KTH Architecture and the Built Environment

Comparative Life Cycle Assessment of Surgical Scrub Suits

The Case of Reusable and Disposable Scrubs used in Swedish Healthcare

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Abstract

Within the healthcare sector, large quantities of different materials and products are consumed on a daily basis. Recurrently growing awareness about humanity's negative impacts on the environment have initiated for environmental aspects to be considered on several levels within the healthcare sector. Introducing environmental guidelines within procurement is one example of such an initiative. However, in order to take such aspects into consideration, availability of environmental information concerning the products to be procured is necessary.

This thesis was conducted to evaluate and compare the environmental impacts, in a life cycle perspective, of a single-use and a multi-use surgical scrub suit. Accordingly, the main purpose has been to give the County Councils of Örebro and Uppsala decision support and thereby enable them to take environmental impact into account in future procurement of surgical scrub suits. The evaluation is based on certain environmental aspects, assessed to be relevant and of interest for the given case. To ensure a methodical structure and high credibility, this LCA has been conducted in accordance with the ISO 14040-standard.

The studied products are two types of surgical scrub suits, one reusable for 100 uses, and one disposable. Besides the lifespan, the material composition of the two products differs. Results showed that that the reusable scrubs have considerably lower environmental impact within the studied categories. The main reason for this is the longer lifespan of the reusable garments, which results in substantially decreased environmental impacts per use within all phases of the lifecycle except usage. Further, the results indicated that farming/production of cotton and usage of fossil fuel-based energy are important contributing factors within a majority of the assessed environmental impact categories. Currently available alternatives exist, which could possibly substitute these factors, and thus decrease the total environmental burden of the garments substantially.

Keywords

Life cycle assessment, LCA, surgical scrubs, textiles, environmental procurement, healthcare

Sammanfattning

Varje dag konsumeras stora mängder material och produkter inom vårdsektorn. Samtidigt har den ständigt växande medvetenheten om mänsklighetens negativa påverkan på miljön medfört ett ökat hänsynstagande inom olika delar av vårdsektorn. Införande av riktlinjer för miljöanpassad upphandling är ett exempel på ett sådant initiativ. Men för att kunna använda miljömässiga aspekter i upphandling är tillgången till miljödata för produkterna nödvändig.

Denna uppsats utfördes för att ur ett livscykelperspektiv utreda och jämföra miljöpåverkan av två typer operationsarbetskläder, en engångs- och en flergångsmodell. Huvudsyftet med studien var att ge landstingen i Örebro och Uppsala län ett beslutsunderlag, och därmed underlätta för dem att ta hänsyn till miljöaspekter i framtida upphandlingar av operationsarbetskläder. Miljöbedömningen av plaggen är baserad på utvalda miljöpåverkanskategorier som bedömts som relevanta och av intresse för denna undersökning. För att försäkra en god metodologisk struktur och hög trovärdighet, har denna Livscykelanalys (LCA) utförts i enighet med riktlinjerna i ISO 14040-standarden.

De studerade produkterna är två typer av operationsarbetskläder, en som kan återanvändas 100 gånger, och en för engångsbruk. Utöver plaggens livslängd skiljer även materialsammansättningen dem åt. Resultaten visade att de återanvändningsbara kläderna har betydligt lägre miljöpåverkan inom alla studerade kategorier.

Den huvudsakliga orsaken till detta är flergångsplaggens betydligt längre livscykel, vilken resulterar i en avsevärd minskning i miljöpåverkan per användning inom alla dess livscykelfaser förutom användningen. Vidare indikerade resultaten att odling och tillverkning av bomull, samt användningen av energi från fossila bränslen, hör till viktiga bidragande faktorer till miljöpåverkan inom flertalet undersökta miljöpåverkanskategorier. Redan idag finns alternativ som skulle kunna ersätta dessa faktorer och därmed minska plaggens totala miljöbelastning avsevärt.

Nyckelord

Livscykelanalys, operationskläver textilier, miljöanpassad upphandling, sjukvård

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1. Background and Introduction

Within the healthcare sector, large quantities of different materials and products are consumed on a daily basis. Hygiene and safety when dealing with patients along with service quality and comfort for the user are of highest priority within the sector. It is not surprising that the weight of these aspects often becomes prioritised over aspects of sustainability and environmental impact, when e.g. making the choice of products in procurements (Karlsson & Öhman, 2004). However, during the last decades, environmental issues have been given increasing weight within all levels of society, and have been reflected in political decisions, legislation and societal norms. Accordingly, environmental considerations have had increasing influence within the health sector. For instance, several organisations and movements working for green healthcare have emerged.

Health Care Without Harm (HCWH) is one of the most prominent organisations of this type, with members from over 50 countries. As an international organisation, through which governments, non-governmental organizations and mainstream health care institutions collaborate, HCWH works for reducing the negative environmental and social impacts of healthcare (Health Care Without Harm, 2012). In Sweden there is an initiative called Sustainable Healthcare, which works with promotion of solutions for economically, socially and environmentally viable healthcare (Sustainable Healthcare, 2008). Other examples of organisations that work for introducing greener ways of practicing healthcare are; Teleosis Institute[1], Health and Environment Alliance[2], Practice Green health[3] and Green Guide for Healthcare[4].

In Sweden, most of the environmental initiatives within healthcare are taken at a regional level. The majority of the Swedish healthcare is publically owned, and the authorities in charge of this sector are the regional County Councils (Landsting). It is important to note that there are two separate authorities at the regional level in Sweden; County Councils (CC) and County Administrative Board (Länsstyrelsen, abbreviated CAB). While the CC is a regional political authority elected by voters within the county, the CAB is a government authority, working with implementation of government policies throughout the county. Most of the regional environmental work is managed by CABs, even though they can collaborate with CCs within certain areas.

There are no specific environmental requirements for the CCs, however they are encompassed by several general Swedish directions and laws. The Environmental Code of Sweden (Miljöbalken, abbreviated MB, SFS 1998:808), applies with varying extent to businesses, organisations and all other actors within Sweden. Especially the second chapter in MB, containing "rules of consideration" has a wide area of application. These rules state e.g. that

[1] http://teleosis.org/
[2] http://www.env-health.org/
[3] http://practicegreenhealth.org/
[4] http://www.gghc.org/

"everyone who operates a business or performs an action should conserve raw materials and energy, as well as utilising opportunities for reuse and recycling"[5] (SFS 1998:808).

Much of the environmental work in Sweden is also influenced by the sixteen environmental quality objectives which have been set at a national level (Naturvårdsverket, 2012). At a regional level, each CAB is assigned to set their own goals within locally prioritised areas. However, the CABs generally cooperate with CCs and municipalities throughout development and implementation of the regional objectives (Länsstyrelsen Örebro, 2005). Especially objectives concerning the healthcare sector, like e.g. handling of medical waste are set in collaboration with CC (Miljömålsportalen, 2012). These objectives are not legally binding, but are still often used as guidance for what progress is expected within the state the environment in Sweden.

Due to the absence of strictly binding directions, the environmental undertakings within different CC's can vary considerably. Guidelines that concern CCs make it possible for a rather free interpretation of how to work with environmental questions. For a more detailed insight into the environmental work of a CC, some examples from the County Council of Örebro (Örebro läns landsting, abbreviated ÖCC), which is of special interest as it provides the main case of this study, are presented below.

1.1 Environmental Undertakings within Örebro CC

Several environmental undertakings have been made within the organisation of ÖCC. For instance, they have an environmental policy which states that all activities within ÖCC shall contribute to an ecologically sustainable development, protect both the external and internal environment, as well as promote public health, now and in the future. [6] The policy (Örebro läns landsting, 2008) also states that ÖCC will work actively towards:

- reducing emissions, waste, and consumption of natural resources;
- integrating environmental considerations in every decision in the organisations daily work, for continuous improvements;
- being a driver for environmental compatibility through procuring, buying and ordering goods and services which cause the least environmental impact.

The county council has further composed an environment- and sustainability program, containing their vision, aspirations and planned actions. Planetary boundaries, a concept comprising how the stability of global systems is jeopardised by diverse human impacts on the environment, constitute a basis for this document.[7] In the programme, ÖCC has identified several challenges which concretise what a sustainable development implies for their operations. One of these challenges concerns sustainable resource consumption and reads as follows: "ÖCC utilises resources in a sustainable way. This means that primarily renewable resources are used, and that non-renewable resources are managed in closed-loop systems."[8]

[5] Own translation
[6] Own translation
[7] For more information about planetary boundaries, see section 4.3 below.
[8] Own translation

(Örebro läns landsting, 2012). The program also contains five environmental goals that state areas of focus specifying actions on which their environmental work shall focus. Goal number four addresses the consumption of products and points out the importance of considering sustainability and the environment when purchasing products. Specifically, resource efficiency and adaptation to eco-cycles are to be prioritised in procurement and purchases. Several planned actions are stated in connection to the goal, one of which is to use life cycle assessment (LCA[9]) when procuring.

Alongside the increasing environmental concern, consumption rates within the healthcare sector are growing, and during recent years the usage of single-use products within the county has increased (Örebro läns landsting, 2012). There are several arguments for using single-use products. One of the main reasons is that they are practical and hygienic, but also because they often are cheaper than the reusable alternatives. This development is clearly contributing to the growing material consumption, which generally is associated with increasing environmental deterioration.

However, it is not always evident whether the use of either reusable or disposable products has greater environmental impact. When looking directly at two products, one that can be reused 100 times and 100 pieces of a disposable type, it can seem likely that it would take a greater amount of resources to produce the 100 specimens than the 1 reusable. Nevertheless, looking at the whole life cycle of a product, the raw materials, which it is made out of, only represent a small part of the total amount of resources needed to produce, transport, use and finally dispose the given product. Therefore, in order to compare the actual environmental impact of the given products, it is important to consider their whole life cycles.

1.2 Environmental Procurement

In the western society, which in many aspects is driven by economic factors, the purchasing choice of a consumer can have considerable power. The demand of consumers is thus one of the factors that directly affect what supply is offered on the market. Further, the increasingly prominent connection between consumption patterns and negative environmental impacts has entailed aspirations for taking environmental aspects into account in purchasing decisions (Alfredsson, 2002). By choosing products with lesser environmental impact, private consumers can influence which products will be stocked on the shelves in e.g. grocery stores, on a daily basis. One way of doing this on a larger scale is by introducing environmental guidelines for procurement. Environmental procurement is advocated by several organisations that deal with trade regulation, ranging from international to local level. On a macro level, FN, OECD and EU use recommendations and directives for environmental procurement as an instrument for increased environmental performance among their member states (Miljöstyrningsrådet, 2012). Special weight is put on the introduction of environmental requirements in public procurement. Reasons for this lie in the fact that the purchases of public authorities make up a significant part of a countries BNP (within EU it constitutes 16%

[9] LCA is a method for assessing an objects (product or service) environmental impact from ”cradle to grave”, thus throughout its whole life cycle. This method has been standardised through the development of the ISO 14040 standard series. For more information, see Chapter 4.

of the unions total BNP). Thus, the authorities are a powerful actor, and can by their demand have significant impact on the supply of environmentally sound products and services offered on the market (EU Report, 2007).

In Sweden, there is national legislation stating that authorities should take into account environmental and social considerations in public procurement, when the type of procurement motivates it (Lagen om offentlig upphandling, LOU (SFS 2007: 1091), 1 kap. 9 a§). Further, there are laws, both EG-directives and national Swedish law, for equal treatment and counteracting of discrimination in selection of products and suppliers (Lagen om valfrihets-system (SFS 2008:962), Directive 2004/18/EG). Therefore it is of importance to set clear standards regarding considered environmental criteria when conducting environmental procurement. Support in the choice of criteria and setting of environmental requirements is offered by the Swedish Environmental Management Council, (Miljöstyrningsrådet). This council is a governmental organ which has developed a set of procurement criteria, divided into different product categories. The criteria are available for anyone to apply, and are widely used by companies and authorities in procurement of products, services and work contracts. (Mlijöstyrningsrådet, 2012)

Procurement within ÖCC

Procurement within ÖCC is handled in two separate systems. The procurement of consumable goods (products that are consumed in high quantities) is directed by the Product Management Group (abbreviated PMG, original name Varuförsörjningen), a procurement entity where five of Sweden’s county councils collaborate. Procurement of remaining products and services is handled by administrations within ÖCC. Thus, different sets of criteria are applied for different product groups. Within ÖCC’s administrations, a set of basic environmental requirements is generally applied when procuring. These requirements concern; compliance with the “rules of consideration” in the Swedish Environmental Code (SFS 1998:808); Producers’ responsibility on recycling of their products (in accordance with Swedish legislation); Energy use; Content of hazardous substances in products; Production and contents of packaging. Further, a number of product categories (including e.g. furniture, food, vehicles and textiles) are considered as environmentally prioritised, which allows for setting additional requirements to be included in procurement (ÖCC, 2008). Usually, the environmental criteria of the Swedish Environmental Management Council are applied when setting additional requirements. (Richert, 2012) As mentioned earlier, the ÖCC has also introduced environmental guidelines for procurement in their environmental strategy. These guidelines are of a visionary kind and show the counties attempts to introduce a wider environmental consideration in procurement. However, they do not impose any binding requirements.

Concerning the procurement of consumable goods PMG have their own environmental requirements. The base requirements overlap those of ÖCC, however, PMG have one additional requirement concerning availability of information about the product. More stringent requirements are applied for environmentally prioritised product groups. Further, the PMG also apply a set of case-specific guidelines within all their procurement (Richert, 2012).

2. Purpose and Objectives

Based on their fourth environmental goal about products, the ÖCC decided to investigate the environmental impact of some of the products that they use in their daily work. One example of products that are frequently used within healthcare is surgical scrub suits. The health sector within the county of Örebro has previously utilised reusable scrub suits, but during recent years disposable alternatives have appeared on the market. With the same advantages as mentioned above for disposable products, ÖCC is considering which type of scrub suits to use in the future. As mentioned before, the environmental impact of products is one of the aspects to be considered in the counties procurement. Therefore, ÖCC has appointed for this LCA to be performed, so that the environmental aspects of the two types of scrub suits can be assessed.

The objective of this study is to evaluate and compare the environmental impacts, in a life cycle perspective, of a single-use and a multi-use surgical scrub suit. Accordingly, the purpose is to give the County Councils and other actors who might find the evaluated products of interest, decision support and thereby enable them to take environmental impact into account in future procurement of surgical scrub suits. The evaluation is based on certain environmental aspects, assessed to be relevant and of interest for the given case. Life Cycle Assessment is the method used to perform this study.

This LCA was conducted on behalf of the ÖCC. Consequently operations within the ÖCC provide the main case for the user and disposal phases of the assessment. The County Council of Uppsala (abbreviated UCC) also showed great interest in this study, and were willing to provide data concerning usage and disposal within their organisation. Thus, data from UCC was used in sensitivity analyses of these phases, allowing for a broader application of the results.

The target audience of the results are primarily the ÖCC and UCC. As this is a master's thesis, the results are also published through the university and thereby available to the public. The results of this LCA are thus for external use, and will not directly have any influence on the companies that produce the investigated products. However, the final report is of course also available to the companies that are involved in the products life cycles.

Research questions:

- Which of the studied objects is environmentally favourable relative to the studied impact categories?
- Which parts of each life cycle have the greatest potential environmental impact, and how does this differ between the two products?
- Within which impact category does each of the products have their highest environmental impact, in relation to the average global yearly emissions?

3. Outline of This Thesis

The following chapters of this thesis comprise the theoretical framework, literature review, the LCA in accordance with the ISO-14040 framework and results.

Chapter 4, Theoretical Framework, presents the outlines of LCA and the ISO-14040 framework, followed by a section about the concept of Planetary Boundaries.

Chapter 5, Literature Review, covers previous LCA-research within fields relevant for this paper. These include LCA's within the fields of: textiles, healthcare, procurement and LCA's comparing reusable with disposable products.

Chapter 6, LCA of Single- and Multi-use Surgical Scrubs, presents the phases of Goal and Scope, LCI and LCIA-methods.

Chapter 7, Results, comprises the results and main findings of the LCIA along with performed sensitivity analyses.

The final chapter, *Chapter 8, Discussion and Conclusions,* contains three parts. Firstly, limitations of the results are discussed. The second section presents the conclusions relative to posed research questions, and the final part concerns reflections and suggestions.

4. Theoretical Framework

In this chapter, the concept of LCA and its main characteristics are described. Further, the international ISO-14040 standard series are introduced, divided into the four main phases of: *goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation*. The theoretical framework also includes a presentation of the concept of planetary boundaries, which are later used in the analysis of environmental impact.

4.1 What is LCA?

Life cycle assessment (LCA) is a method for analysing the environmental impact of a given object (product, service, system etc.). From the extraction of raw materials, production and transports, to consumption and disposal - an LCA takes into account all the different stages in the life cycle of the studied object. Hence, the term "from cradle to grave" is often used to describe the scope of an LCA. This holistic perspective is important in order to avoid so called problem shifting, when actions for reduction of environmental impact in one phase of a life-cycle lead to increased impact elsewhere (Finnveden et. al., 2009).

Generally, LCA is a method of quantitative character and qualitative aspects should only be used when not possible to stay within the quantitative field (Guinée et al., 2004).

LCA studies can be used in numerous different applications. Guinée et al. (2004) suggests that the four main areas of application are:

- Analysing the origins of problems related to a particular product
- Comparing improvement variants of a given product
- Designing new products
- Choosing between a number of comparable products

The applications are often customised to suit the requirements, circumstances and intended results of the given case. Depending on the purpose of the study, both the approaches and tools used in an LCA can differ significantly. For more information about different LCA applications see e.g. the ILCD-Handbook (2010) by JRC-IES, or Baumann & Tillman (2004).

It is important to distinguish between two different types of methods for LCA. The first kind is called attributional or accounting and refers to a comparative and retrospective study (Baumann & Tillmann, 2004). This kind of LCA is of a descriptive kind, and investigates the different physical flows in a life cycle that are of environmental relevance. A second common category of LCA is the change oriented and prospective type, which focuses on how environmental impacts within certain phases of a life-cycle will change in response to potential decisions (Finnveden et. al., 2009). Besides the effects within a process chain, change oriented LCA can also incorporate a wider view, considering effects on other products, or parts of society like market mechanisms. (JRC-IES, 2010)

Generally, slightly different methodological choices are made depending on weather an attributional or change oriented approach is used. Thus need for distinctions between these two types of LCA has been noted recurrently, and it is still debated in which cases the different methods are most appropriate. According to Finnveden et al. (2009) a structuring of the different fields of LCA is needed, so that clarity between issues concerning the handling of time, space, as well as economic and social issues, can be attained.

4.2 ISO 14040

In 1997, the European Committee for Standardization published their first set of international guidelines for the performance of LCA. This ISO 14040 standard series has become widely accepted amongst the practitioners of LCA and is continuously being developed along with progressions within the field of LCA (Rebitzer et al. 2003). The guidelines for LCA are described in two documents; ISO 14040, that contains the main principles and structure for preforming an LCA, and ISO 14044, which includes detailed requirements and recommendations. Furthermore, a document containing the format for data-documentation (ISO/TS 14048), as well as technical reports with guidelines for the different stages of an LCA (ISO/TR 14049 and ISO/TR 14047), are available in this standard series. (Carlsson & Pålsson, 2011)

Following the ISO guidelines, an LCA is conducted in four phases; goal and scope definition, inventory analysis, impact assessment, and interpretation. Here follows a short description of the content within each of the four phases.

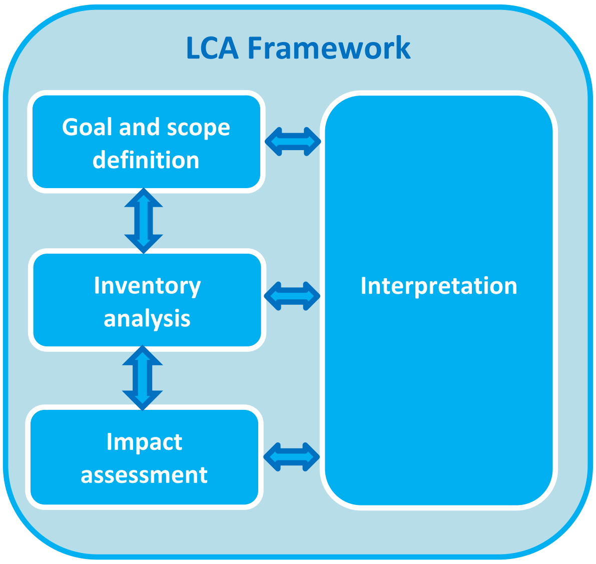

Figure 1: The four stages of LCA, with arrows indicating interaction between stages. (ISO 14040:2006, p8)

Goal and Scope Definition

This initial step defines the context of the LCA, where goal, scope and boundaries etc. are decided. ISO 14040 (2006) provides specific guidelines on what these different parts should include. For instance, the goal of the study should state the intended application, causes for performing the study, what audience it is intended for, and whether the results are intended to be used in publically available, comparative statements.

Further guidelines within the goal and scope definition concern detailed requirements for scope definition, as well as recommendations for functional unit, system boundaries, and data quality requirements.

It is stated in the standard (ISO 14040, 2006) that "the scope should be sufficiently well defined to ensure that the breadth, depth and detail of the study are compatible and sufficient to address the stated goal." (ISO 14040, 2006. p.11) Hence, a specific and clear initial goal and scope definition is crucial in order for the upcoming results to be correctly interpreted. If this is not achieved, the risk for unintentional misinterpretations and misuse of the results increases. However, as the LCA is of iterative character, this phase is reviewed and revised throughout the rest of the LCA process. (JRC-IES, 2010)

As mentioned above, a Functional Unit (FU) is determined at this stage, and defines the "unit of comparison which assures that the products being compared provide an equivalent level of function or service" (U.S.EPA, 2006, p79). Care should also be taken when selecting the FU as it will be used as a base for the format in which results will be displayed. A correct FU is of special importance in comparative LCA, as it will found the base for comparison between the studied objects. Thus, it is of vital importance for the accuracy of the study, as s well as the relevance of the results. (U.S.EPA, 2006)

Life Cycle Inventory (LCI)

The second of the four phases is the life cycle inventory analysis (LCI) which is also the phase which generally requires the highest input of effort and resources. In addition to data collection, the inventory analysis includes data acquisition and modelling. (JRC-IES, 2010) Initially, data is collected from all the activities within the investigated system in order to quantify the inputs and outputs that are of interest for the study. As the data for different parts of the system can be collected in diverse ways, and from a number of different types of sources, it is of importance that measures are taken to reach uniformity and consistency when the subsystems are unified into one life cycle. (ISO 14044, 2006)

The information obtained during this process is further used to construct detailed models of the different flows within the system. These flowcharts are designed according to the system boundaries defined in the previous phase.

One of the difficulties that can appear when trying to identify flows within a system is when an industrial process also generates other products than those of interest for the LCA. How to determine which flows are accountable for the studied life cycle is an allocation problem. The ISO standard states that allocation should be avoided as far as possible by either division of the unit process or expansion of the product system. When allocation cannot be omitted, the flows within the system should be divided between the different products, based on quantifiable relationships between them. (ISO 14044, 2006)

Life Cycle Impact Assessment (LCIA)

The aim of the LCIA phase is to describe the environmental consequences of the material and energy use, as well as emissions, which have been quantified in the inventory analysis. From quantified units of different substances, a translation is made here, so their impacts within different environmental aspects can be assessed. (Baumann & Tillmann, 2004) Throughout the last decades, several methods with standardised characterisation models have been developed for facilitating this transformation of raw data into environmental impacts. (Goedkoop et al., 2009)

Following the ISO-standard (ISO 14044, 2006), there are three obligatory elements to be included in the LCIA. Firstly impact categories, indicators and models for characterisation of the aspects are selected. The impact categories represent the types of environmental impacts which are of concern for the given LCA, like for example depletion of resources, global warming and eutrophication. Category indicators and characterisation models are then chosen to fit for assessment of the chosen categories. The second element is called classification, and consists of assigning the LCI results to the chosen impact categories. Finally, the characterisation is done, where the results of impact within each category are calculated. To provide transparency, it is of importance that all the methods for assessment and calculations are documented.

There are also four optional elements for the assessment: normalisation, grouping, weighting and data quality analysis. For more information about these procedures, see section 4.4.3 in the ISO 14044 standard.

Interpretation

Because LCA is an iterative process, a continuous reflection over which changes can be done in the inventory model, to better suit the goal of the study, is practiced. Thus, interpretation is part of all the steps which follow the goal and scope definition, interpretation is necessary. However, the final step of the LCA consists of a broader interpretation where the results of the LCIA are assessed in relation to the aim and research questions of the study. In a comparative study, assessments of the different products are analysed and compared. The final purpose of this phase is to derive conclusions and often also provide recommendations. (JRC-IES, 2010)

In accordance with the ISO standard, the phase of interpretation includes elements of identification, evaluation and conclusions. More specifically, these elements involve:

- identification of the significant issues based on the results of the LCI and LCIA phases of LCA;
- an evaluation that considers completeness, sensitivity and consistency checks;
- and conclusions, limitations, and recommendations (ISO 14040, 2006).

4.3 Planetary Boundaries

The concept of *planetary boundaries* has been used as a baseline in ÖCC's environment- and sustainability programme. Hence, it is of interest for the county council to relate the results of this study with the guidelines and planned measures of the programme. Such a connection is done in this thesis by choosing LCIA-methods which can be related to the planetary boundaries.

In 2009, a group of scientists led by Johan Rockström wrote an article about sustainability, where limits to our earth's carrying capacity, divided into nine different categories were stipulated. The article, *Planetary Boundaries: Exploring the safe operating space for humanity* (Rockström et.al. 2009), has received much attention within the sphere of sustaina-bility research and reached out to a large audience through education and media.

With a baseline in the fact that humanity thrives on earth because of certain prevailing conditions on our planet (the state of Holocene), Rockström et al. suggest that these conditions are threatened by the system changes that we impose on nature by diverse environmental impact. Anthropogenic[10] environmental impact is divided into nine key earth system processes: climate change, ocean acidification, reduction in stratospheric ozone, biogeochemical nitrogen cycle and phosphorous cycle, global freshwater use, land system change, biological diversity loss, chemical pollution and aerosol loading. These categories were identified as being key systems because of their high significance and wide ranging effects within the spheres of earth. Together they cover the:

- biological, geological and chemical cycles of four key elements essential to life on earth (nitrogen, phosphorus, carbon, and water),
- planets main physicals circulation systems (climate, stratosphere and ocean systems)
- biological features of earth which build up its resilience and self-regulating ability (marine and terrestrial biodiversity, land systems),
- and two significant impacts associated with global effects that result from human activities (aerosol loading and chemical pollution) (Rockström et.al. 2009).

For each category, a boundary is set within which it is supposed that humanity can operate safely. However quantified limits have only been set for seven of the categories. Because of deficient scientific understanding, boundaries for chemical pollution and aerosol loading have not yet been possible to define.

Through quantification of boundaries, Rockström et. al. could estimate in which state our planet lies within each of the categories. Results of this quantification show that humanities impacts on the earth systems biodiversity loss, nitrogen cycle and climate change already have transgressed the boundaries of a safe operating space (see figure 2 below).

[10] Caused by humans.

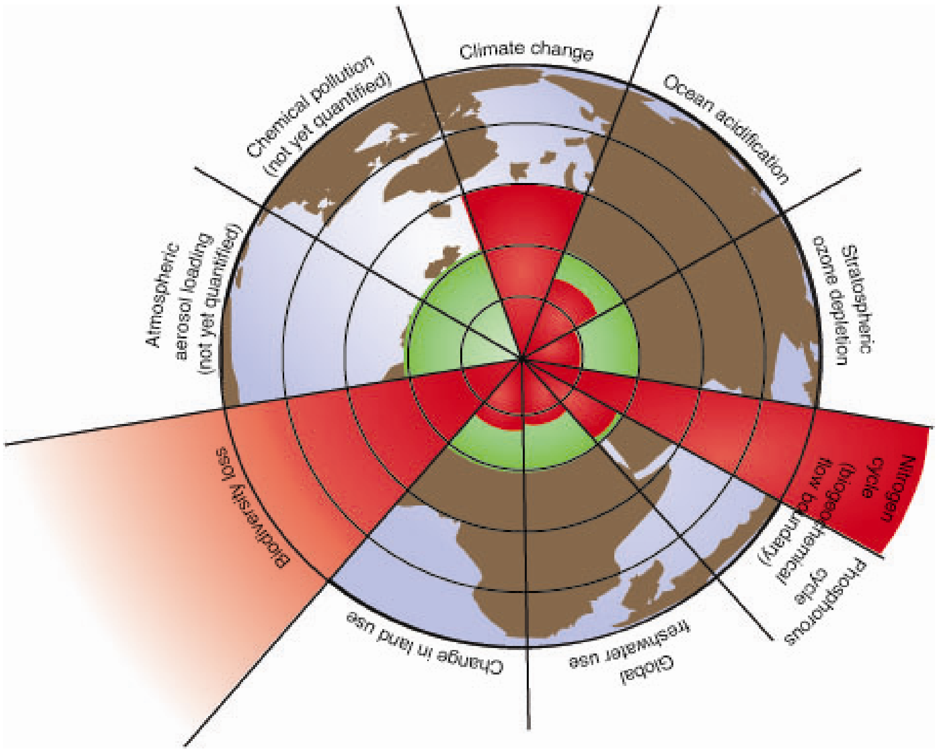

Figure 2: The safe operating space is within the inner fields marked in green. Note that the extinction rates of the Biodiversity loss boundary exceed the space available in the image. (Figure retrieved from Stockholm Resilience centre, *Planetary Boundaries Research* [online])

A continuous transgression of the boundaries might result in disruption of the relatively stable state of the Holocene. Such an event would lead to changes in the environment and increase the fluctuations within its different systems, which could have catastrophic effects on humanity. It is so far uncertain for what amount of time the boundaries can be transgressed before the resilience of the planet is strained beyond return, and we are pushed out of the Holocene. (Rockström et.al. 2009)

All of the considered systems are very complex, and constantly affect, and co-function with, countless external factors. Generally, there is still a lack of scientific knowledge concerning many of these effects and connections. In order to make the quantification possible, calculations of each boundary are based on the assumption that none of the other boundaries are transgressed. However, it is important to note that in reality it is most credible that interactions among planetary boundaries will occur, and thereby change the safe level of one or several systems. These knowledge gaps and assumptions result in a zone of uncertainty around each quantified threshold. Consequently the boundaries which are set are not definite, but rather preliminary attempts for quantification of limits. (Rockström et.al. 2009)

5. Literature Review

This chapter presents earlier research and studies which are of relevance for this thesis. The area of interest includes LCAs on textiles, within healthcare, within procurement and generally LCAs comparing reusable with disposable products.

5.1 LCA of Single- vs. Multi-Use Products

Comparative LCAs that study single- and multi-use products represent a relatively common application of LCA. However, as clothes or textiles generally are produced for reusable purposes, quite few LCAs within this specific field are available. One exception is found in the case of diapers, where several studies comparing reusable (fabric) diapers with disposable ones have been conducted. In 1990, the company which had introduced disposable diapers onto the American market, commissioned Arthur D. Little (an international consulting firm, with specialisation in environmental issues) to make a comparative life cycle assessment of disposable diapers and reusable ones (Arthur D. Little, 1990). Since then, several assessments of this kind have been conducted, though, with different types of limitations and most of them being performed, or commissioned by organisations with a vested interest in the results (Environment Agency, 2005).

In 2001, however, the Environment agency of the UK, commissioned an objective and independent environmental LCA study of disposable and reusable diapers, which was published in 2005. There are several similarities between the life cycles of the two types of diapers and the surgical scrubs assessed in this study. Namely, that the reusable product contains cotton, and includes a washing loop in its life cycle, while the disposable product is largely made of synthetic materials. The results of this study revealed no significant differences in environmental impact between the two types of diapers. It was also determined that the main environmental impacts were found in different life cycle stages of the studied products. (Environment Agency, 2005)

Several types of comparative LCAs, of reusable and single use products have been conducted within the area of healthcare, most commonly for the purposes of decision support. Some examples of products assessed are; laparotomy pads (Krümmerer et al., 1996), suction receptacles (Ison & Miller, 2000), bioreactors (Mauter, 2009), anaesthetic drug trays (McAlister et al., 2010) and sharps containers (Grimmond et al., 2011).

5.2 LCA of Textile Products within Healthcare

Narrowing it down further, to research assessing products similar to the scrub suits of this LCA, a few interesting studies have been conducted. In 1993, the company Arthur D. Little made an independent study where the environmental impacts of single-use and reusable drapes and gowns were assessed. As well as for the diaper studies mentioned above, the results of this study showed that the environmental impact of these products was of similar extent, though within different impact categories. Thus, from an environmental point of view, the results did not point in favour of any of the products. (McDowell, 1993) In 1998, a similar study was conducted in Germany, assessing single-use versus mixed-reusable surgical drapes (Dettenkofer et al., 1999). The mixed-reusable drapes consisted of both a reusable cotton drape and an impermeable disposable plastic drape, which gave this alternative the environmental burden of both cotton drapes and disposable drapes. In this case the results showed a greater environmental impact of the mixed-reusable alternative.

In 2003, CIT Ekologik AB performed a comparative LCA of surgical gowns, where single-use and multi-use gowns were assessed. The results of this study showed that the reusable alternative, in respect to a vast majority of the studied environmental aspects, was the better choice. (Eriksson & Berg, 2003) A similar study was conducted in 2008, at the RMIT University in Australia, where laundered surgical gowns were compared with disposable gowns. Likewise, the results showed that the disposable gowns had greater potential environmental impact within the majority of analysed impact categories (eight out of nine). The lesser impacts of reusable gowns were determined to result from the products longer lifespan, which in turn decreases the weight of manufacturing impacts relative to the whole life cycle (Carre, 2008).

5.3 Reflections Based on Reviewed Literature

There are many similarities between CITs study on gowns and the one performed here, but also important differences. For instance, the products that are compared have different components, and different environmental impacts are assessed. Also, in CITs study, mostly average data within given sectors were used, while this study to a greater extent is based on specific data for the studied case. Overall, this study is adjusted to better suit the needs and demands of ÖCC.

When looking at the previous studies, it becomes prominent how small specific details in each studied case, can have significant impact on the results. For example, in Ison & Miller's (2000) study on suction receptacles, two reusable alternatives were compared with one single-use. Both reusable alternatives were actually the same product, but used in different hospitals and had therefore dissimilarities within the use phase. The results showed that one of the reusable alternatives had far lower potential environmental impact than the single use receptacle, while the other reusable alternative higher (in all categories besides resource depletion). The significant difference between the reusable products depended on which washing process was used in the hospitals.

This example demonstrates how relatively small parts of a products life cycle can be of essential importance for the results. Thus, results of LCA's conducted on very similar products, using the same methodology, might not me applicable on other cases. Furthermore, beside differences in products life cycles, results also depend on assumptions, data quality, boundaries etc. Therefore, much care has to be taken when drawing conclusions based on previous LCAs or making comparisons between products.

6. LCA of Single- and Multi-Use Surgical Scrubs

This chapter describes the three first phases of LCA according to the ISO-standard; *Goal and Scope Definition*, *Life Cycle Inventory Analysis* and *Impact Assessment*. Note that the goal and scope definition addresses topics usually described in the methodology chapter of a thesis.

6.1 Goal and Scope Definition

6.1.1 Goal of the Study

The goal of this LCA is to study and evaluate the potential environmental impacts of a single-use and a multi-use surgical scrub suit, from a life cycle perspective. Throughout this assessment, the attempt is to use as complete and accurate data as possible, to create a factual model of the life cycles and their environmental impacts. The results of the life cycle inventory are evaluated based on certain environmental aspects, assessed to be relevant and of interest for the given case. Additionally, the study attempts to investigate which parts of each life cycle have the greatest environmental impact, and how this differs between the two products.

The reason for performing this study lies in ÖCC considering which type of scrub suits to use in the future. Environmental impact of products is one of the aspects to be considered in the county's procurement. Therefore, ÖCC has appointed for this LCA to be performed, so that the environmental aspects of the two types of scrub suits can be assessed.

Operations within the ÖCC provide the main case for the user phase of the assessment. As the CC of Uppsala (abbreviated UCC) also showed great interest in this study, data from UCC was used in a sensitivity analysis of these phases, allowing for a broader application of the results.

The intended audience of the results will primarily be the County councils of Örebro and Uppsala. As this is a master's thesis, the result will also be published through the university and thereby available to the public. The results of this LCA are thus for external use, and will not directly have any influence on the companies that produce the investigated products.

With some reservations due to the limitations of this study (it is conducted within the time- and resource boundaries of a master thesis) the results are intended to be used in comparative statements and will be disclosed to the public.

6.1.2 Scope of the Study

The systems studied in this LCA, are the life cycles of two different types of surgical scrub suits, one single use, and one reusable for 100 uses. While the disposable scrubs mainly consist of polypropylene, the main component of the reusable scrubs is cotton. Both types of scrub suits consist of a blouse and trousers, which surgical personnel wear underneath surgical gowns. The main function of the scrub suits is to work as a barrier, obstructing particles from the bodies of the personnel to spread out into the room.

Individually, the two life cycles are assessed using the cradle-to-grave approach, starting with the raw material acquisition, through manufacturing, usage and to the final step of waste management.

The foreground system studied in this LCA includes the production of fabric, production of clothes, usage (washing in the case of reusable scrubs) and disposal. Several background systems have also been included in the assessment, mainly covering the acquisition and production of materials used in the scrubs manufacturing. Within the foreground system, data concerning the specific processes within scrubs manufacture have been collected, while the sub systems have been assessed with generic process data.

Table 1: Included parts in the studied life cycles, divided into foreground, and background systems.

Foreground:	**Background:**
Production of fabric Production of clothes Washing (reusable scrubs) Disposal Transports	Cotton production Polyester production PP production Viscose production Latex production Production packaging materials (PE, Corrugated board).

Functional Unit
The unit of comparison between the two studied products is:

1 use of a scrub suit of an average medium size, which fulfils the requirements of the European standard EN 13795, within ÖCC

One use was selected because it is the most basic unit of comparison between the two types of scrubs. When choosing this functional unit consideration was also given to the permeability of the scrubs, because it is one of their main functions. As the European standard EN 13795 sets quality and safety parameters for surgical textiles, and it is considered as of importance for the county councils, the fulfilment of the standard was included in the functional unit. Because the sizing systems for the two types of scrubs differ, the size is defined in two ways. Both chosen sizes (*M* and *155-175 cm/60-80 kg*) represent a regular size medium. The size chosen for this assessment was the most frequently used within the hospitals of ÖCC during last year.

6.1.3 System Boundaries

The life cycle of a studied object is defined by inputs, outputs, energy- and material flows etc., which reach far beyond the factories where the production is conducted. Consequently, it is of great importance to carefully consider where to draw the line between what should be included in the life cycle and what is insignificant for a given study. In a comparative LCA study it is of special importance that the processes which vary between the two systems are included. Below follows a description of the system boundaries of this study, divided into four different types of boundaries.

Boundaries in relation to natural systems

The boundary between natures systems and the life cycle of the studied product, the so called cradle, is set to raw material extraction, or farming in the case of cotton. Further, all the steps of production, transports, distribution, usage and disposal, are included. The grave of the life cycle is reached when there is no more human involvement, and the constituents become part of the natural systems through emissions into air, water, and soil.

Geographical boundaries

The life cycles of the studied products are spread among different parts of the world. Phases of raw material extraction and farming, as well as manufacture of the products will be assessed on a global scale. A narrower geographical boundary is drawn within the phases of usage and disposal, as these phases take place within the borders of Sweden. More specifically, these final phases are assessed according to circumstances within the counties of Örebro and Uppsala.

When assessing environmental impact, average impact values are used as point of reference. Thus, no consideration is taken to the differences in sensitivity among diverse habitats and ecosystems in different parts of the world.

Time boundaries

The study is conducted in 2012, and refers to prevailing circumstances. As this LCA is of attributional type, with a purpose to assess current environmental impact, no future projections are taken into account. In line with this, long term emissions are excluded.

Boundaries within the technical systems - related to production capital

A products life cycle is built up of several different subsystems, which together enable the manufacture, transport and use of products. This study assesses the life cycle of the systems, which includes all of the resources that the product is made out of, as well as the flows of water and energy needed to complete its life cycle.

The life cycles of infrastructure such as machines, vehicles, roads and buildings which are used in the scrubs-systems are not included. However, the energy or fuels consumed in the use phase of capital goods such as heat and electricity for buildings and fuel for transport vehicles are included in the study.

Designing of products and the administrative work which is connected to the studied life cycles are not assessed.

Boundaries with other systems

Within the practice of LCA, there are divergent opinions about how to draw the lines between two life cycles which merge into each other. One common example where this question occurs is when the waste from one product is incinerated, and energy is produced to be used in a new products life cycle. Besides the generation of energy, materials which would have been used to produce that energy in other cases are avoided.

In this LCA, boundaries with other systems, and the allocation of environmental burdens between them, are based on the recommendations of the international EPD system[11], which are also in line with the requirements and guidelines of the ISO14040 and ISO14044

[11] EPD (Environmental Product Declarations) by the International EPD Cooperation (IEC)

standards (IEC, 2008). In accordance with these recommendations, the Polluter Pays (PP) allocation method is applied. For allocation of environmental burdens when incinerating waste, this implies that all of the processes in the waste treatment phase, including emissions from the incineration are allocated to the life cycle in which the waste is generated. Following procedures for refining of energy or materials used as the input in a following/receiving process, are allocated to the next life cycle.

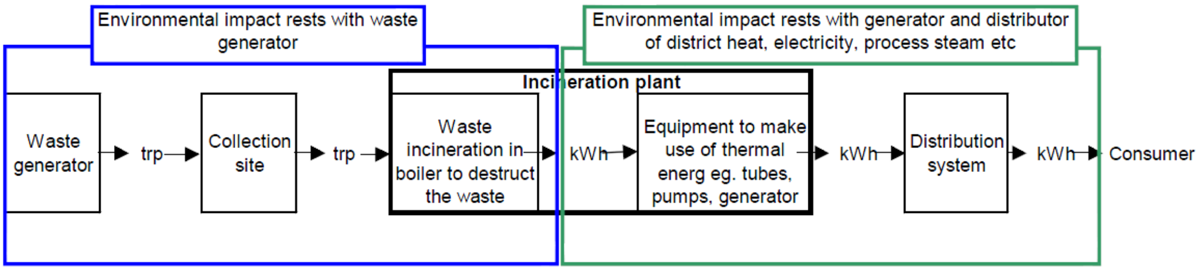

Figure 3: Allocation of environmental impacts between two life cycles according to the PP allocation method. Here regarding to incineration of waste and resulting energy products (Image from IEC, 2008, p14).

In the case of recycling (e.g. cardboard/plastic), environmental burdens are accounted for outside of the generating life cycle, and have thus been allocated to the subsequent life cycle which uses the recycled materials as input.

In this LCA, the heat and electricity recovered from the incineration of waste has been taken into account, but modelled as an empty energy process which does not affect the inputs of the life cycle. Recovered energy from waste incineration has been presented and discussed in the results in comparison to cumulative energy demand. Avoided materials due to recycling of cardboard and plastics have not been taken into account.

6.1.4 LCI Modelling Framework

An attributional modelling framework is applied in the LCI, because it is best suited for the purpose of this study. More specifically, an attributional modelling framework was chosen over a consequential, because this LCA is focused on analysing the potential environmental impacts of currently existing processes and products. The outcomes of this study are not aimed to give propositions for changes in any current processes (which is often the case in consequential modelling). Thus, in this case an attributional assessment without assumptions on changes in production or other future circumstances gives sufficient information about the environmental impacts of the studied objects.

The methodology of the inventory analysis comprises data collection, modelling of the supply chain and calculation of environmental impacts. Thus, the LCI process started with determining which data sets were necessary to include in the inventory. After this determination, the collection of specific data was initiated, with continuous documentation in tables. The last step of the inventory phase included transferring the specific data into models and complementing the inventory with general data for processes such as raw material extraction and transports. As this work was made iteratively, and acquisition of several data was delayed, the work process did not follow these steps in sequence. The completion of the different steps rather made simultaneously, along with incoming data.

During the inventory phase, four life cycle phases were identified: production of fabric, production of garments, usage and disposal. Consequently, the modelling of processes within the studied life cycles was organised according to the four phases.

Contact with the manufacturers of the products, or representatives appointed by them, has been maintained throughout the collection and modelling of data. This allowed for supplementary questions and explanations to be given in case of ambiguity in the datasets received.

6.1.5 Data Quality

Because this is a study of two specific products data are, as far as possible, site-specific and thus collected from the different productions stages. This is of importance so that the data is representative for the studied products. However, where data could not be obtained, or when a phase in the life cycle was not specific for the product, average data representing common practices were used to fill in the missing links. To omit discrimination, where specific data could not be attained for one of the products, generic data have been used for both products. All data concerning raw material extraction (farming in the case of cotton) and refining are non-specific for the products, and have been collected from LCA inventory databases such as Ecoinvent and ELCD.

The sources of data used in the inventory were chosen based on consistency with the assessed process, and preferably representing values within the last decade. When generic data is used, at first hand data representative for countries with similar technological conditions has been used, rather than setting geographical proximity as a standard.

All of the specific data collected have been supplied by the manufacturers of the products. Thus, verification or control of the obtained data, other than an estimation of their reasonability, has been difficult to make. Concerning the generic data, reliable and widely acknowledged data sources have been used as far as possible. When data from less conventional sources have been used, it has been documented in the LCI phase.

6.1.6 LCIA Method

Impact categories chosen for the LCIA of this study are based on the environmental issues which are addressed in the *planetary boundaries*, previously described in section 4.3. Of the nine categories for which planetary boundaries are set, seven have been assessed here: climate change, biogeochemical nitrogen cycle and phosphorous cycle, aerosol loading, reduction in stratospheric ozone, global freshwater use, land system change and ocean acidification. Impacts on *chemical pollution* and *biological diversity loss* have been excluded because of lack of information concerning chemicals used in several processes of the life-cycle, and in the second case, because there is no good way to quantify loss of biodiversity as an environmental impact in LCA.

For analysing the inventory results, primarily the ReCiPe 2008 impact assessment method was used. The ReCiPe method was composed in cooperation between several important actors within the LCIA development, (RIVM, CML, PRé Consultants, Radboud Universiteit Nijmegen and CE Delft) (ReCiPe, 2009). This method contains 18 set midpoint indicators, and standardised models for characterisation and classification of emissions. Seven of the indicators in ReCiPe were chosen for this LCIA, based on their consistence with six of the categories of the planetary boundaries (see figure 4). Remaining categories in ReCiPe, which were not used in this assessment, are: terrestrial acidification, human toxicity, photochemical oxidant formation, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, ionising radiation, urban land occupation, natural land transformation, mineral resource depletion, fossil fuel depletion. Excluded categories were not assessed due to a lack of direct links between them and the categories of the planetary boundaries. For more information about the compliance between the chosen midpoint indicators and planetary boundaries, see table 13 in section 6.3

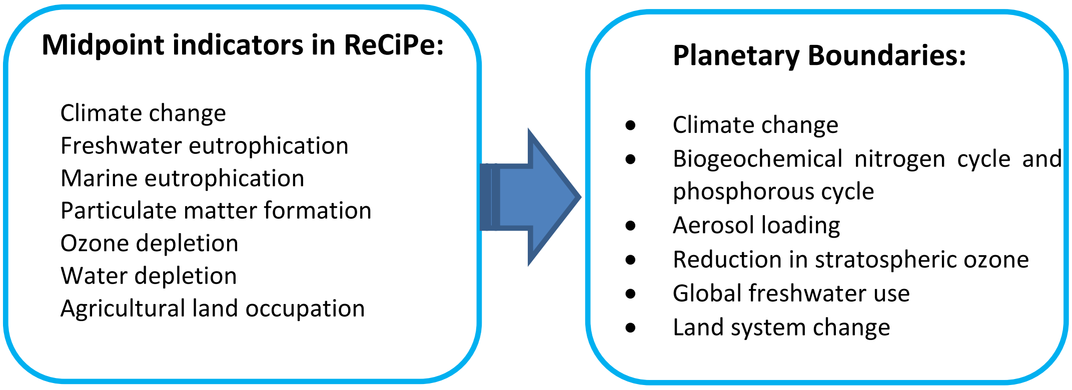

Figure 4: The indicators used in the LCIA, and their correspondence with categories addressed in the concept of planetary boundaries.

The category *ocean acidification* is indicated by levels of carbonic acid in the oceans, which is directly connected to atmospheric CO_2 levels. At present, there is no LCIA method that only assesses CO_2 emissions exclusively (there are several methods for assessing climate change, which include all of the GHG gases). For assessing impacts on ocean acidification, all recorded emissions of CO2 levels were used.

In addition to the impact categories mentioned above, *energy use* was added to complement the others. Energy is a resource of great importance for basically all phases of the life cycle, and gives a comprehensible image of the environmental "effort" put into the product. Energy use was assessed with the CED method (Cumulative Energy Demand), which divides consumed energy into renewable and non-renewable sources. This method is based on the CED-method published by Ecoinvent (Swiss centre for life cycle inventories), and which has been extended by the Pré Consultants to include more of the materials included in the SimaPro software. CED computes the different energy types consumed throughout a life cycle, distinguishing different types of primary energy, and their specific heating values. (Hischier et al., 2010)

A common way for making the results of an LCIA more tangible is by putting them into a context. This method is called normalisation, and means that a scaling factor is applied so that the results can be related to a reference value. In this study, normalisation values have been applied from Sleevik et. al. (2008, with latest adaption made in 2010) which are standardised in the ReCiPe method. The reference values of emissions and consumption used are those of average global emissions measured in 2010.

In all the impact categories except ocean acidification, pre-set classification and character-isation factors have been applied (see table 13 in section 6.3). For assessing impacts on ocean acidification, emissions of CO_2 levels were used, divided into three types of CO_2, all characterised with factor 1. A normalisation factor for average global emission of CO_2 in 2010 was applied on the results.

Following the ISO standard, weighting of environmental impact is not permitted in the case of comparative assertions which will be disclosed to the public (ISO14040, 2006). Thus no weighting has been performed.

More information and details concerning the impact categories used in the LCIA can be found in section 6.3.

6.1.7 Sensitivity Analysis

Sensitivity analyses have been conducted in the cases where data gaps have occurred, or when assumptions have been made. The main difference between the life cycles of the assessed products is that the reusable scrubs have a significant usage phase. Since the impact from transports and washing can vary considerably between different cases, sensitivity analyses were conducted using data from UCC. Using realistic data in the analyses also gives the results increased reliability. More information about sensitivity analyses procedures and their results can be found in section 7.4.

6.1.8 Allocation Procedures

In processes where other products than the assessed scrubs are included (such as washing, and incineration), and where sub division has not been possible, allocation by weight has been conducted. In some cases other types of allocation have also been included, which has been documented in the LCI chapter.

In the final stage of the life cycle, both products are incinerated as municipal waste. The waste scenario used allows for specifying what type of waste is incinerated, and in which quantities. Thus, allocation of emissions from incineration was based on mass.

The application of allocation by mass is an accepted method commonly used in life cycle assessments. However, it does lower the overall accuracy of the data.

6.1.9 Delimitations within the Life Cycles

To avoid overseeing of significant parts of the studied systems, no initial cut off criteria were set. After data collection, because of different reasons, parts of the system were excluded from the assessment. Excluded parts and reasons for exclusion are described in the following bullet points.

- Out flows, such as heat and steam, from the different phases of the studied life cycles are excluded, because the environmental impact they cause is insignificant in relation to other parts of the LCA.
- Parts of the life cycle which are identical for both of the studied products, e.g. transports within the hospital, have been excluded. This affects the precision of the results when assessing the life cycles individually. However, no phases which are likely to have significant environmental impact have been excluded in this way.
- The study is limited to assess the fabric of the scrubs and some of the details that are attached when sewing the scrubs. Cuffs and waistband are included in the study, while

the smaller pieces, such as buttons, thread, transfer prints and size tags lie outside of the boundary. In total, the excluded materials account for 3.6 mass-percentages of the reusable garments and 3.7 mass-percentages of the disposable. The exclusion of these parts could have some impact on the results of this study, and are further discussed in the discussion chapter, under 8.1.

- Different types of chemicals are used in several phases of the life cycles, and were initially planned to be included in the assessment. Due to confidentiality concerns most of the formulations of the different agents could not be accessed. Consequently, the use of chemicals has not been included in this LCA. The production and use of laundry detergent has been included because it was assumed to have significant environmental impact within other impact categories, such as eutrophication.
- It was initially intended to include the sewing of scrubs in this assessment. Due to inconsistencies in data, the process of sewing scrubs was excluded. Specifically, the energy-data had been allocated based on sewing-time for one of the products, and on weight allocated for the other. Further, the electricity used for sewing the multi-use scrubs was about 100 times higher compared to the single use garment, and when trying to investigate the reason for this difference, no accurate information concerning what was included in the energy data could be obtained. Based on these uncertainties, the sewing process was excluded. This process would in both cases only have included electricity as energy input, and the chances that it would have had any substantial significance for the environmental impact of the products are relatively small.
- The transports to and from the sewing facilities are included in the assessment, as well as the materials added when making the garments (cuffs, elastic ribbon, string).
- Packaging materials and transports within the sub systems haven not been included. Thus, e.g. the packaging and transportation data for the raw materials used in the production of scrubs fabric have not been assessed.
- In the modelling of several processes, data for Switzerland has been used to represent Swedish conditions. The reason for this is that datasets in Ecoinvent have been developed for Switzerland, however are stated to represent average central-European conditions.

6.1.10 LCA Software

Several different software for assistance in LCA modelling have been developed during the last decades. After a brief research of available alternatives the SimaPro 7.2 software, was chosen for this study. SimaPro was developed by Pré Consultants and is widely used by LCA practitioners around the world. The software allows for model building in a systematic and transparent way, and in accordance with the ISO-14040 standard series. (Pré Consultants, 2012) Models can be built based on both specific data and standardised data derived from the databases available through SimaPro, and results are displayed in process trees, graphs and inventory tables. The software also allows for building and analysing models part by part, and thus determine which part of the life cycle that has the greatest potential environmental impact.

6.1.11 Assumptions

The life-span of the reusable scrubs was set to 100 washes, based on information from Textilia (the company in charge of the laundry service of the studied garments). However, there are several factors that can affect the life span of the scrubs, like e.g. losses occurring throughout the different stages of treatment, staining or accidental ripping. On the other hand, tests conducted by the producer of the garment have shown that the scrubs should last for 120 washes. Based on these uncertainties, a sensitivity analysis was conducted where the environmental impacts of the scrubs were simulated for different numbers of uses. It was initially intended to run the sensitivity analyses for both higher and lower numbers than 100. When the first results for 100 uses were shown to already have a vast differentiation between the two life cycles, which would keep increasing with raised numbers for usage, it was decided that the sensitivity analysis would focus on lower numbers of reuse only.

When not specified what type of electricity is used in a process, it was assumed that average electricity mix of the country where the process takes place is used.

Within all processes concerned, the distance for transports of waste to incineration or recycling was assumed to be 50 km.

6.1.12 Critical Review Procedure

According to the ISO 14040 standard, it is necessary to conduct a critical review when the results of an LCA are used “to support comparative assertions“ (ISO14040: paragraph 7.2). Important points that the review should assess include that the steps of classification, characterisation, normalisation, grouping and weighting elements are adequate and well documented (ISO14040, 2006).

As a natural part within the performance of a master thesis, the critical review procedure includes comments and direction from the supervisor throughout the execution of the study.
For the examination, review by an examiner which in this case is an expert within the field of LCA, and has neither been involved in the process of performing this LCA, nor has any vested interest in the results.

Additionally, a critical review regarding compliance with the ISO 14040-standard has been performed by an independent expert (Marcus Wendin at Miljögiraff). Comments from the review can be found in appendix A.

6.2 Life Cycle Inventory

In this section follows a presentation of the collected data, calculations, assumptions, and how the models of the two investigated systems were built. The presented data is mainly grouped into the main categories of materials, energy and transportation. Further, sub-headings with product specific inventory information vary between the two describes systems.

The first section covers information about the reusable scrubs system, which is followed by a section describing the disposable scrubs system. The third sub-chapter presents data procedures that were common for both systems. Note that information concerning transports is mainly placed in the common sub-chapter in section 6.2.3, where also the inventory tables for transports are found.

Throughout this chapter, references for the used data are listed in the tables.

6.2.1 Inventory of Reusable Scrubs

This section describes the life cycle of the reusable scrubs and the data that was used to model it. The sub-sections are divided into *System and Materials*; *Weight of Scrubs; Energy; Combined Heat and Power plant; Washing Detergent* and *Reusable Waste Scenario.*

The System of Reusable Scrubs and its Materials

One set of mediums sized scrubs of the reusable type weight 529 grams. The fabric contains 69% cotton, 30% polyester and 1% carbon yarn. Manufacture of the fabric is situated in Japan, and is divided between three different factories within the country. Production proceeds through the following four processes; manufacture of polyester spun carbon yarn, spinning of yarn, weaving and dyeing. For sewing the scrubs, the fabric is first transported by sea to Sweden, and then shipped further to Estonia. During the assembling of the garments, cuffs (polyester), elastic ribbon (polyester and latex), string (polyester), thread, transfer print and size labels are added. As mentioned before, this LCA is delimited only to assess the fabric, cuffs, elastic ribbon and string.

When complete, the scrubs are shipped back from Estonia to Sweden and delivered to customers. After each use at the hospital, scrubs go to laundry. The process of laundry is divided into following stages; sorting of dirty laundry, washing and centrifugation, finish treatment in steam tunnel, folding and packing.

Once the scrubs have been used 100 times (controlled via identification chips), they are sent from the laundry to a thermal power plant for incineration.

Figure 5 below shows a flowchart of all the main processes included in the reusable scrubs system. The purple frame represents the system boundary, and the grey areas within it show processes not included in the study. Most of the arrows in the figure coincide with transports, and the main transports are indicated with text.

The rolls of fabric are packed in polyethylene film when transported to Europe. After sewing of garments, trousers and shirts are packed in bundles, tied together with strips of fabric left over from production (as the strips of fabric are leftovers from production they are not considered as packing material, but accounted for as waste from sewing). The bundles are transported in boxes of corrugated board, lined with a protective plastic layer.

The unit where the scrubs are unpacked has thorough waste sorting routines, where both plastics and corrugated board are sorted for recycling. Based on this, the waste scenario of the packaging materials was modelled for 100% recycling of both cardboard and plastic (for more details see section *Waste Scenario of Reusable Scrubs).*

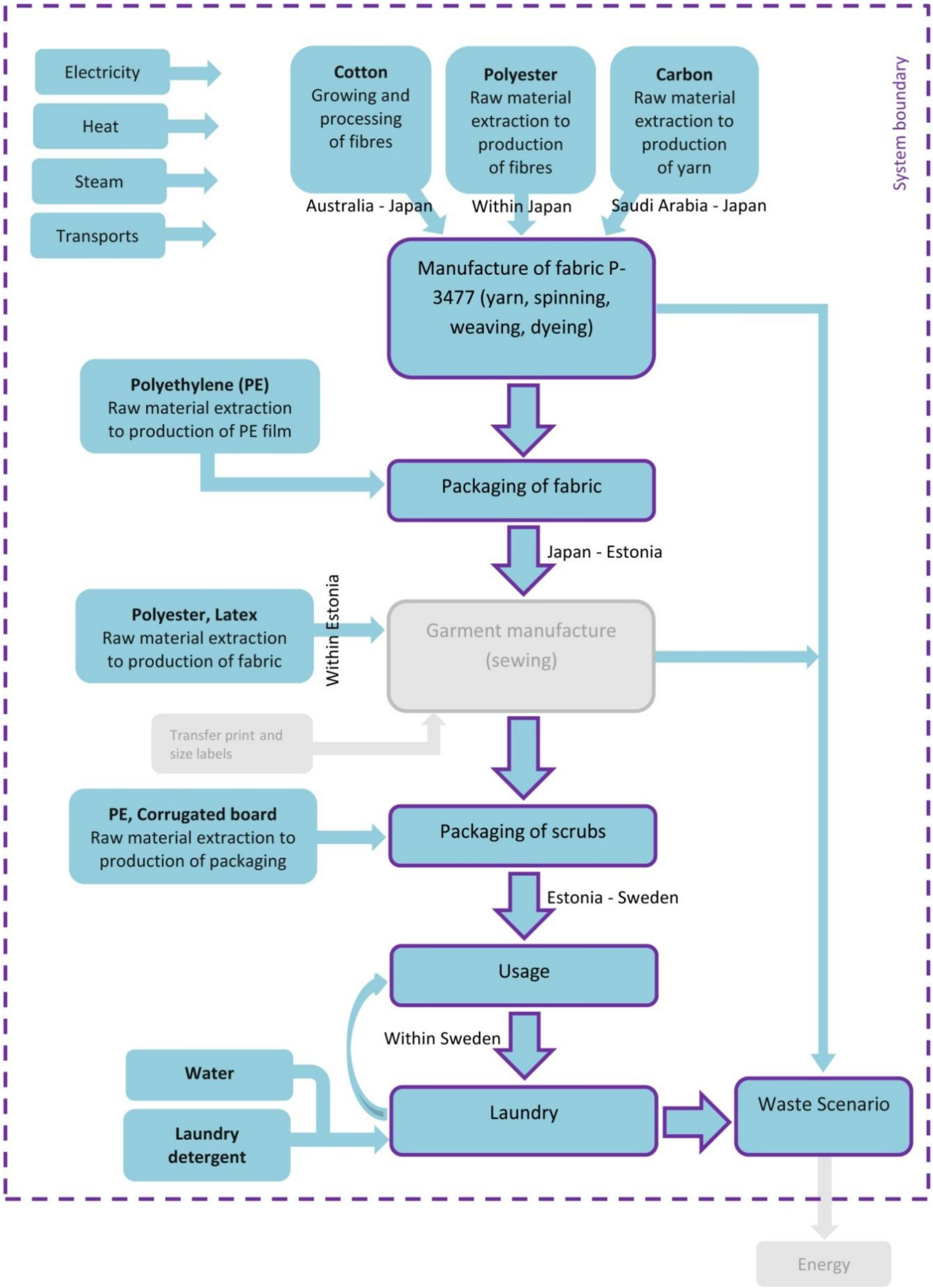

Figure 5: System flowchart of reusable scrubs. Boxes marked in grey are not included in the assessment. The texts in connection with some of the arrows indicate the main transports within the life cycle.

When transporting the scrubs between the laundry and hospitals, no disposable packaging is used. The garments are placed on shelves in a container wagon, and protected with a reusable cover on top. The environmental impact of the cover has not been assessed in this study.

Table 2: Materials included in the main system of the reusable scrubs life cycle. Note that the table has one column for weight per set, and one for weight per FU. The difference is that because the set is reused 100 times, one FU only uses one hundredth part of the total flows in production. Thus, in all processes except usage, the weight per set is divided with 100.

Process	Material	Weight kg/1 set	weight kg/ FU	Reference of value	Modelled with
Production of fabric	Cotton	0.618	6.18E-03	Unitika Textiles, 2012	Cotton fibres, ginned, at farm/kg/CN (Ecoinvent)
	Polyester	0.268	2.68E-03	Unitika Textiles, 2012	PET (bottle grade) E (Industy data 2.0)
	Carbon yarn	0.0089	8.90E-05	Unitika Textiles, 2012	Carbon fibre 1 (Idemat 2001), Yarn production, bast fibres/kg/IN (Ecoinvent)
Out	Solid waste	0.2097	2.10E-03	Unitika Textiles, 2012	Reusable waste scenario*
Sewing	Fabric	0.5513	5.51E-03	Cubik T.A. AB, 2012	Above mentioned
	Polyester (cuffs)	0.045	4.50E-04	Cubik T.A. AB, 2012	Polyester fabric I (Idemat 2001) with subtracted transportation data
	Latex (elastic ribbon)	0.0078	7.80E-05	Sjuntorp Band AB, 2012	Latex, at plant/kg/RER (Ecoinvent)
	Polyester (elastic ribbon, string)	0.0162	1.62E-04	Sjuntorp Band AB, 2012	Same as for cuffs
Out	Spills from prod.	0.0912	9.13E-04	Cubik T.A. AB, 2012	Reusable waste scenario*
Packaging	Polyethylene (fabric)	0.0014	1.40E-05	Unitika Textiles, 2012	packaging film, LDPE, at plant/kg/RER (Ecoinvent)
	Polyethylene (clothes)	0.0021	2.14E-05	Cubik T.A. AB, 2012	packaging film, LDPE, at plant/kg/RER (Ecoinvent)
	Corrugated board (clothes)	0.0159	1.59E-04	Cubik T.A. AB, 2012	Corrugated board boxes, technology mix, production mix, at plant, 16,6% primary (ELCD)
Usage per wash cycle	Water	2.1344	2.13	Textilia, Örebro, 2012	Tap water, at user (Ecoinvent)
	Laundry detergent	0.0028	2.85E-03	Textilia, Örebro, 2012	E. Saouter & G. Hoof, 2001.**

* For more information about the waste scenario, see section *Reusable waste scenario*, below.

** For more information about the modelling of the laundry detergent, see section *Washing Detergent,* below.

Weight of Scrubs

The reusable scrubs were weighted in two places of their life cycle, once directly after the sewing process and once in the laundry process. At the laundry unit, 10 sets were weighed and the mean value was used as average weight. The weight of the reused scrubs at laundry proved to be about 10% lower compared to the weight of the newly manufactured set. Based on this, it was assumed that the weight of the scrubs is reduced during the lifecycle.

The weight value gained from the sewing unit was used when assessing transportations of the scrubs from production to customer, while the weight gained from the laundry unit was used when modelling the washing phase (water and laundry detergent was measured per kg laundry) and transports in the usage and disposal phases.

Energy

The production of fabric is divided between three factories; 1) yarn manufacture, 2) spinning & weaving, 3) dyeing. Energy consumed in the different stages of production mainly comes from onsite generators fuelled with liquefied natural gas (LNG) and oil. Partially, electricity from the Japanese grid is also used. Information concerning the division of energy for heating and the electricity used in the processes could not be attained, thus no such distinction is made in the data. As no data was available for the assessment of LNG, data for gaseous natural gas were used.

For production of carbon yarn, no process data for making the carbon fibres into yarn could be found. Instead, data for yarn production from bast was added to the carbon fibre data.

In the washing process, in addition to electricity, two types of energy are used; district heating and steam. Both of these energy types are mainly produced in a combined heat and power (CHP) plant, as steam (95°C for the heating and 195°C for the production steam). The production of heating is connected to a bigger district heating network which includes waste incineration, while the production steam is only produced in the CHP plant in Örebro. As some of the machines (for example the mangle) within the laundry unit are not used in the handling of the scrubs, the energy used by such machines was not included in the energy consumption of the unit.

Table 3: Energy use within the main system of the reusable scrubs life cycle. For information about the unit kWh/FU, see explanation in table 2. The energy used in the sewing of scrubs was not included in this assessment.

Process	Source of energy	kWh/set	kWh/FU	Reference of value	Modelled with
Production of Fabric	Yarn prod (natural gas)	1.8812	0.0188	Unitika Textiles, 2012	Heat, at cogen 200kWe lean burn, allocation energy/CH (Ecoinvent)
	Spinning, Weaving (electricity)	4.6936	0.0469	Unitika Textiles, 2012	Electricity, medium voltage, at grid/JP (Ecoinvent)
	Spinning, Weaving (oil)	2.2954	0.0230	Unitika Textiles, 2012	Heat, at cogen 200kWe diesel SCR, allocation energy/MJ/CH (Ecoinvent)
	Dyeing (electricity)	1.8298	0.0183	Unitika Textiles, 2012	Electricity, medium voltage, at grid/JP (Ecoinvent)
	Dyeing (natural gas)	16.3706	0.1637	Unitika Textiles, 2012	Same as for yarn production.
Sewing	-	-	-	-	-
Washing	Electricity (100% hydro)	0.1659	0.1659	Textilia, Örebro, 2012	Electricity, hydropower, at power plant/SE (Ecoinvent)
	Heating of building (distr. heat)	0.3244	0.3244	Textilia, Örebro, 2012	Åbyverket CHP* & Disposal, hazardous waste, 25% water, to hazardous waste incinera-tion/kg/CH (Ecoinvent) with added energy recovery.
	Production energy (steam)	1.1363	1.1363	Textilia, Örebro, 2012	Åbyverket CHP

* For more information about the modelling of Åbyverket CHP see the next section, *Combined Heat and Power Plant (CHP)*.

Combined Heat and Power Plant (CHP)

A major part of the energy used in the reusable system is consumed as heating and production energy in the washing process. As mentioned above, most of this energy comes from the CHP plant in Örebro, called Åbyverket. Since the fuel type can have significant influence on the environmental impact of energy production, the specific fuel mix of the CHP plant was used to model the energy production. This fuel mix mainly consists of wood fuels (59%). Oil, peat, electricity, heat pumps (extracting heat from waste water), and coal are also used (see figure 6 below).

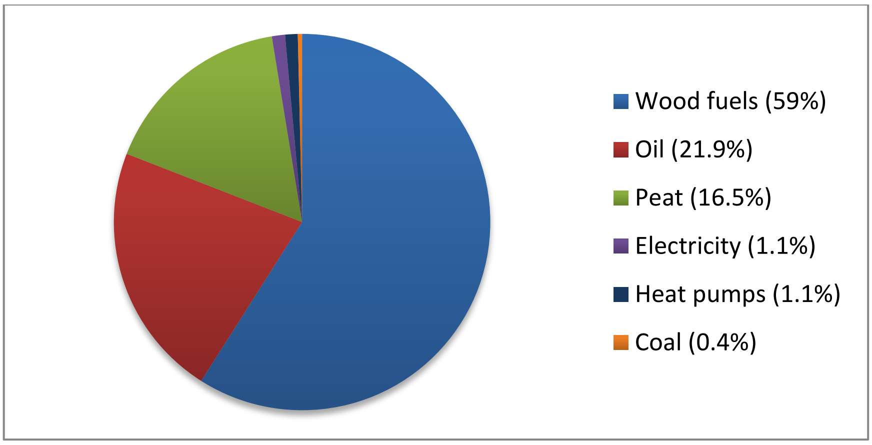

Figure 6: Distribution of fuels used for production of energy within the CHP of Örebro (Åbyverket, 2010).

The fuel inputs, along with the environmental impacts connected to their extraction/ production, were modelled with generic data, mainly from the Ecoinvent database. In the table below, the different inputs of fuels are presented more specifically, along with the generic data used for modelling them.

Table 4: Fuel mix used in Åbyverket year 2010 (Åbyverket, 2010)

Fuel type	%	Modelled with
Wood chips	44.6	Wood chips, mixed, u=120%, at forest/m3/RER (Ecoinvent)
Wood pellets	6.8	Wood pellets, u=10%, at storehouse/m3/RER (Ecoinvent)
Slipers (wooden parts of former railway tracks)	7.6	Logs, mixed, at forest/m3/RER (Ecoinvent)
Oil	21.9	Fuel oil (low sulphur) from refinery Europe (LCA Food DK)
Peat	16.5	Peat, at mine/kg/NORDEL (Ecoinvent)
Electricity	1.1	Electricity, medium voltage, at grid/kWh/SE (Ecoinvent)
Heat pumps	1.1	Heat, at heat pump 30kW, allocation heat/MJ/CH (Ecoinvent)
Coal	0.4	Hard coal supply mix/kg/DE (Ecoinvent)

In the assessment of impacts from the incineration at the CHP, specific data was obtained for inputs to and emissions from the process. These specific data, however, only include the main emission flows (NO_x, CO_2, S, N_2O, NH_3 and particles). Generic data with more specified emissions could have been used to model the incineration process, but because only outdated data for peat (15% of the fuel mix) incineration were found, the specific data were selected in this case. Since the data only included emissions of fossil CO_2, emissions for biogenic CO_2 were added, based on the amount of incinerated wood fuels.

A large portion of the energy in the district heating network is produced in the same CHP plant. However, about 10% of the heat within the network comes from a waste incineration plant (for hazardous waste). Thus, the same data as for Åbyverket was used to model 90% of the heat, while the remaining 10% was modelled with generic data from Ecoinvent, for hazardous waste incineration (disposal, hazardous waste, 25% water, to hazardous waste incineration/kg). A heating value for recovered energy of 17 MJ per kg was added to the process, based on recommendations in the documentation of the same Ecoinvent process (as recovered energy was not part of the original process).

District heating is also used in the alternative washing process (for UCC) used as comparison in the sensitivity analysis. The CHP plant used to produce heat in the case of UCC mainly uses wood fuel (83%) and oil (14%). Remaining fuels consist of bio oil and biogas (in total 3%). As specific emission data for the CHP, which produces this heat, could not be obtained, generic data for incineration of wood[12] (84.5%) and oil[13] (15.5%) were used to model the process. Generic CHP data were considered more suitable in the case of UCC because available generic data for the fuel mix were up to date (updated in 2011), which was not the case for the CHP used in ÖCC.

The production steam, on the other hand is, in the laundry unit used in the case of UCC, 100% oil fuelled. Production of the process steam was modelled with data from ELCD (Process steam from light fuel oil, heat plant, consumption mix, at plant, MJ SE).

Washing Detergent

There are many different kinds of washing detergents, with variable formulations of ingredients and thus with varying environmental impact. The company that produces the detergent used when washing the scrubs would not reveal information about the ingredients. Therefore, the detergent was modelled in accordance with a hypothetical formulation of washing powder published by E. Saouter and G. Hoof for Proctor and Gamble (2001). Generic data for washing agents available in the Ecoinvent database were used to model the detergent. Datasets for modelling the ingredients was found for 98% of the applied formulation, the remaining 2% were modelled as water.

Manufacture of all the contributing chemicals has been included, but no production scenario for the assembly of the detergent has been modelled. Based on earlier studies (Van Hoof et. al., 2001; Eriksson & Berg, 2003), it was assumed that the process of assembling the agent does not entail significant environmental impact.

[12] Modelling data: Ecoinvent, heat, at cogen 6400kWth, wood, emission control, allocation energy/CH
[13] Heat, light fuel oil, at industrial furnace 1MW/

Table 5: Composition of the washing detergent according to weight percentage. The left column contains the formulation used for the laundry detergent in this LCA (Saouter & Hoof, 2001) and the right column shows which datasets were used to assess them. Due to lack of adequate datasets, the ingredients antifoam and protease were modeled as water.

Ingredients	weight %	Modelled with following Ecoinvent data
Na-Silicate powder	3.1%	Sodium metasilicate pentahydrate, 58%, powder, at plant/
AE7-pc	4.0%	Ethoxylated alcohols (AE7), petrochemical, at plant/
Sodium carbonate	17.0%	Sodium carbonate from ammonium chloride production, at plant/
AE11-PO	2.0%	Ethoxylated alcohols (AE11), palm oil, at plant/
Water	14.2%	Water, deionised, at plant/
Zeolite	20.0%	Zeolite, powder, at plant/
Perborate mono hydrate	8.7%	Sodium perborate, monohydrate, powder, at plant/
Perborate tetra hydrate	11.5%	Sodium perborate, tetrahydrate, powder, at plant/
Sodium sulfate	0.4%	Sodium sulphate, powder, production mix, at plant/
FWA DAS-1	0.2%	DAS-1, fluorescent whitening agent triazinylaminostilben type, at plant/
LAS-pc	7.8%	Polycarboxylates, 40% active substance, at plant/
Polyacrylate	4.0%	Butyl acrylate, at plant/
Citric Acid	5.2%	Acetic acid from butane, at plant/
Antifoam S1.2-3522 0.5%, Protease 1.4%	1.9%	Water, deionised, at plant/

Mainly for the purpose of neutralizing effluent water from the washing process, but also to counteract static electricity, an ”antistatic & acidifying” agent is added in the laundry process. Because no inventory data for such products was found, this agent was not included in the assessment.

Waste Scenario of Reusable Scrubs

When modelling waste scenarios in the SimaPro software, all of the materials used as input in the model end up as waste, categorised into specified waste types. In the waste scenario, different treatment alternatives can specified for each waste category. The reusable waste scenario was modelled to separate the following materials: cardboard, PE, PET and compost, see details in table 6 below.

Cotton is by weight the main material of the system and enters the model as cotton fibres, which have a pre-set waste type of compost. Thus, all of the used cotton ends up in the waste scenario as compost. Because about 62% of the cotton fibres is processed into the scrubs fabric, that share of the compostable waste has been modelled with textile incineration.

The second main material used in the manufacturing of the scrubs is polyester, which in the waste scenario has been modelled with data for incineration of mixed plastics.

As mentioned in the description of the reusable scrubs system, due to careful sorting routines, all of the materials used for packaging are assumed to be recycled.

Table 6: Division of separated materials in the waste scenario of reusable scrubs.

Material	Waste type	Modelled with
Cotton	Compost	62% *Disposal, textiles, soiled, 25% water, to municipal incineration/kg/CH (Ecoinvent)* with added energy recovery. 38% *Composting organic waste (Ecoinvent)*
Polyester	PET	100% *Disposal, plastics, mixture, 15.3% water, to municipal incineration/kg/CH (Ecoinvent)* with added energy recovery.
Packaging PE	PE	100% *Recycling PE (Ecoinvent)*
Cardboard	Cardboard	100% *Recycling cardboard (Ecoinvent)*
Remaining waste	All other	100% *Disposal, municipal solid waste, 22.9% water, to municipal incineration/kg/CH)* with added energy recovery.

Remaining waste types (in total 1.7% of the waste stream) were assumed to go to incineration as municipal solid waste.

The method used for allocation of environmental burdens between adjoining life cycles (in the case of e.g. incineration and material recycling), concerning recovered energy, and avoided materials is explained in section 6.1.3 *Boundaries with other systems*.

The cleansing process for outflows of the water that is used in the washing process along with the weight of the washing detergent have been assessed with data from 2000, for a Swiss water treatment plant (*treatment, sewage, unpolluted, from residence, to wastewater treatment, class 2*). This data comes from the Ecoinvent database, and is considered to be well applicable to modern treatment practices in Europe.

6.2.2 Inventory of Disposable Scrubs

This section describes the life cycle of the disposable scrubs and the data that was used to model it. The sub-sections are divided into *System and Materials*; *Transports*; *Energy* and *Waste Scenario*.

The System of Disposable Scrubs and its Materials

A set of the disposable scrubs weigh 159 grams, and is composed of two types of fabric; a nonwoven polypropylene (PP) outer fabric, and a lining containing 70% viscose and 30% polyester. Production of the spun bound PP material is situated in China, while the lining material is imported from Israel. Sewing also takes place in China, wherein cuffs for legs and arms (100% polyester), a waist band (97% cotton), thread, buttons and a label tag are added. As mentioned before, this LCA is delimited only to assess materials in fabric, cuffs and waist band (which make up about 96% of the total fabrics weight).

After manufacture, the scrubs are shipped to a warehouse in Belgium where they are stored until sent to customers on demand.

Once the scrubs have been used, they are disposed of as mixed waste, and sent to incineration.

Figure 7 shows a flowchart of all the main processes included the reusable scrubs system. The purple frame represents the system boundary, and the grey areas within it show processes not included in the study. Most of the arrows in the figure coincide with transports.

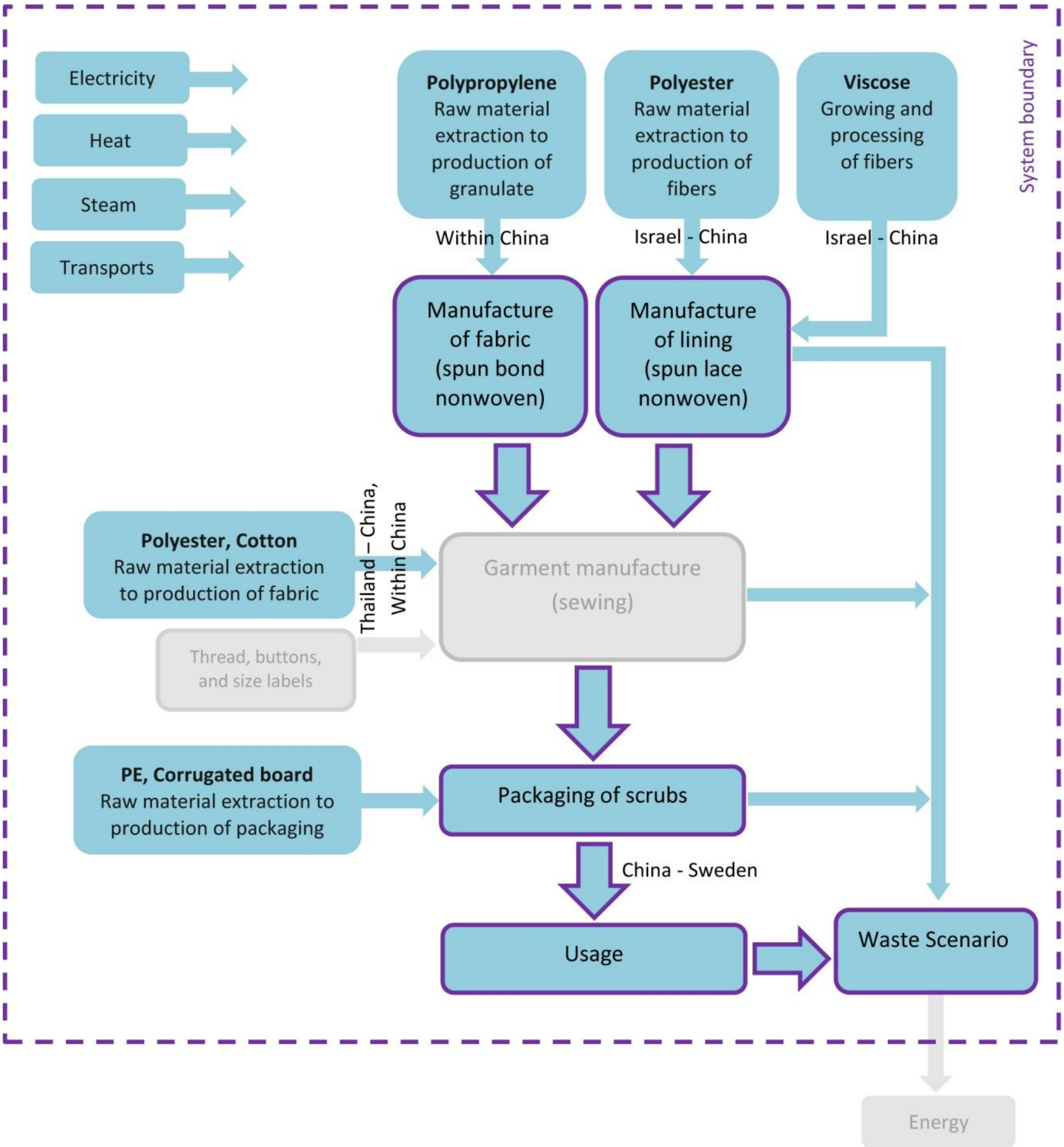

Figure 7: System flowchart of disposable scrubs. Boxes marked in grey are not included in the assessment. The texts in connection with some of the arrows indicate the main transports within the life cycle.

Trousers and shirts are packaged separately in polyethylene bags. The one-piece bags are then packed in one larger polyethylene bag inside a box of corrugated board. When the scrubs are used, the cardboard box is routinely sorted for recycling, while the plastic packaging is thrown among other types of waste for incineration. Based on this, the waste scenario of the packaging materials was modelled for 100% recycling of cardboard, and 100% incineration of plastic (for more details see section *Disposable waste scenario*).

Table 7: Materials included in the main system of the disposable scrubs life cycle. Because one set of scrubs is consumed in every use round, the FU if the reusable scrubs is equal to the weight/set.

Process	Material	weight kg/1 set & FU	Reference of value	Modelled with
Production of fabric	Polypropylene granulate	0.1263	IVL, 2012	Polypropylene, granulate, at plant/kg/ (Ecoinvent)
	Viscose	0.0271	IVL, 2012	Viscose fibres, at plant/kg/GLO (Ecoinvent)
	Polyester	0.0116	IVL, 2012	Polyester fabric I (Idemat 2001) with subtracted transportation data
Out	Solid waste	0.0091	IVL, 2012	Disposable waste scenario*
Sewing	Fabric (lining+spunbound PP)	0.1671	IVL, 2012	Above mentioned
	Polyester	0.0128	IVL, 2012	Same as Polyester above
	Cotton	0.0119	IVL, 2012	Textile, woven cotton, at plant/kg/GLO (Ecoinvent)
Out	Spills from prod.	0.0390	IVL, 2012	Disposable waste scenario*
Packaging	Polyethylene	0.0149	IVL, 2012	packaging film, LDPE, at plant/kg/RER (Ecoinvent)
	Corrugated board	0.0462	IVL, 2012	Corrugated board boxes, technology mix, production mix, at plant, 16,6 % primary (ELCD)

* For more information about the waste scenario, see section *Disposable waste scenario*, below.

Transports

It was assumed that the transports from the warehouse in Belgium to the hospitals are made by land with lorry (alternatively they could have been shipped over the Baltic Sea). For more information about transports see the section *Transports*, under 6.2.3.

Energy

Specific values for the amounts of consumed energy in the production of polypropylene fabric were acquired and assessed with generic data for those energy types. As no specific data for the production of the polyester/viscose fabric (used for the lining) were available, generic data for production of polyester fabric from the IDEMAT 2001 (2004) database were used for modelling those processes. It was assumed that the fabric production from a polyester/viscose mix, consumes the same amount of energy as production of pure polyester fabric.

The electricity used in production of fabric was assessed with generic data for average Chinese grid mix, from the Ecoinvent database (2007).

Table 8: Energy use within the main system of the disposable scrubs life cycle. Because one set of scrubs is consumed in every use round, the FU is equal to the kWh/set of the reusable scrubs.

Process	Source of energy	kWh/set & FU	Reference of value	Modelled with
Production of fabric:	Spunbound PP, Diesel	0.0001	IVL, 2012	Heat, light fuel oil, at industrial furnace 1MW/MJ/(Ecoinvent)
	Spunbound PP, Natural gas	0.2102	IVL, 2012	Heat, natural gas, at industrial furnace >100kW/ (Ecoinvent)
	Spunbound PP, Electricity	0.2119	IVL, 2012	Electricity, medium voltage, at grid/kWh/CN (Ecoinvent)
	Lining, Natural gas	0.1713*	Ecoinvent, Idemat 2001	Natural gas to CH (LCA Food DK)
Sewing:	-	-	-	-
total	all	0.5935	-	-

*calculated for an energy value of 11.05 kWh/Nm^3 for natural gas.

Waste Scenario of Disposable Scrubs

The disposable waste scenario was modelled to separate the following materials: PP, PET, Textile, PE and cardboard, see details in table 9, below.

Because the PP is the main material used in the lifecycle of disposable scrubs, it was modelled separately from the other plastics in the waste scenario. PET and PE were modelled with data for incineration of mixed plastics. Cotton and viscose used in the scrubs are categorised as textiles and modelled as such for incineration.

Table 9: Division of separated materials in the waste scenario of disposable scrubs.

Material	Waste type	Modelled with
Polypropylene	PP	100% Disposal, polypropylene, 15.9% water, to municipal incineration/kg/CH *(Ecoinvent)* with added energy recovery.
Polyester	PET	100% *Disposal, plastics, mixture, 15.3% water, to municipal incineration/kg/CH (Ecoinvent)* with added energy recovery.
Textile	Textile	100% *Disposal, textiles, soiled, 25% water, to municipal incineration/kg/CH (Ecoinvent)* with added energy recovery.
Packaging PE	PE	100% *Disposal, plastics, mixture, 15.3% water, to municipal incineration/kg/CH (Ecoinvent)* with added energy recovery.
Cardboard	Cardboard	100% *Recycling cardboard (Ecoinvent)*

As mentioned in the description of the disposable scrubs system, all of the PE material used for packaging is assumed to go to incineration. All of the cardboard is assumed to be recycled.

The method used for allocation of environmental burdens between adjoining life cycles (in the case of e.g. incineration and material recycling), concerning recovered energy, and avoided materials is explained in section 6.1.3 *Boundaries with other systems*.

6.2.3 Common Data Procedures

In this section, the LCI procedures and data which were common for both systems are presented.

Packaging

Specific values from the producers of scrubs and from the purchasing units were used when assessing the quantities of packaging materials for the scrubs. Packaging materials used in the sub systems (production of polyester, cotton, etc.) have not been assessed.

Transports

Because detailed information concerning road transports could only be attained for few of the transports, generic data from the Ecoinvent database for a diesel fuelled lorry transporting between 16-32 tonnes of goods, and classified as Euro 3 (European emission standards) was applied on all road transports except for the waste transports. This data covers a wide range of transportation types and gives consistency to the transport data, as well as it diminishes the chances for discrimination between the specified and unspecified means of road transportation. The choice of Euro class 3 was based on the average classification of the European heavy transportation vehicle fleet (European Environment Agency, 2011), as data for Asia were not available. The waste transports were modelled with data from Ecoinvent, for a municipal waste collection lorry in western European conditions (Transport, municipal waste collection, lorry 21t/CH).

Generic data was also used for the assessment of sea transportation. Data from the database ELCD, for a container ship with the carrying capacity of 27500 tonnes was used for all sea transports (Container ship, ocean, technology mix, 27.500 dwt pay load capacity).

Because all of the specific data for the transportation vehicles were pre-set in the databases, the only calculation made in the LCI was *tonnes of the transported good*kilometres* (the unit in which the data were given, tkm).

In several of the life cycle stages waste is generated. The distance for transportation of waste to incinerator or recycling was assumed to be 50 km.

In tables 10 and 11 below, all of the transports of the foreground systems of the reusable and disposable scrubs are presented.

Table 10: Inventory data for the transports of the reusable scrubs system. Note that the transport distances represent kilometres that one set of scrubs is transported throughout its life cycle. Because one set of scrubs only is transported once for 100 uses, except the usage stage, the total tkm within all of the other phases has been divided by 100.

Phase	Means of transport	Distance (km)	tkm/FU	Reference of value
Production of fabric *(raw materials to prod. and transports within prod.)*	Container ship ocean, technology mix, 27.500 dwt pay load capacity (ELCD)	21 670*	0.0517	Unitika Textiles, Cubik T.A. AB, 2012
	Transport, lorry 16-32t, EURO3 (Ecoinvent)	1 130	0.0037	Unitika Textiles, Cubik T.A. AB, 2012
Sewing *(fabric from prod. (Japan) to sewing unit Estonia) and materials to sewing unit*	Container ship (same as above)	23 080*	0.1273	Cubik T.A. AB, 2012
	Lorry (same as above)	968	0.0041	Cubik T.A. AB, 2012
Usage *(scrubs from clothes prod. to custo-mer and transports to and from laundry)*	Container ship (same as above)	280*	0.0015	Cubik T.A. AB, 2012
	Lorry (same as above)	1 219	0.0066	Textilia Örebro, 2012
Disposal *(all of the generated waste)*	Municipal waste collection lorry	50	0.0005	Estimated

*Distance partly or entirely estimated with Google Maps.

Table 11: Inventory data for the transports of the disposable scrubs system.

Phase	Means of transport	Distance (km)	tkm/FU	Reference of value
Production of fabric *(raw materials to prod.)*	Container ship ocean, technology mix, 27.500 dwt pay load capacity (ELCD)	12 000*	0.4651	IVL, 2012
	Transport, lorry 16-32t, EURO3 (Ecoinvent)	1 700	0.1886	IVL, 2012
Sewing *(materials to sewing unit)*	Container ship (same as above)	2 900*	0.0371	IVL, 2012
	Lorry (same as above)	370	0.0046	IVL, 2012
Usage *(scrubs from clothes prod. (China) to customer (Sweden)*	Container ship (same as above)	19 000*	4.1819	-
	Lorry (same as above)	1 790*	0.3940	IVL, 2012
Disposal *(all of the generated waste)*	Municipal waste collection lorry	50	0.0126	Estimated

*Distance partly or entirely estimated with Google Maps.

It proved to be very difficult to attain information about how long the sea-transportation routes are. To estimate the distances between harbours, Google Maps was used. Google Maps is an online mapping service which allows drawing of transportation routes and estimating distances.[14] Google Maps was also used when estimating the distance some of the road transports.

Recovered Energy

As mentioned in section 6.1.3 *Boundaries with other systems*, the energy recovery from waste incineration is modelled as an empty process and does not affect the CED results, nor the energy inputs throughout the studied life cycles. Amounts of recovered energy have still been considered as of importance as a benefit beyond the system boundary, and are discussed in the results section. Values for generated heat and electricity from the different incinerated waste types were applied directly from the different incineration processes in Ecoinvent (which in

[14] Google Maps website; http://maps.google.se/

accordance with the EPD standard[15] are documented, but not included in the standardised datasets). These values represent average recovered energy for European conditions.

Table 12: Values for recovered heat and electricity from 1 kg of incinerated waste, divided into the four main waste types of in this LCA.

Waste type	Heat (kWh)	Electricity (kWh)
Mixed waste	0.600	0.281
Plastic mix	1.953	0.967
Textiles	0.794	0.378
PP	2.094	1.039

Calculation of Yearly Use

The number of total yearly usage of surgical scrubs within ÖCC (used for comparison in the results section) was estimated through adding the amount of laundered scrubs during 2011 and the amount of purchased disposable scrubs 2011 (146 955+60). The amount of purchased disposable shirts exceeded the amount of trousers. An explanation to this is that the shirts are also used for other functions than in surgeries. Therefore the estimated number of sets was based on the amount of purchased trousers.

Main Data Sources

All of the specific data for reusable scrubs system were received from concerned manufact-urers. Contacts were held with representatives from the units of fabric production, garment manufacture, details manufacture and laundry.

In contrary, most of the specific data for modelling the disposable scrubs system was received from IVL (Swedish Environmental Research Institute), an institute previously hired by the disposable scrubs manufacturer to conduct an LCA of their scrubs. As the results of the conducted LCA are classified, requested data sets were printed into separate documents before I could access them. Explanations and clarifications of the received data sets were done through contact with representatives from IVL. Thus, no contact was held with any of the manufacturing units.

Use of propriety data, from a single source is most representative for the assessed product, but does also obstruct the reproducibility of this study, and the possibility to verify data.

6.3 Life Cycle Impact Assessment

The methodology used in this thesis has already been partially introduced in section 6.1.6 of the Goal and Scope definition. This chapter further describes each impact category and their connections to the earth system processes discussed in the concept of planetary boundaries.

Within this project, the aim has been to use impact categories which are cohesive with seven environmental issues chosen for this LCIA, and which have been alerted in the concept of planetary boundaries (Rockström et.al., 2009). How the planetary boundaries were set, or how the earth systems are doing in relation to them, is not of central importance in this LCA. The main reason for using the concept of planetary boundaries is that the categories within have

[15] As explained in sections 6.1.3, *Boundaries with other systems*.

been identified as of great importance for the main systems of the Earth, and because negative human impact on them could impose serious threats for humanity.

Even if the impact categories of the ReCiPe 2008 method (Goedkoop et al., 2009) were not designed to apply on the chosen set of earth system processes as have been done in this study, these approaches involve corresponding environmental impacts, and are therefore compatible.

In table 13 below follows a demonstration of all the assessed impact categories, their units and corresponding earth system processes (when applicable).

Table 13: Environmental impact categories.

Impact category	Unit	Earth system process	Description
Climate change	kg CO_2 eq.	Climate change	Climate change, also known as global warming, refers to effects on the climate which are caused by human emissions of greenhouse gases (GHG) such as carbon dioxide (CO_2) and methane. The GHG's have a confining effect on heat that otherwise would radiate from Earth's atmosphere into space. Impact category assessed with the characterisation and classification factors of ReCiPe 2008 method, which is based on the CO2 equivalency factors published in the IPCC report 2007.
Eutrophication	kg P eq. & kg N eq.	Nitrogen- & phosphorous cycles	Eutrophication refers to increased nutrient levels in the environment, potentially causing abrupt shifts in aquatic and marine systems (Rockström et.al.,2009). Emissions of nitrates (salt compounds form nitrogen, N) and phosphorous (P) are the main cause of eutrophication. Impact category assessed with the characterisation and classification factors of ReCiPe 2008 method, where eutrophication potential is divided into phosphorous equivalents (in freshwater systems) and nitrogen equivalents (in sea water systems). Both of types of eutrophication are considered in this in this impact category.
Particulate matter formation	kg PM10 eq.	Aerosol loading	Aerosols are small particles of matter that are suspended in air. Besides natural aerosols like vapour or pollen, small particles are emitted in combustion of e.g. fossil fuels. Increased levels of aerosols on the atmo-sphere influence the Earth's radiation balance and have been proven to have adverse effects on human health (Rockström et.al.,2009). Impact category assessed with the characterisation and classification factors of ReCiPe 2008 method, where particulate matter formation potentials (PMFP) are converted to PM10-equivalents.
Ozone depletion	kg CFC-11 eq.	Reduction in stratospheric ozone	Surrounding Earth, the ozone layer forms a protective shield which filters out almost 99% of the sun's ultra violet radiation. Emissions of compounds like e.g. chlorofluorocarbons (CFC's) have a degrading effect on the ozone layer, and have caused holes in the layer. Impact category assessed with the characterisation and classification factors of ReCiPe 2008 method, where ODS (ozone depleting substances) are converted to kg CFC-11 eq.

Impact category	Unit	Earth system process	Description
Ocean acidification	kg CO_2	Ocean acidification	When CO_2 dissolves in water, carbonic acid is (H_2CO_3) formed. At present, oceans work as a CO_2 sink absorbing roughly 25% of human emissions, and continued increases in atmospheric CO_2 levels will lower the pH- level of oceanic surface water. Increased acidity is expected to cause disturbances in marine eco-systems and have significant effects on both marine and terrestrial food chains (Rockström et al., 2009). As there is no developed LCIA method for assessing ocean acidification, a simple assessment of CO2 emissions* has been used to determine the ocean acidification potential of the scrubs life cycles.
Freshwater use	m^3	Global freshwater use	Human freshwater use has increased alongside climbing population rates. Even though this resource is abundant in some parts of the world, water scarcity is a growing issue globally. In the vulnerable regions large water abstractions can cause shifts in freshwater cycles, which can affect biodiversity, food, and health security (Rockström et al., 2009). Impact category assessed with the characterisation and classification factors of the ReCiPe 2008 method, where water resources are divided into 22 types of water with equal characterisation factor. Water flows utilised in hydropower plant to create energy are not included in this method.
Agricultural land occupation	m^2a	Land system change	Transformation of natural landscapes into agricultural land poses damage to the biodiversity originally occurring on that land. Further, on a large scale, it can affect regulatory system functions such as the hydrological cycle (Rockström et al., 2009). Impact category assessed with the characterisation and classification factors of the ReCiPe 2008 method, where agricultural land occupation is divided into various kinds of agriculture. There is a difference between land occupation and changes of land usage. However, as Rockström et. al (2009) suggested, the boundary for land system change should be measured by the share of land occupied by agriculture. The unit m^2a, is read as m^2 times the estimated years of occupation.
Total energy use	MJ	-	Energy use is another way to look at impact, which gives a perspective easier to interpret from a societal point of view, as well as environmental. Impact category assessed with the characterisation and classification factors the CED (Cumulative energy demand) method, which is based on the method published by Ecoinvent and expanded by PRé Consultants. Results are divided into consumed energy from renewable and non-renewable sources. No normalisation factors are applied.

*The difference between CO_2 emissions and the CO_2 equivalents assessed in the climate change category is that the previous only assesses CO_2, while the later includes several greenhouse gases which are weighed into one unit (CO_2 equivalents).

7. Results

The results chapter begins with a presentation of aggregated results, showing LCIA results for both systems within all of the impact categories. Results for each impact category are then shown and described for both systems in parallel. Four main life cycle phases were identified during the inventory phase and assessment; production of fabric, production of clothes, usage and disposal, thus the results are grouped accordingly.

7.1 LCIA Results for all Categories

Results in this section are presented for both systems in comparison, with and without normalisation applied. If not stated otherwise, all the presented values show results per FU. Further, the results in this chapter represent estimated potential values, and are not exact depictions of factual environmental impacts.

To give a comprehensive view, the first graph depicts the sum of potential environmental impact of the two studied systems within all of the nine studied impact categories. No scaling factor has been applied, and the columns simply indicate the ratio between the two studied systems. The life cycle of disposable scrubs has the higher potential impact within all the studied categories. Within the categories ozone depletion, water depletion, and renewable CED, the difference in potential impacts between the two types of scrubs is least prominent. The main explanation for the lower overall environmental impact of the reusable scrubs is due to its reuse. When the environmental impact within all of the phases, except usage, is divided between 100 uses, the total impact is substantially decreased. If the reusable scrubs could only be used once, their potential impact on the environment would, in most impact categories, have exceeded that of the disposable scrubs. In chapter 7.4 a sensitivity analysis can be found where alternative numbers for usage rounds for the reusable scrubs are analysed.

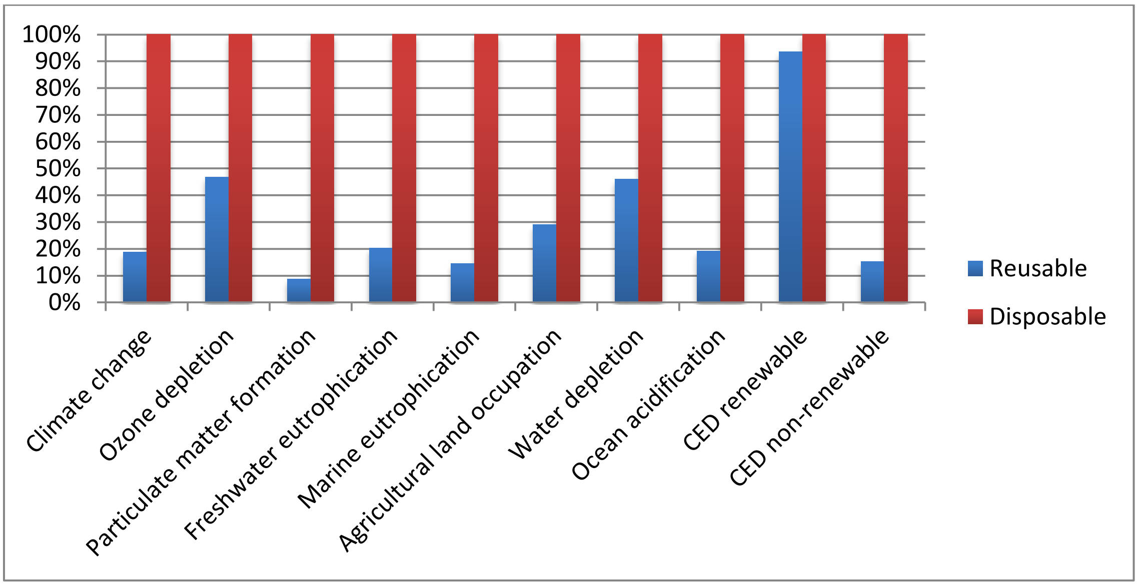

Figure 8: Results of all impact categories, characterised. The product with the higher environmental impact within a given category is shown as 100 % impact, and impact of the other product as a proportion of that value.

In table 14 below, the specific values for potential environmental impact within the nine studied impact categories are presented. The FU “one use” is the main unit of comparison within this study. To show the potential impact in another context, practically applicable within healthcare, results in this table are also presented per yearly consumption of scrubs within the hospitals of ÖCC (approximately 147000 sets).

Impact category	Unit	Disposable/FU	Reusable/FU	Disposable/year	Reusable/year
Climate change	kg CO_2 eq	1.96E+00	3.68E-01	288 595	54 044
Ozone depletion	kg CFC-11 eq	5.04E-08	2.36E-08	0.007	0.003
PM formation	kg PM10 eq	3.69E-03	3.23E-04	543	48
Freshwater eutrophication	kg P eq	7.26E-05	1.48E-05	11	2
Marine eutrophication	kg N eq	2.75E-03	4.00E-04	404	59
Agricultural land occupation	m^2a	5.35E-01	1.55E-01	78 583	22 817
Water depletion	M^3	1.06E-01	4.87E-02	15 596	7 163
Ocean Acidification	kg CO^2	1.78E+00	3.41E-01	261 392	50 142
CED, non-renewable	MJ-Eq	2.62E+01	3.99E+00	3 851 729	586 560
CED, renewable	MJ-Eq	3.55E+00	3.33E+00	522 602	488 844

Table 14: Specific results for disposable and reusable scrubs within all impact categories, presented in unit per FU and units per yearly consumption of scrubs within the hospitals of ÖCC.

To illustrate the amounts of emissions on a yearly basis, an example is given here comparing CO_2 emissions with amounts emitted during the common practice of driving. A newly bought passenger car in Sweden, did in 2010 on average emit 153g of CO2 per 1 driven kilometre. (Trafiktverket, 2011) Emissions of CO2 equivalents from a yearly usage of disposable scrubs would in this comparison translate to driving 1 886 242 km, or 47 rounds around the earth[16]. The same comparison made with the reusable scrubs would give a diving distance of 353 230 km, or 9 rounds around the earth.

As mentioned in section 6.1.6, a common way to contextualise impact assessment results within LCA is to perform normalisation. Normalisation factors have been applied for seven of the nine categories, and normalised results can be found in the figure below. Because normalisation values are representing global average yearly consumption/emission values for one person, the results for one FU become very small. Nevertheless, adding such a scaling factor enables to portray the relative impacts of the different categories in relation to each other.

Figure 8 shows that the highest potential environmental impact of the disposable scrubs, relative to its normalisation value, lies within the categories climate change, particulate matter formation, ocean acidification and freshwater eutrophication. For the reusable scrubs, although substantially lower than of the disposable scrubs, the highest impact is within freshwater eutrophication, followed by climate change and ocean acidification. The categories of climate change and ocean acidification basically measure the same emissions, except that the climate change category also includes other greenhouse gases. Thus, the causes of impacts within these two categories will be discussed together. The reason for not placing ocean acidification as a part within the climate change category is to avoid a perceiving of it as being of less importance.

[16] Counted with an earth radius of 6378,137 km (Nationalencyklopedin, 2012).

Potential impact levels within the category of ozone depletion are shown to be very minor. Thus the further assessment is focused on the other impact categories.

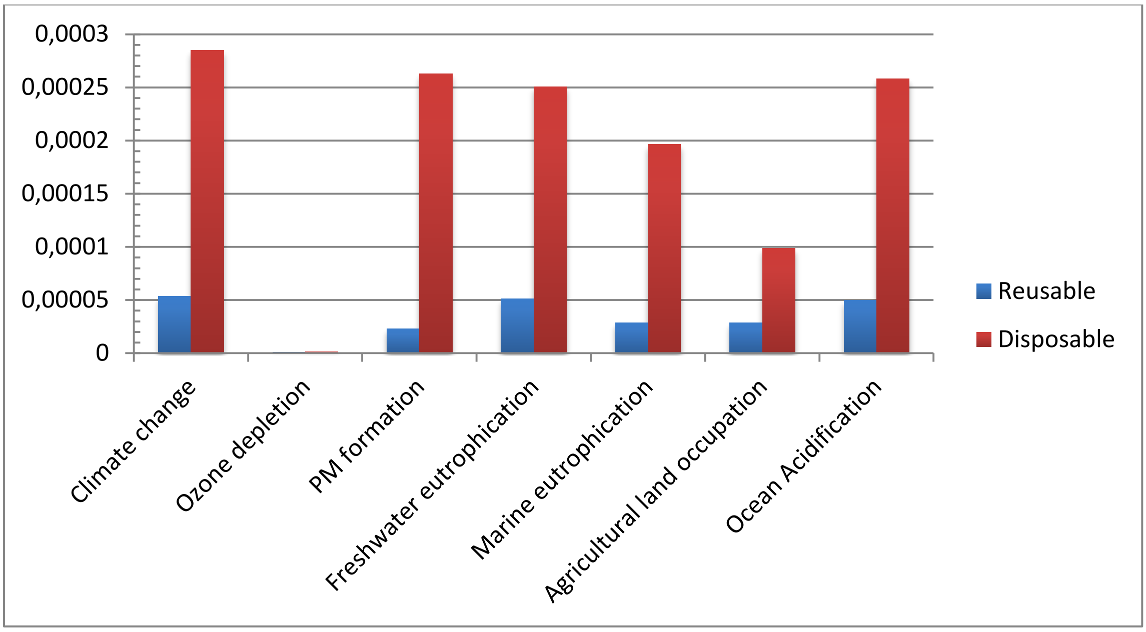

Figure 9: Results with normalised values per 1 FU, for all impact categories except water depletion and CED. The impact is portrayed as the share of an average global citizen's yearly emissions in 2010.

No normalisation values have been applied for the categories CED and water depletion. Table 15 indicates that, despite water the consumption within the washing phase of the reusable scrubs, the total potential water consumption for 1 FU is substantially higher in the case of disposable scrubs. Total energy use is also considerably higher in the life cycle of disposable scrubs, even though the amount of consumed energy from renewable sources of reusable scrubs exceeds that of the disposable scrubs. Including energy recovery from waste incineration (in the bottom of table 15) into the CED data would not have affected the outcomes significantly.

Note that the energy use within the process of sewing the scrubs has not been included in this assessment.

Impact category	Unit	Reusable	Disposable
Water depletion	m3	0.0487	0.1061
CED renewable	MJ	3.3251	3.5548
CED non-renewable	MJ	3.9898	26.1996
CED total	MJ	7.3149	29.7543
Recovered heat	MJ	-0.0345	-1.34
Recovered Electricity	MJ	-0.0168	-0.662

Table 15: Consumption of water and cumulative energy demand (divided into renewable and non-renewable sources) of reusable and disposable scrubs.

It should be noted that if the recovered energy was modelled to replace other energy inputs within the life cycle, it would not only decrease the energy use, but also emissions connected to production of that energy. Thus, the environmental impact of the disposable scrubs would have been slightly lower than at present. However, such a decrease would not have had any significant particular influence on the results.

7.2 Reusable Scrubs

In this chapter follows a more detailed presentation of the environmental impacts within the different phases of the reusable scrubs life cycle and how they contribute to the whole.

As shown in figure 10 below, the phases of fabric production and usage are the main contributors to the environmental impacts within the studied categories. Clothes production, packaging and waste scenario have a comparatively small effect on the total impact. A visibly high consumption of renewable energy within the usage phase relates to the electricity used in the washing of scrubs, which originates from 100% hydro power. Impacts within climate change, agricultural land occupation, and ocean acidification also high within the usage phase. The transports within the usage phase only contribute with between 1- and 5% of the total impact of usage. Accordingly, the washing process entails the remaining environmental impact. Within all of those categories, consumption of energy (used for heating and as process steam) from the cogeneration plant and the district heating network, have the greatest impact. Usage of oil and peat for fuels cause the biggest impact within CO_2 emissions, and along with wood fuels also the majority of emissions within PM formation. The wood used as fuel in the cogeneration plant solely entails approximately 52% of the total agricultural land occupation within the life cycle of reusable scrubs.

Within the category of water depletion, despite the water consumption of the washing process, over 90% of the impact lies within fabric production. The single main contributor to the water depletion within the fabric production is the cultivation and processing of cotton fibres. The cotton is also the main contributor to the freshwater eutrophication category, making out about 57% of total emissions of phosphorous equivalents. Further, almost half of the impact within agricultural land occupation derives from the cotton cultivation.

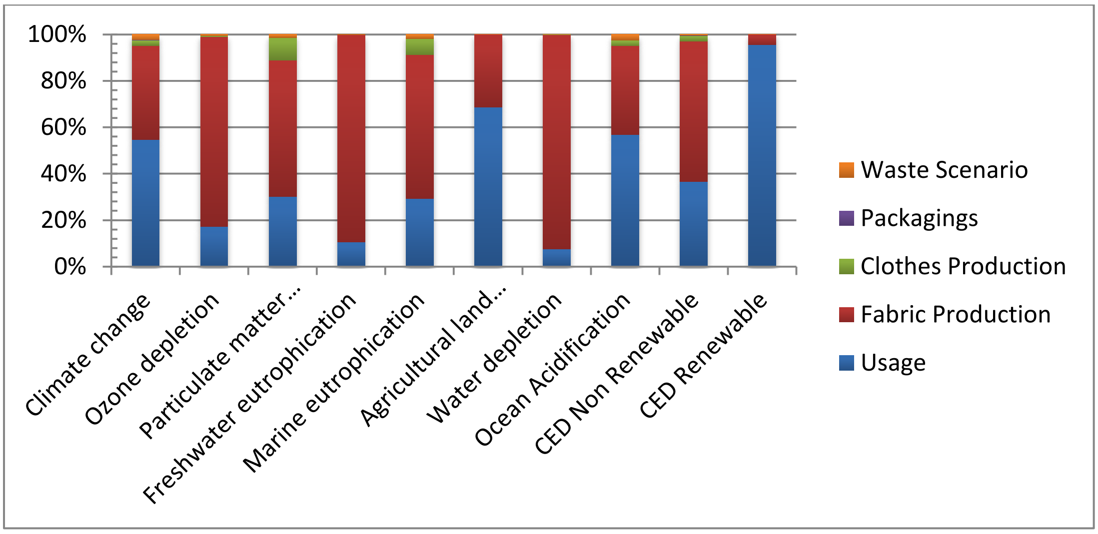

Figure 10: Contribution of the five life cycle phases, including fabric production, clothes production, packagings, usage and waste scenario, to the assessed impact categories. The usage category includes transports from production sites to hospital and the washing process.

The fabric production phase also has a relatively high impact within climate change and ocean acidification. Most of the CO_2 emissions within the fabric production are caused by the energy use throughout the fabric production process.

7.3 Disposable Scrubs

In this section follows a more detailed presentation of the environmental impacts within the different phases of the disposable scrubs life cycle and how they contribute to the whole.

In comparison with the reusable, the division of impacts between contributing phases is less evident for the disposable scrubs. Fabric production and clothes production have the highest overall impact within all of the categories, although the impact of waste scenario- and usage phase cannot be dismissed.

As was demonstrated in figure 9, the highest potential environmental impact (among normalised categories) of the reusable scrubs life cycle lies within the following categories: climate change, ocean acidification, particulate matter formation, marine eutrophication and freshwater eutrophication. The highest emissions of CO_2, affecting mainly climate change and ocean acidification, derive from the fabric production, within which following factors are of highest relevance: electricity use (Chinese grid mix), and the production of its materials (polypropylene, viscose and polyester). Emissions from waste incineration and clothes production contribute to approximately 23% each, of the total GHG-emissions.

Within the categories of PM formation and marine eutrophication the production phases of fabric and clothes give the main impact. Similarly as in the above mentioned categories, the main contributions within these phases are electricity use and material production. The third main contributor within these categories is the usage phase, which comprises the overseas transportations between clothes manufacturer and the hospital.

The high impact indications of clothes production within water depletion and freshwater eutrophication depend on the cotton which is used for the waistband of the scrubs (11.9 grams). This indicates the very substantial impact that cotton production has within these categories.

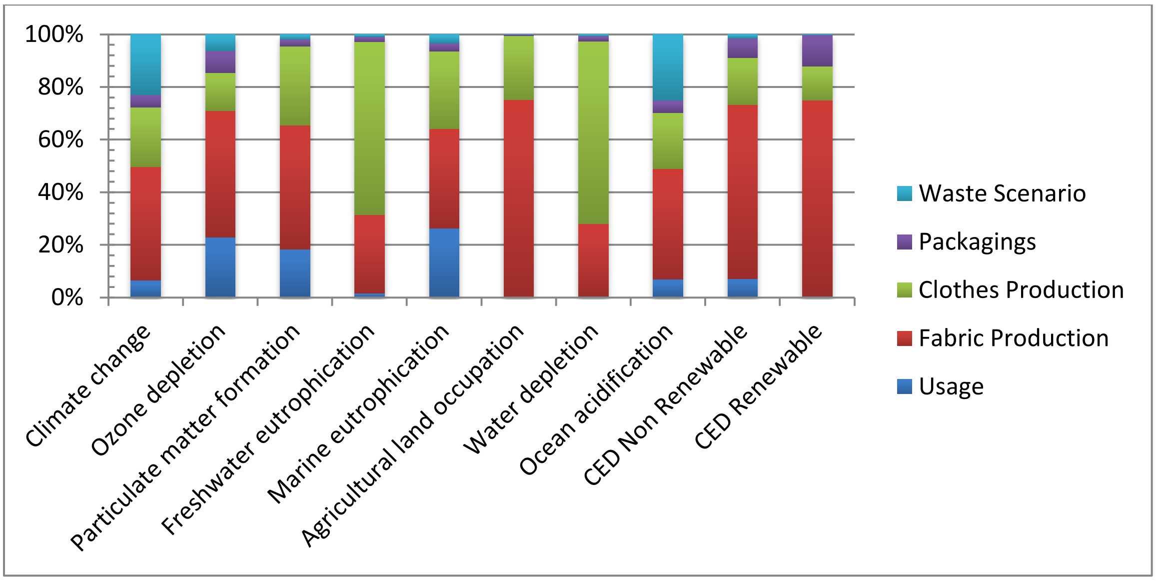

Figure 11: Contribution of the five life cycle phases including fabric production, clothes production, packagings, usage and waste scenario, to the assessed impact categories. The usage category includes transports from production sites to hospital.

Fabric production has the markedly highest impact within both of the CED categories as well as in agricultural land occupation. The energy demand within the process of fabric production is mainly caused by production of polypropylene fibres, though production of viscose fibres and consumption of process energy in the fabric production are also of some relevance.

7.3.1 Transports

The environmental impact of transports has in the previous grouping been displayed as part of the life cycle phases. In the case of reusable scrubs, the impacts caused by transports are negligible in proportion to the other phases/processes, therefore they have not been analysed separately.

For the disposable scrubs, the cumulative transports are of significance for some of the impact categories. For instance, transports cause approximately 23% of the impact within PM formation, 33% within marine eutrophication and 40% within the ozone depletion category. While the two first mentioned categories are mostly affected by the sea transportation, the road transports solely contribute to 40% of the impact within ozone depletion.

7.4 Sensitivity Analyses

In the following section, the results of performed sensitivity analyses are described. Results of the sensitivity analyses are presented as percentage deviation from the initial results-data, as well as illustrated in diagrams.

7.1.1 Lifespan of Reusable Scrubs

One factor that influences the results of this LCA substantially is how many times the multi-use scrubs can be reused. The laundry service which controls the number of uses of each garment has set a limit to 100 uses, so this value was set as standard. The true lifespan of a scrub could also be higher or lower. Based on the results above it can be derived that a further increased lifespan of reusable scrubs would only add to the already markedly higher impact of the disposable scrubs life cycle. Thus, more interesting to investigate changes with lower numbers of reuse applied. Sensitivity analyses were run for 80, 60 and 40 reuse rounds of reusable scrubs, and compared with the standard lifespan of 100 uses.

As expected, figure 12 indicates that the environmental impact of reusable scrubs increases within all of the categories when the lifespan of the scrubs is shortened. Table 16 shows the numerical deviation of the impacts of the different usage scenarios relative to the original amount of 100 uses. All the displayed numbers apply to the FU.

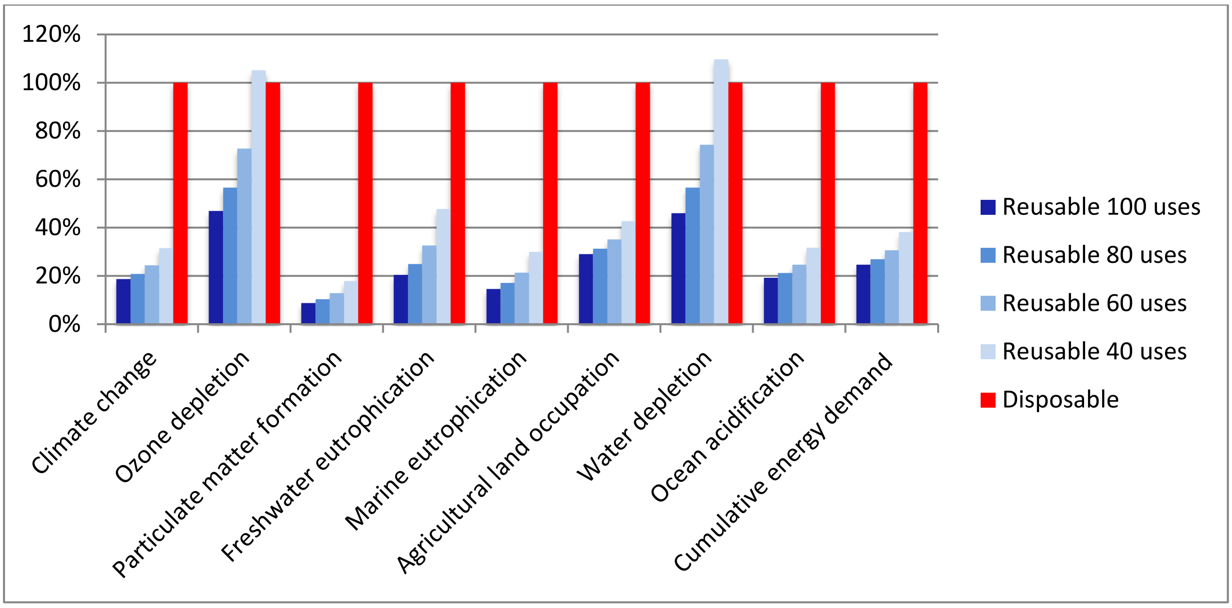

Figure 12: Variations in the relationship between reusable and disposable scrubs due to varying numbers of reuse. For simplification, the category CED is displayed as one, and not divided into renewable and non-renewable sources.

When reducing the lifespan of reusable scrubs to 40 uses two of the potential environmental impact categories exceed the values of disposable scrubs; ozone depletion and water depletion. The category of ozone depletion still shows negligible impact results when normalised. It should be noted that the likelihood for the reusable scrubs only to have a lifespan of 40 uses is very small. Nevertheless, it is interesting to run the analysis with such a reduced number to show the point where impact result start changing.

Impact category	Unit	Reusable 100 uses	Reusable 80 uses	Reusable 60 uses	Reusable 40 uses	Disposable
Climate change	kg CO2 eq	3.68E-01	4.09E-01	4.79E-01	6.18E-01	1.96E+00
Ozone depletion	kg CFC-11 eq	2.36E-08	2.85E-08	3.66E-08	5.29E-08	5.04E-08
Particulate matter formation	kg PM10 eq	3.23E-04	3.80E-04	4.74E-04	6.63E-04	3.69E-03
Freshwater eutrophication	kg P eq	1.48E-05	1.81E-05	2.36E-05	3.47E-05	7.26E-05
Marine eutrophication	kg N eq	4.00E-04	4.70E-04	5.88E-04	8.23E-04	2.75E-03
Agricultural land occupation	m2a	1.55E-01	1.67E-01	1.88E-01	2.28E-01	5.35E-01
Water depletion	m3	4.87E-02	6.00E-02	7.88E-02	1.16E-01	1.06E-01
Ocean acidification	kg CO2	3.41E-01	3.78E-01	4.39E-01	5.62E-01	1.78E+00
Cumulative energy demand	MJ	7.31E+00	7.99E+00	9.11E+00	1.13E+01	2.98E+01

Table 16: Results from the analysis where impacts from alternative lifespans of 80, 60 and 40 uses are compared to the original assumption of 100 uses. In the column to the far right the results of reusable scrubs are displayed for further comparison.

In summary, this sensitivity analysis shows that a plausible increase or decrease in the amount of uses of the reusable scrubs would not have any significant influence on the outcome of the preformed impact assessment.

7.1.2 UCC's Case of Usage and Disposal

A sensitivity analysis was also run where data in the user phase of the reusable scrubs was changed for values from another laundry unit (the laundry service used in UCC). Besides the laundry process, a small difference in the transport distance from the storage unit in Belgium to customer was made.

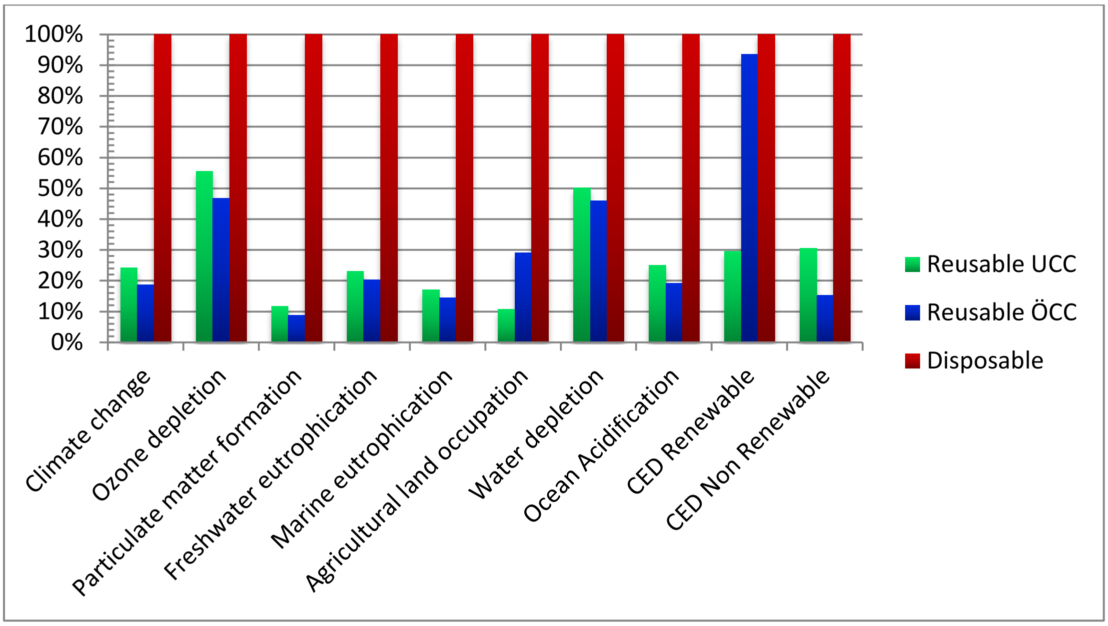

Figure 13: Environmental impact of the disposable scrubs with values for the usage phase of UCC, compared to the previous results for reusable and disposable scrubs. The life cycle with the higher environmental impact within a given category is shown as 100% impact, and impact of the compared units as a proportion of that value.

When changing the parameters in the laundry process, a small variation occurs in the results within all of the studied impact categories. The most significant reason for these changes lies in the divergent types of energy used in the compared laundry processes. The table shows that the non-renewable energy used in the UCC case, is about the double in comparison to the ÖCC case. It is the oil used as fuel in the production of process steam which gives this indication in the UCC case. Even though the consumption of district heating energy used in the UCC case is lower, and with lesser overall environmental impacts (lower share of fossil fuels in the fuel mix) the total impact of consumed fossil fuels exceeds that of ÖCC.

The second parameter that increases the environmental impact within the UCC scenario is that the transport between the laundry service and the hospital is 111 km, compared to 15 km within ÖCC.

Besides the renewable CED category, the ÖCC case also has a significantly higher impact within the agricultural land occupation category. This impact is directly linked to the higher amounts of wood fuels used to produce the energy used in the ÖCC case.

It should be noted that more detailed data concerning the washing process was received from the laundry unit in ÖCC. For instance, processes which were not used in the laundry of the scrubs were not included in the data. In the case of UCC, such a division of processes could not be made, thus data for total consumption within the laundry unit was used and allocated by weight.

The washing process of both laundry units is rather similar, and no greater differences were revealed in the results. One parameter which in reality differs between the processes, but which was modelled with identical data is the laundry detergent. Most of the main ingredients of modern laundry detergents (such as surfactants, phosphates, zeolites and silicates) were represented in the generic detergent, and its environmental impact within the categories was barely noticeable. Therefore, it is not very likely that changes in the proportions of the laundry detergent would have had any significant influence on the results.

Conclusively, this sensitivity analysis indicates that differences in the usage stage of reusable scrubs can have some impact on the cumulative environmental impact of the product. However, the difference did not affect the results between reusable and disposable scrubs much. It is very unlikely that a different scenario for the user phase could affect the results in a way that would significantly change the outcome of this study.

7.5 Summary of Results

In summary, the results of this study indicate that the environmental impacts of the disposable scrubs substantially exceed those of the reusable scrubs. The main reason for this is the longer lifespan of the reusable garments, which results in substantially decreased environmental impacts per FU within all phases of the lifecycle except usage.

Manufacture of cotton, plastics along with usage of fossil fuels are the three single main contributing factors, and the highest impacts are places within the fabric production phase within both types of scrubs. In the case of the reusable scrubs, the washing phase also has a significant environmental impact.

Sensitivity analyses were performed to investigate the robustness of the model, by examining the deviations occurring when changing two central parameters of this study. Results indicated that possible deviations within these parameters would not have had any considerable effects on the outcome of the assessment.

In chapter 6, several previous studies were introduced. Compared to the results of previous LCAs on reusable and disposable textiles, the outcome of this thesis show similar tendencies. Generally, reusable textiles have lesser environmental impact, compared to disposable alternatives, because of their longer lifespan.

8. Discussion and Conclusions

This final chapter is divided into three parts: a description of circumstances of this thesis which might have affected the results; the main conclusions in accordance with the research questions; and further suggestions and reflections.

8.1 Limitations of Results

In this chapter, several circumstances and uncertainties which might have affected the outcome of this study are discussed.

No impact category assessing chemical use or toxicity was included in this study. Certainly, several types of chemicals are used throughout the life cycles of the assessed products, and including them would give increased environmental impact. For instance, the significant environmental impacts of conventional cotton farming and production are nowadays common knowledge. Conventional cotton farming generally requires considerable amounts of pesticides as well as fertilizers. Further, in the dying process of cotton fabric industrial chemicals are widely used (Clay, 2003). Also within the production of several other materials different additives and dyes are added within both life cycles. Some of these chemicals could have been accounted for through generic data (for example in cotton production). However, as a large portion of additives and chemicals used in the production processes could not be assessed, it was decided that excluding them would give a more equitable result.

It should also be mentioned that several of the default impact categories (specified in section 6.1.6) included in the ReCiPe method for impact assessment were not included in this study because of their limited connections to the planetary boundaries. The way of choosing impact categories for this LCA has been based on the preferences of the ÖCC. As with all LCAs, the choice impact categories have an effect on the results. In this study, the chosen impact categories cover a wide area of environmental issues, and a majority of impacts commonly identified as most central for the state of our planet (namely by Rockström et. al, 2009).

The composition of laundry detergents can vary significantly among different brands and manufacturers. A fabricated laundry detergent was used to model both washing scenarios in this LCA. Environmental impacts from the laundry detergent showed to have very marginal environmental impacts, most likely because of the small quantities used in one FU. The question whether the actual detergent used in the reusable life cycle would have had a different impact on the environment, could still be raised.

In both cases of fabric production, generic data was used to model inputs, and specific energy data was used for the fabric production processes. However, no data concerning emissions from the production processes were attained, and assessed environmental impacts from the production only include consumed materials and energy. Thus, the actual environmental impacts of the studied garments probably exceed the values indicated in the results.

Several of the smaller components of the scrubs, as well as the energy used in the sewing process have been excluded in this study. The thread, buttons, size labels and transfer prints obviously all have some environmental impacts. Excluded components are of similar type for both products (except the buttons of the disposable scrubs, for which there is no matching equivalent for the reusable garment. As the volumes of these components are very small, it is not very likely that they would have a significant effect on the results. Varieties in production techniques between the two products are consequently not likely to have any greater effects on the results.

The suggested energy use for sewing, which was excluded because of inconsistencies in data, did initially not have any particularly significant effect on the total environmental impact (energy use in earlier production stages is considerably higher). Thus the exclusion of this phase is assumed to lower the overall environmental impacts somewhat, however not with significant effects on the results.

8.2 Conclusions

The final chapter addresses the three research questions of this study and discusses the results.

- *Which of the studied objects is environmentally favourable relative to the studied impact categories?*

In a study where impacts within several different types of categories are assessed, it is not possible to merge the results into one score, unless a more subjective method of weighting is applied. Thus, if the compared products would have had peaks within different categories, it would have been difficult to determine which one would be environmentally favourable. The consistence of the results in this study, however, makes it possible to determine that the reusable scrubs have considerably lower environmental impact within the studied categories.
For each reuse of the multi-use scrubs, the environmental impact from the laundry procedure, replaces the impacts which would have been caused throughout the production processes, if it was a disposable garment. Clearly, the reuse provides the environmental benefit of the multi-use scrubs.

- *Which parts of each life cycle have the greatest potential environmental impact, and how does this differ between the two products?*

Within the life cycle of the disposable scrubs, the phases of fabric production and clothes production are the major contributors to the cumulative environmental impact. The production of raw materials and usage of fossil energy in production and as fuels for transportation are the principal contributing factors. Despite only contributing to about 7 mass-percentages of the disposable scrubs, the cotton used in the waist band gives an environmental impact comparable to that of the polypropylene which is the main material of the garment (and even exceeds it considerably in two categories).

The phases of fabric production and usage are the main contributors to the environmental impact within the reusable scrubs life cycle. It should be noted that the fabric production has such a large effect on the life cycles total environmental impact, despite of its contribution being divided by 100 uses. Like in the case of disposable scrubs, the main environmental impact of the reusable scrubs derives from the raw materials and energy used in production of fabric.

A noticeable difference between distributions of impacts within the two compared lifecycles is that the impacts within the reusable life cycle are polarized to the two stages of fabric production and usage, while in the disposable case being more evenly spread between the different phases. This difference can be explained with the fact that the same amounts of materials are handled in all of the phases within the disposable scrubs. On contrary, in the case of reusable scrubs, all phases except usage refer to one hundredth of a scrub. Despite only representing one hundredth of the environmental impacts created in the production of one reusable set of scrubs, the fabric production is a major contributor to the cumulative emissions of the life cycle.

- *Within which impact categories does each of the products have their highest environmental impact, in relation to the average global yearly emissions?*

Referring to the normalised results, this question includes results within all of the categories except water depletion and CED.

There is no category within either of the compared scrubs that clearly exceeds other categories. Within the disposable life cycle, the highest impact is within climate change, closely followed by PM formation, ocean acidification and freshwater eutrophication. In the case of the reusable scrubs, the main impact is evenly divided between climate change, ocean acidification and freshwater eutrophication.

The very low outcome of normalised results should not be seen as an indication on the garments low environmental impact. In fact, the yearly emissions from one person are not really comparable to emissions from one usage of a product. However, normalisation of the results was useful to show the significance of the divergent emissions, relative to one another.

8.3 Reflections and Suggestions

♦ The results showed that farming and production of cotton has a very significant impact in several of the assessed categories. During recent years, new types of durable natural fibres have been developed (e.g. bamboo). If the cotton used in the scrubs could be replaced with another material with lesser environmental impact the total environmental burden of the garments could decrease substantially. Further, usage of fossil fuels for energy production also showed to be an important contributing factor to the assessed environmental impact. Namely, combustion of oil is used in several processes. Switching to renewable sources for production of heat and electricity would reduce these impacts considerably. However, different types of renewable fuels would implicate varying environmental impact, for example the usage of biofuels would in most cases result in higher impacts within agricultural land occupation. Thus, depending on which impacts focus is set, different energy sources could be chosen as most suitable.

♦ At present all of the single-use products used within ÖCC are disposed of with incineration, however the council have considered to start recycling some of the disposable products. In the case of disposable scrubs, recycling as an alternative waste scenario would very likely decrease the environmental impacts compared to the present practice of waste incineration.
A difficulty coupled with the recycling of disposable scrubs it that they contain several different materials, which would have to be separated in order for material recycling to take place.
How the environmental impact of the disposable product would change if they were recycled, and weather it would have any significant effects on the impacts relative to the reusable scrubs could be investigated through a change-oriented/consequential LCA. This type of LCA would be better suited because it uses methods specially adapted for comparison of actual environmental impacts of an object with alternative scenarios.

♦ Within public procurement, in order to use environmental impact as a parameter in the decision, it is necessary to set specific criterions for environmental performance. The results of this LCA show within which impact categories the main environmental burdens of the scrubs are, along with several other factors concerning environmental impacts within the studied categories. This information could in several ways be used as a foundation when stipulating environmental criterions. For a complete evaluation of which product is better suited for the purposes of ÖCC, other aspects would also have to be weighed in a procurement decision. Matters of comfort, quality and hygiene as well as costs related to each set of scrubs would be a good complement to the environmental decision support provided through this LCA.

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Appendix A, External Review

MILJÖGIRAFF

External review

External review of LCA

Administrative information

Product name: Comparative Life Cycle Assessment of Surgical Scrub Suits

Contract: 246 Sweco external review

Contact at company: Martyna Mikusinska at KTH / Sweco

Review by: Marcus Wendin at Miljögiraff

Type of audit: Main LCA verification

PCR relevant for this product: "Textile yarn and thread" (partly relevant)

LCA related comments

This review of the LCA report was based on the ISO 14048 and in general understanding of the results. The comments are divided into the four steps of LCA below.

Goal and scope

The goal is clear on all points.
The functional unit (FU) description has after review been changed to embrace the two different products.
In the scope it is noted that the perspective attribution is used and the PP principle is applied, in accordance to the ISO 14025 standard regarding comparison.
The scope, system boundaries description of has after review been clarified regarding excluded parts in the process step from fabric to suit.

Inventory

The explanation and models include all information needed to reproduce the LCA and to understand the details.

Impact Assessment

The defined questions and choice of method is consequently followed and described clearly.

Interpretation and report

The system has been carefully modelled so that it is valid for comparison. Assumptions and gap in data has been analysed on sensitivity to find potential deviations. The final results are trustworthy, transparent and reproducible.

Marcus Wendin 2012-10-17

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