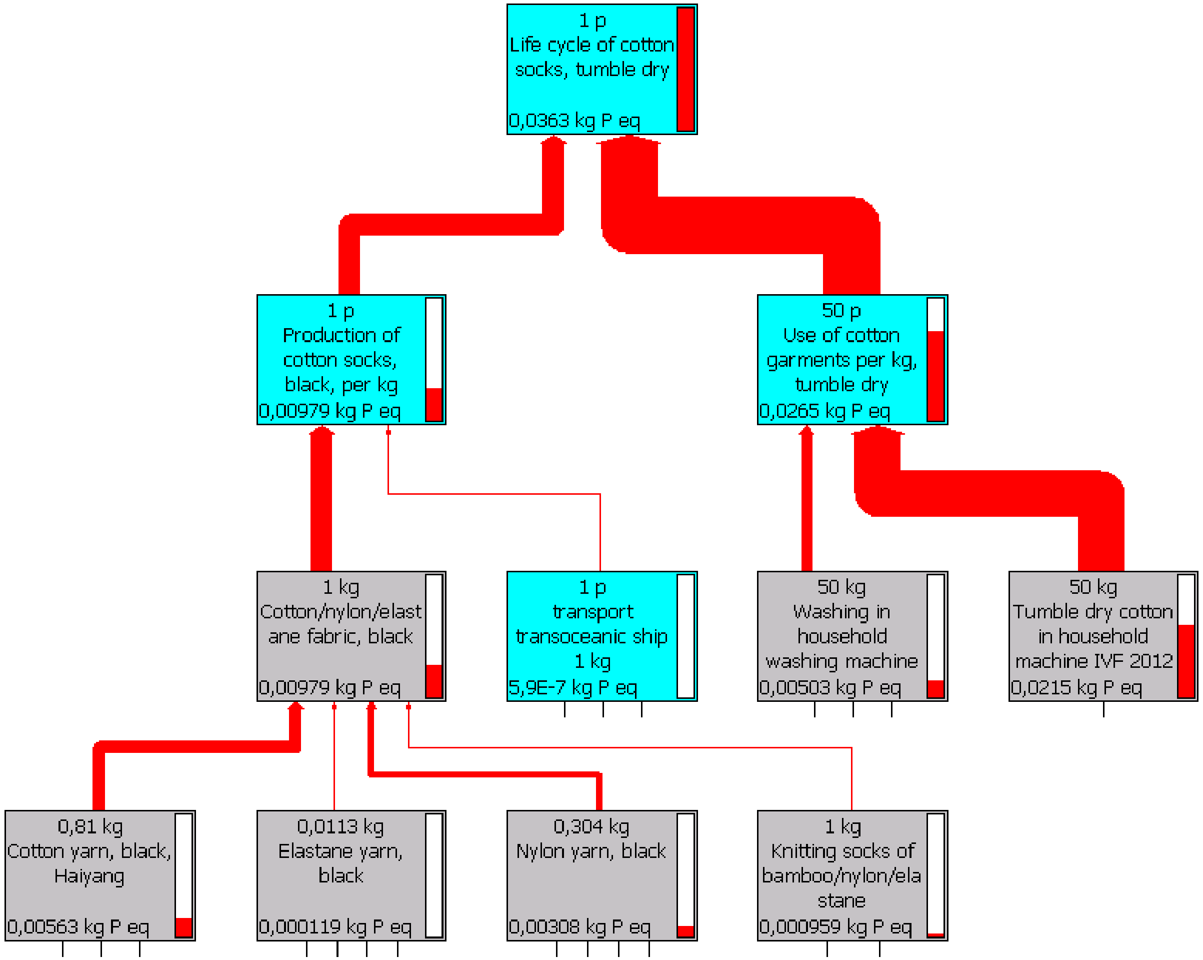
Global warming potential (CO_2-eq), cotton underwear, per kg



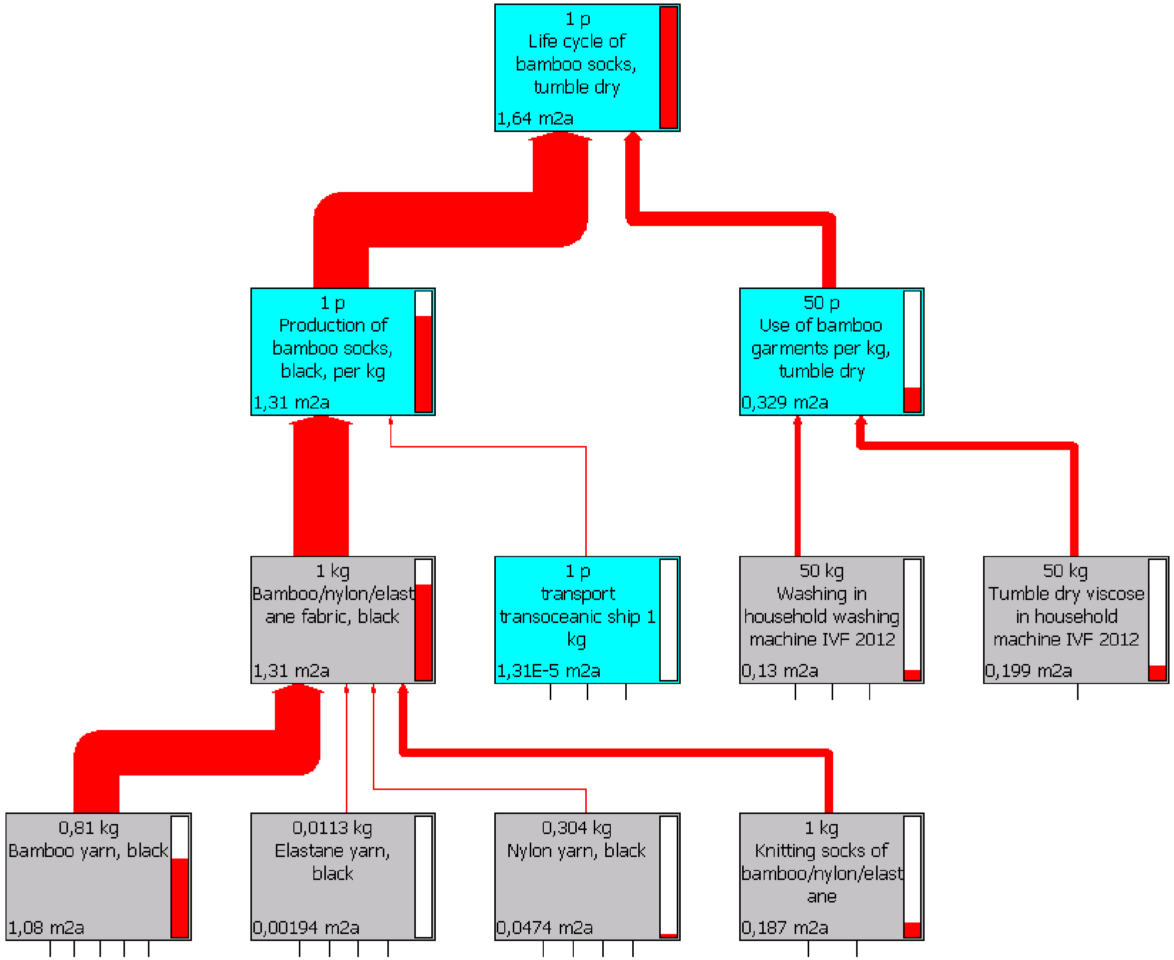
Euthrophication (P-eq), bamboo viscose socks, per kg



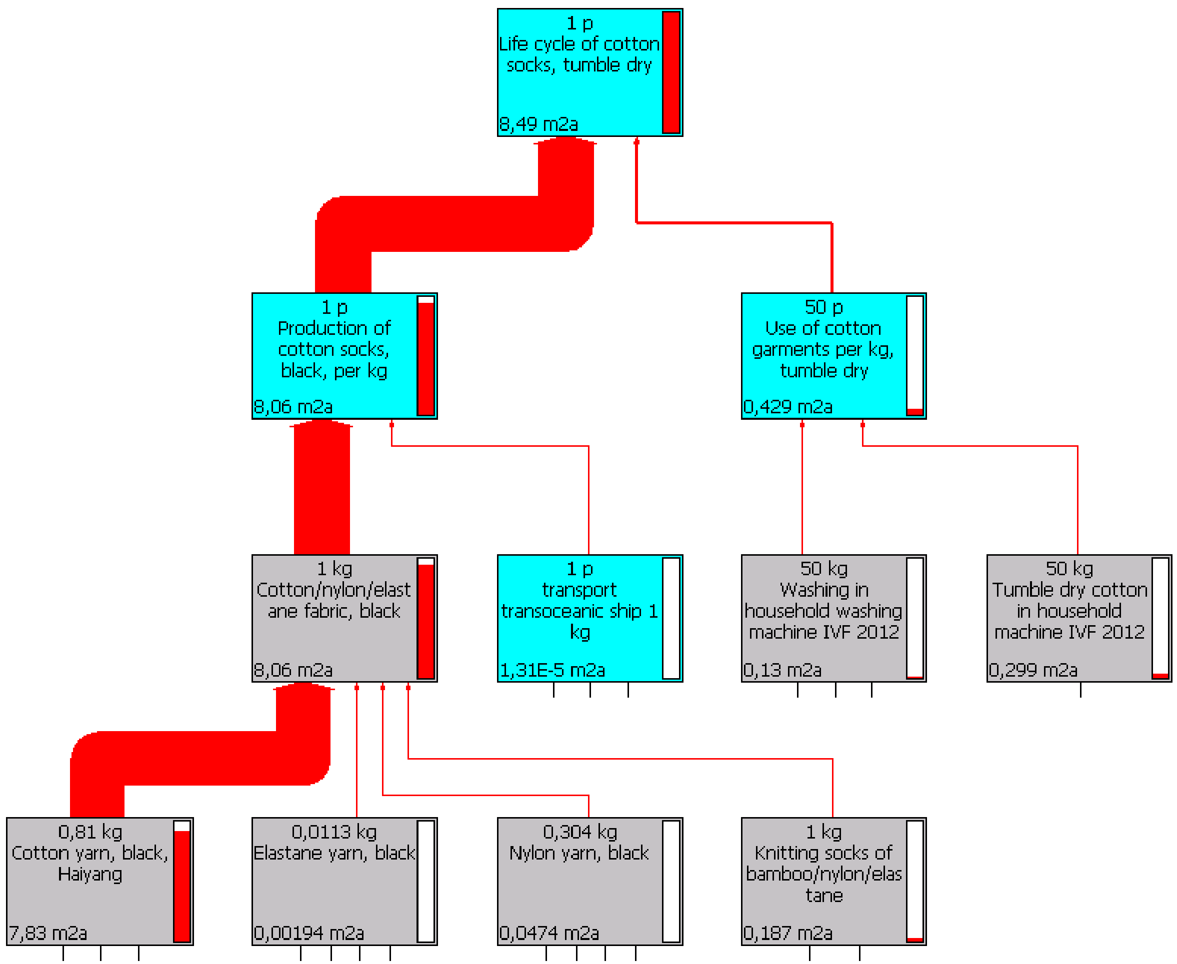
Euthrophication (P-eq), cotton socks, per kg



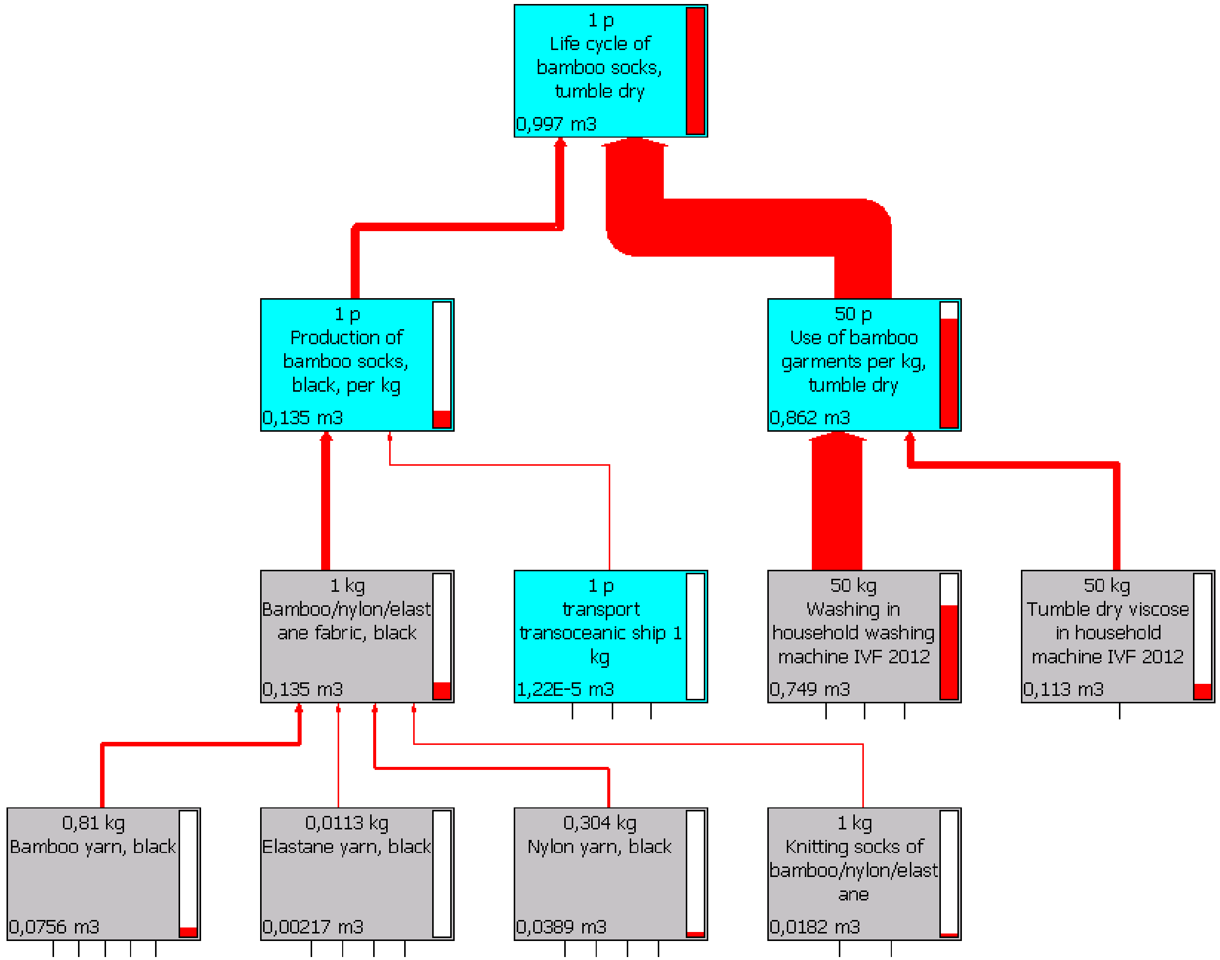
Land use (m^2a), bamboo viscose socks, per kg



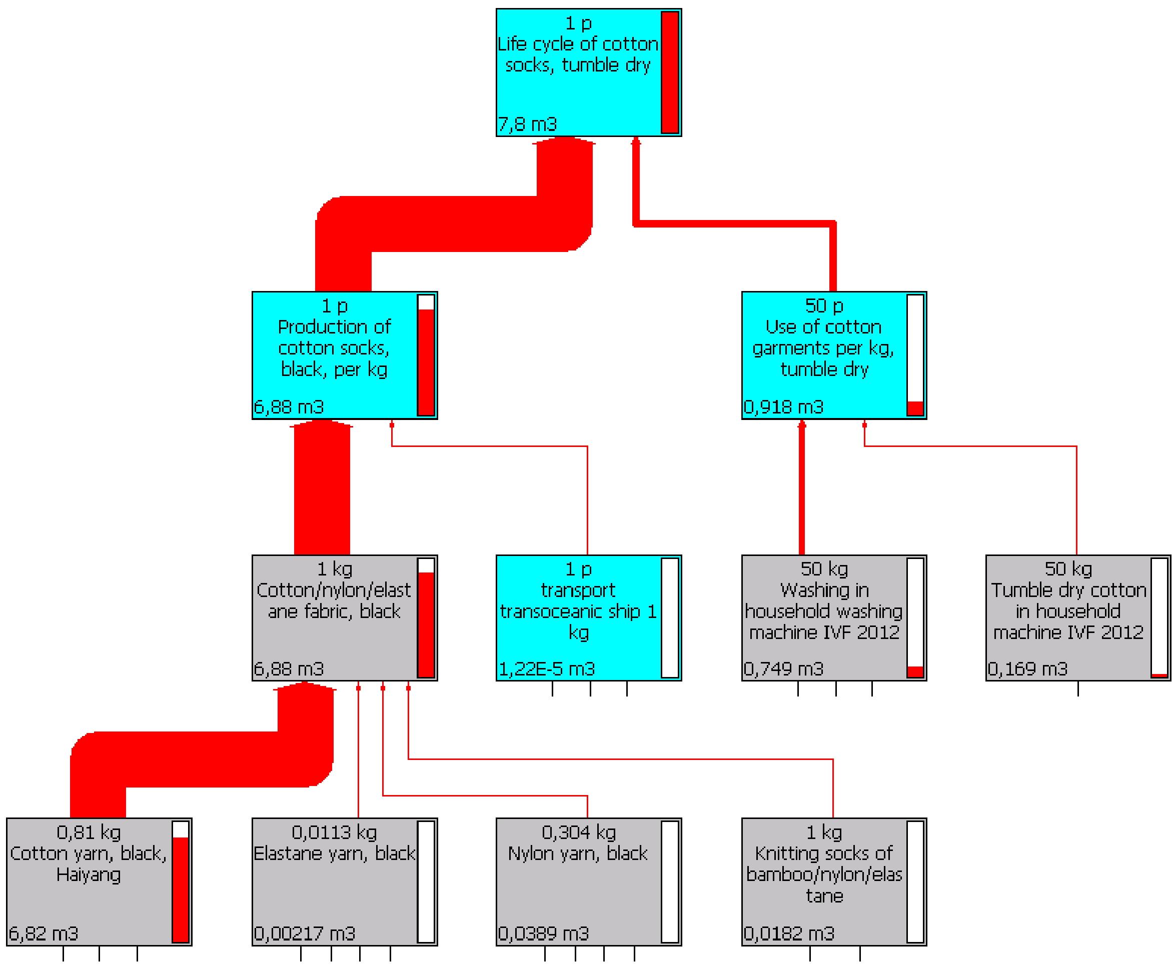
Land use (m^2a), cotton socks, per kg



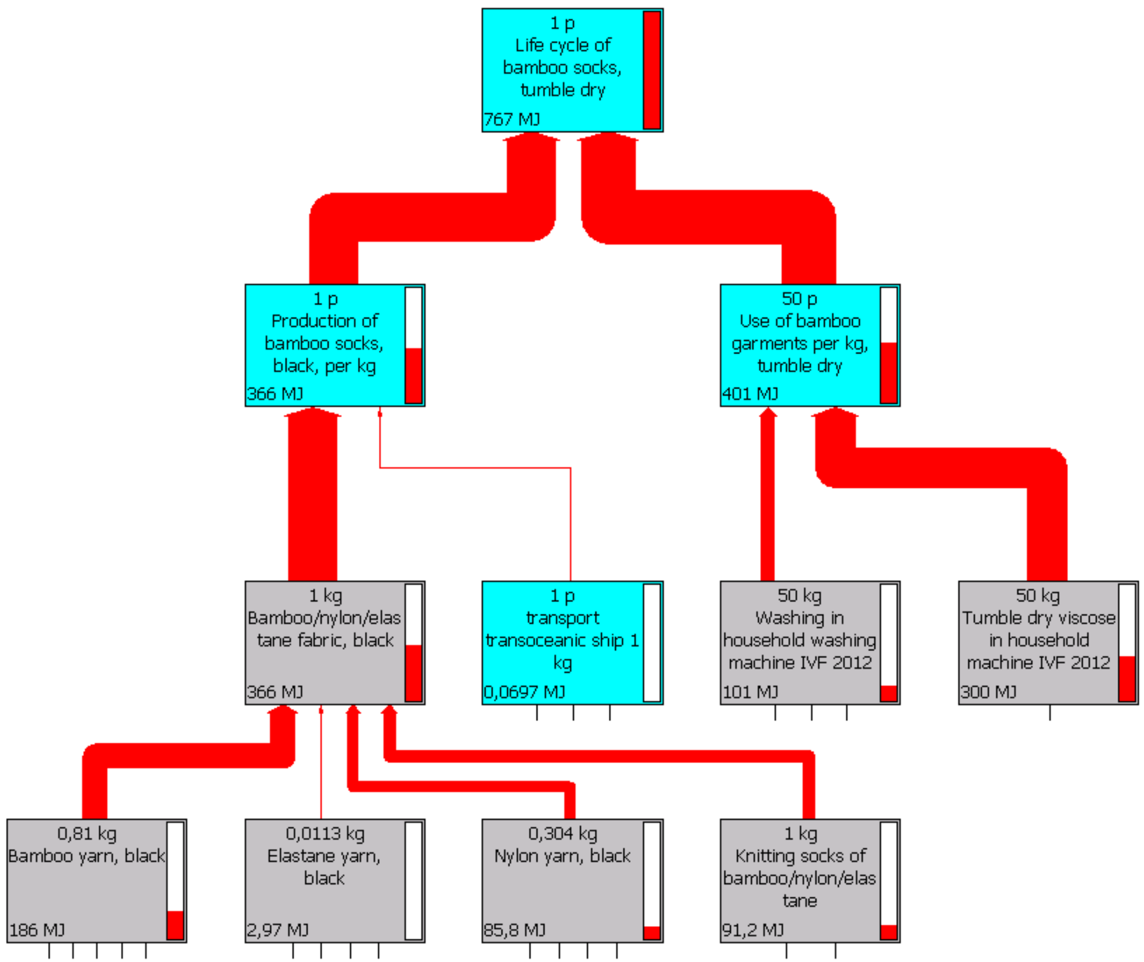
Water consumption (m^3), bamboo viscose socks, per kg



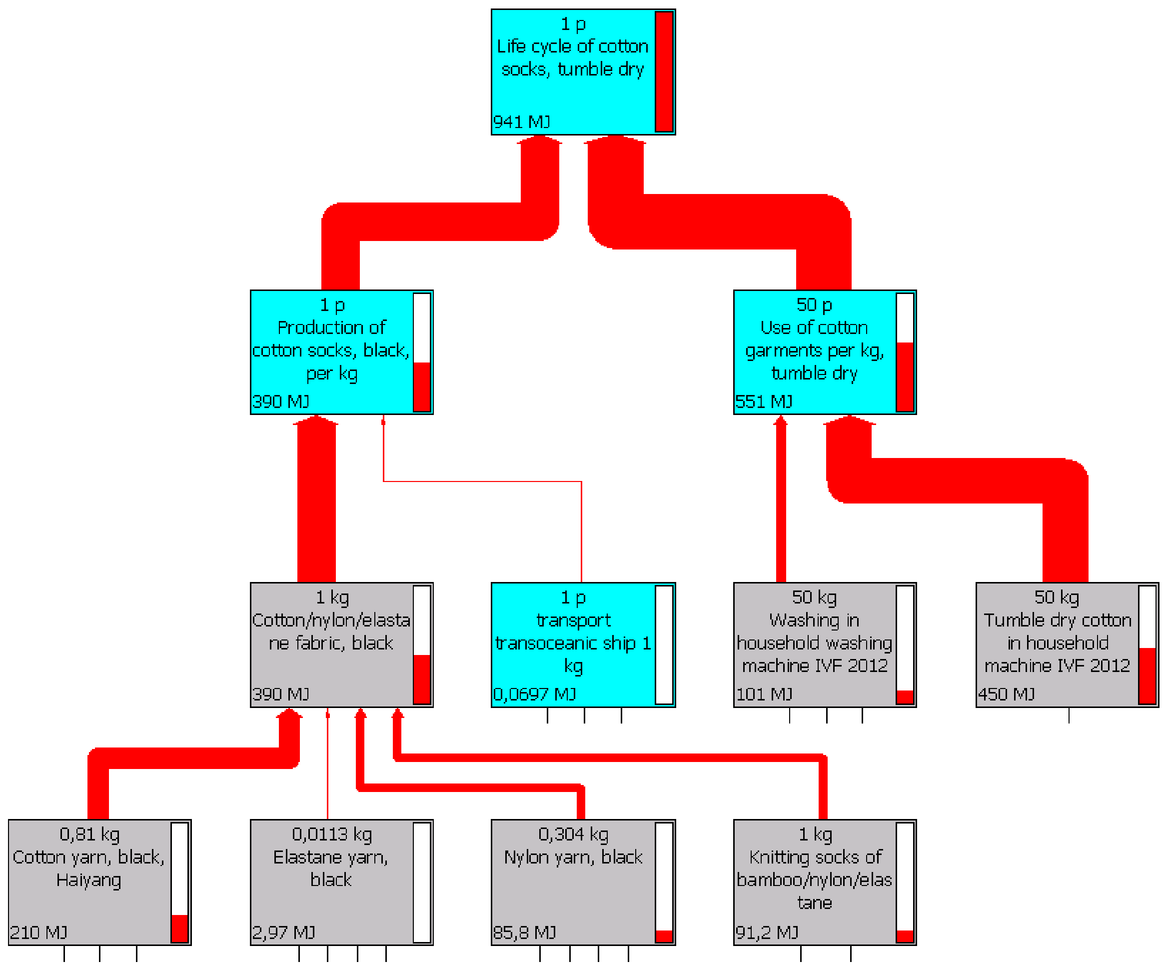
Water consumption (m^3), cotton socks, per kg



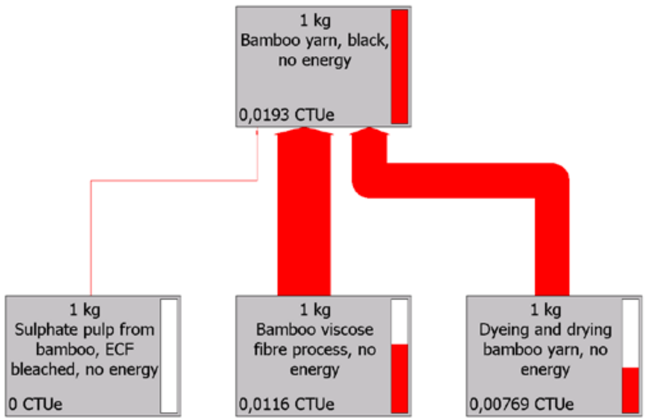
Primary energy consumption (MJ), bamboo viscose socks, per kg

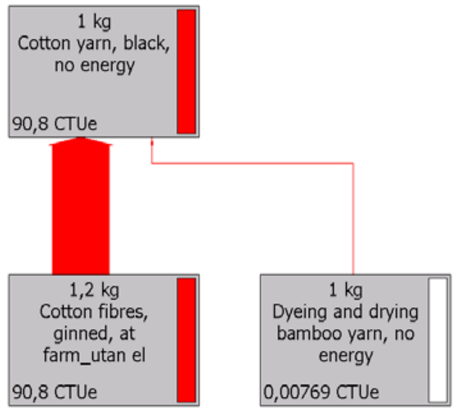


Primary energy consumption (MJ), cotton socks, per kg



Ecotoxicity (CTUe), bamboo yarn and cotton yarn, per kg





Appendix 3. Environmental label's requirements on regenerated cellulose fibres (in Swedish)

Nedan beskrivs vilka krav som ett urval av olika miljömärkningar ställer för att märka viskosfibrer, som även kallas regenererade cellulosafibrer eller regenatfibrer av cellulosa..

- **Bra Miljöval.** Naturskyddsföreningens icke-kommersiella miljömärkning som har som syfte att guida konsumenter till de produkter med högst miljöprestanda. Målet är att endast de bästa av marknadens produkter ska klara märkningen, i motsats till vissa kommersiella märkningar, där fler förväntas klara märkningen för att ett större kundunderlag för märkningen ska kunna erhållas.
- **EU Ecolabel / Miljöstyrningsrådet (MSR).** Syftet med EU Ecolabel är att främja produkter med reducerad påverkan på miljön under hela sin livscykel. Märket är även tänkt som en vägledning till konsumenterna i deras val av produkter som kan bidra till att minska miljöpåverkan ur ett livscykelperspektiv och ge dem information om de miljömässiga egenskaperna hos de märkta produkterna. Miljöstyrningsrådets kriterier syftar till att göra det enklare för upphandlare att ställa miljö- och andra hållbarhetskrav vid upphandling av varor, tjänster och entreprenader.
- **GOTS.** Global Organic Textile Standard är en miljömärkning under International Federation of Organic Agriculture Movements (IFOAM) som är ett globalt samarbetsorgan för organisationer och personer som arbetar med produkter från ekologiskt jordbruk. Eftersom bambu inte är en jordbruksprodukt (i likhet med eukalyptus, gran, bok etc.) kan inte bambuprodukter märkas med GOTS. Dock accepteras viskos utan förbehåll som en mindre del av produkten, se nedan

.

Bra Miljövals krav på regenererade fibrer av cellulosa

Textil 2012 – Ansökan Bra Miljöval 2012:I

C1.2.2 Fiberspinning (Avsnitt 3.2)

Ange typ av regenatfiber ____

Spinningsprocessen

☐ Spinningen har skett i en **N-metylmorfolin-N-oxid-baserad viskosprocess** i ett slutet system.
☐ Lösningsmedlet återvinns till minst 99 %. Ange värde: ____________________
☐ Ovanstående styrks med *bifogad* ***analysrapport*** från ackrediterat laboratorium.

☐ Spinningen har skett i en **Xanthogenatbaserad viskosprocess** i ett icke slutet system. **Klass II**
☐ Kaliumsulfat återvinns till minst 80 %. Ange värde: ________________________________ ☐ Svavelväte återvinns till minst 80 %. Ange värde: ________________________________
☐ Utsläpp av svaveldioxid är max 25 g/kg fiber och år. Ange värde: ______________________
☐ Ovanstående styrks med *bifogade* ***analysrapporter*** från ackrediterat laboratorium.

☐ Spinningen av viskosfibern har skett med annat lösningsmedel än ovan. ***Dokumentation*** *bifogas* Ange typ av lösningsmedel:____

MSRs/EU ecolabels krav på regenererade cellulosafibrer

6. Regenererade cellulosafibrer (inbegripet viskos, lyocell, acetat, cupro, triacetat)

6.1 Halten klorerade organiska ämnen i fibrerna får inte överstiga 250 ppm.

Bedömning och kontroll: Sökanden ska tillhandahålla en testrapport som visar förekomsten mätt med följande testmetod: ISO 11480.97 (kontrollerad förbränning och mikrokolometri).

6.2 Det årliga genomsnittliga utsläppet av svavelföreningar till luften vid tillverkning av viskosfibrer får inte överstiga 120 g/kg tillverkade fiberfilament och 30 g/kg tillverkade stapelfibrer. Om båda fibertyperna tillverkas i en viss anläggning får den totala mängden utsläpp inte överstiga motsvarande viktade genomsnitt.

Bedömning och kontroll: Sökanden ska tillhandahålla detaljerad dokumentation och/eller testrapporter som visar att produkten uppfyller detta kriterium samt ett intyg om överensstämmelse.

6.3 Det årliga genomsnittliga utsläppet från produktionsstället av zink till vatten vid tillverkning av viskosfibrer får inte överstiga 0,3 g/kg.

Bedömning och kontroll: Sökanden ska tillhandahålla detaljerad dokumentation och/eller testrapporter som visar att produkten uppfyller detta kriterium samt ett intyg om överensstämmelse.

6.4 Den årliga genomsnittliga halten av koppar i spillvattnet vid tillverkning av cuprofibrer får inte överstiga 0,1 ppm.

Bedömning och kontroll: Sökanden ska tillhandahålla detaljerad dokumentation och/eller testrapporter som visar att produkten uppfyller detta kriterium samt ett intyg om överensstämmelse.

GOTS

2. Criteria

2.1. Requirements for organic fibre production

Approved are natural fibres that are certified organic, and fibres from conversion period certified according to a recognised international or national organic farming standard by a certification body that has a valid accreditation for the recognised standard it certifies against, and that is IFOAM[12] accredited or internationally recognised (according to ISO 65). Certifying of products as *'in conversion'* is only possible, if the standard on which the certification of the fibre production is based, permits such a certification for the fibre in question. Conversion nature of fibres must be stated as specified in chapter 1.4. of this standard.

2.2. Requirements for material composition

2.2.1. Products sold, labelled or represented as "organic" or "organic – in conversion"

No less than 95 % of the fibre content of the products - excluding *accessories* - must be of certified organic origin or from '*in conversion*' period (identified and labelled as specified in chapters 1.4 and 2.1 of this standard). Up to 5% of the fibre content of the products may be made of non-organic fibres that are listed in chapter 2.4.9. The products must not contain any genetically modified fibres. Blending organic and conventional fibres of the same type in the same product is not permitted. The percentage figures refer to the weight of the fibre content of the products in conditioned status.

2.2.2. Products sold, labelled or represented as "made with x % organic materials" or "made with x % organic – in conversion materials"

[12] International Federation of Organic Agriculture Movements (IFOAM) är ett globalt samarbetsorgan för organisationer och personer som arbetar med produkter från ekologiskt jordbruk.

No less than 70 % of the fibre content of the products - excluding *accessories* - must be of certified organic origin or from *'in conversion'* period (identified and labelled as specified in the chapters 1.4 and 2.1 of this standard). Up to 30% of the fibre content of the products may be made of non-organic fibres that are listed in chapter 2.4.9. The products must not contain any genetically modified fibres. The products may contain a maximum of 10 % of regenerated or synthetic fibres as listed in chapter 2.4.9, except that socks, leggings and *sportswear* may contain a maximum of 25 % of those regenerated or synthetic fibres. Blending organic and conventional fibres of the same type in the same product is not permitted. The percentage figures refer to the weight of the fibre content of the products in conditioned status.

*** bortklippt sektion ***

2.4.9. Requirements for additional materials and accessories

Additional Materials	Criteria
Fibre materials accepted for the remaining non-organic balance of the product's material composition according to chapter 2.2.1. and 2.2.2.	Allowed are: - conventional natural fibres (all non GMO vegetable and animal fibres) - mineral fibres (except asbestos) - regenerated fibres (cellulosic based such as viscose, modal, lyocell or acetate and protein based; the raw materials used must be non GMO) - synthetic (polymer) fibres: only polyamide, polyester, polypropylene and polyurethane (elastane) The additional fibre materials may be mixed with the organic fibres to the fabric or used in certain details of the product. From 1st January 2014 onwards any polyester used must be made from post-consumer recycled material. All additional materials must meet the limit values for residues as listed in chapter 2.4.16.

Appendix 4. Extract about the viscose process from IPPC's Best reference document

BAT for viscose fibres is

- Indoor air emission reduction
  - **to operate spinning frames in houses**
- External air emission reduction
  - to condense the exhaust air from spinning streets to recover CS_2 and recycle it back into the process
  - to recover CS_2 from exhaust air streams through adsorption on activated carbon. Depending on the concentration of H_2S in the exhaust air, different technologies are available for the adsorptive recovery of CS_2
  - **to apply exhaust air desulphurisation processes based on catalytic oxidation with H_2SO_4 production. Depending on the mass flows and concentrations, there are a number of different processes available to oxidise exhaust gases containing sulphur**
- Water emission reduction
  - to recover sulphate from spinning baths. BAT is to remove sulphate as Na_2SO_4 from the waste water. The by-product is economically valuable and sold
  - to reduce Zn from the waste water by alkaline precipitation followed by sulphide precipitation
  - to use anaerobic sulphate reduction techniques for sensitive waterbodies
- Waste reduction
  - to use fluidised bed incinerators to burn non-hazardous wastes and recover the heat for the production of steam or energy.

Appendix 5. Modelling of the processes in the bamboo garment production chain

The detailed modelling of the processes will not be publicly available but used to communicate with suppliers and sub-suppliers.

Appendix 6. Review report from Bureau Veritas