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Life Cycle Assessment of Surgical Care Products

The Cases of a Drape and a Gown

Master's thesis in Industrial Ecology

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2021
www.chalmers.se
Report No. E2021:003

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Cover: The picture shows a drape (over the bed) and a gown (on the person), which are the two products assessed in this study. Picture from Mölnlycke Health Care AB (2021), printed with permission.

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Abstract

Life cycle assessment (LCA) is a valuable tool for assessing environmental and health impacts of products, including those of surgical care. This LCA was conducted in collaboration with the company Mölnlycke Health Care regarding two of their surgical care products: a drape called BARRIER® OP-towel and a Standard Classic operation gown. Scenarios consisting of material changes were defined in order to identify opportunities for lowering environmental impacts related to the two chosen products and also to assess the net human health impacts of the drape using the disability-adjusted life years (DALY) indicator.

Regarding the drape, the findings from this LCA study suggest that there is often a tradeoff between the use of fossil resources and global warming on the one hand, versus land use on the other. While the change of material presents several opportunities for lowering the environmental as well as human health impacts, there is no unambiguously preferable scenario for the drape. Therefore, more radical changes might need to be assessed in order to find more clear-cut environmental improvements. The drape is a net positive contributor to the human health regardless of the chosen scenario. The negative health impacts derived from the LCA are very low compared to the positive health impacts from the use of the product as reported in previous studies.

Regarding the gown, all material changes in the scenarios resulted in considerable reductions in environmental impacts for effectively all impact categories, which is why the implementation of one or more of the material changes assessed is recommended. In addition, more detailed assessments with improved and more case-specific data is recommended, since the assessment of the gown was largely based on generic data and approximations.

Keywords: Life cycle assessment, LCA, surgical scrubs, textiles, healthcare, surgical care products, disposable drape

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Preface

This master thesis of 30 ECTS is carried out as a part of the Master of Science program Industrial Ecology at Chalmers University of Technology. It has been conducted during the fall of 2020 at the Division of Environmental Systems Analysis at the Department of Technology Management and Economics.

The thesis has been conducted in collaboration with the medical solutions company Mölnlycke Health Care AB. I would thereby like to pay special thanks to Lars Lindgren, Elin Näsström and Nils Ljungqvist at Mölnlycke for their guidance and resources provided. I would further like to give many thanks to my academic supervisor Rickard Arvidsson for guiding me through the process and contributing with his expertise.

Finally, I would like to thank my family and friends for constant support and encouragement throughout my educational years at Chalmers.

Beatrice Tobin

Gothenburg, February 2021

1. Introduction

Equipment for surgical care is a central part of today’s health care. Drapes and gowns protect patients and medical workers from exposure to microorganisms and body fluids. At the same time, a recent study from 2019 reports that the global healthcare contributes to an average of 4.4% of the world’s carbon footprint based on data from 2014 (Pichler et al., 2019). The medical industry thus needs to strive to minimize their environmental impacts and ensure that products are net-positive contributors to human health. The most established analysis tool for assessing environmental and health impacts of products is life cycle assessment (LCA), which can be utilized for all kind of products, including those of surgical care (Ness et al., 2007).

1.2 LCA methodology

The framework of an LCA consists of four steps and is described in Figure 1 (Baumann and Tillman, 2004).

The first step when performing an LCA is the *goal and scope definition.* This part includes a specification of the aim of the study, the intended audience and the general context. The functional unit is set, which expresses the function of the product system and gives a basis for comparison that all inputs and outputs can be related to.

In the *inventory analysis,* the relevant inputs and outputs are compiled and related to the functional unit of the study. This is normally the most time-consuming step of an LCA.

The result from the inventory analysis, i.e. the inventory data, is then translated into environmental impacts in the *impact assessment* step. A large number (often >100) of inputs and outputs are then turned into a more limited (often <10) set of impact categories, such as global warming, acidification, eutrophication, ozone depletion and energy use.

Finally, in *interpretation* the results are interpreted in relation to the goal of the study, which might include the identification of hotspots and an uncertainty analysis.

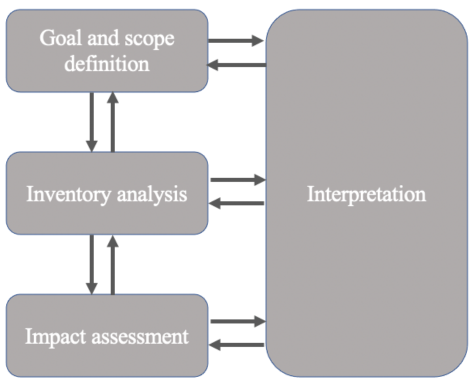

Figure 1. The framework for carrying out an LCA. Adapted from Baumann and Tillman (2004).

1.3 Previous LCA studies of surgical care products and net health impacts

Previous studies indicate that a selection of reusable gowns over disposable could reduce environmental impacts by more than 50% (Vozzola et al., 2020). Another study similarly concludes that a reusable surgical scrub suit has lower environmental impacts than a disposable one, since the main environmental impacts of the studied products derive from the raw materials and energy use during the production of fabric (Mikusinska, 2012). This information suggests that it is important for surgical care producers to look into actions that could improve the environmental performance of their disposable gowns.

Another study compared disposable scissors made of either stainless steel or fibre-reinforced plastic with reusable stainless-steel scissors. The results show that the reusable stainless-steel product produced the lowest environmental impact followed by the plastic disposable and the stainless-steel disposable scissors, indicating that disposable surgical care products need to mitigate their environmental performance in order to compete with those of reusable nature (Ibbotsson et al., 2012).

When assessing products that claim to prevent injuries and save lives, it is important that the net health impact is positive, also when considering a broader life-cycle perspective. Previous studies on have investigated a range of products with presumed positive health impacts, such as airbags, catalytic converters, tire studs, pharmaceuticals and gas sensors for toxic fumes (Arvidsson et al., 2018; Furberg et al., 2018; Gilbertson et al., 2014; Debaveye et al., 2020). Interestingly, not always do the results of these studies show that the products actually prevent injuries and save lives from a life-cycle perspective, such as in the case of the tire studs. In such cases, negative health impacts related to e.g. emissions of greenhouse gases and hazardous substances outweigh the positive health impacts related to the use of the product. To the best of the author's knowledge, no study of the net human health impacts of drapes or gowns have yet been conducted.

1.4 Aim of the study

In this master thesis, LCAs will be conducted on two surgical products: a drape called BARRIER® OP-towel and a Standard Classic operation gown, hereafter reffered to as simply the "drape" and "gown", respectively. The LCAs are conducted in collaboration with the medical solutions company Mölnlycke Health Care AB (Gothenburg, Sweden). By assessing environmental impacts of alternative materials selection and other potential environmental improvements, the knowledge gained will help actors such as Mölnlycke Health Care AB to determine how to best reduce environmental impacts related to their products. In addition, by performing an assessment of the net health impacts of the drape from a life-cycle perspective, the knowledge gained could also contribute to insights and useful knowledge for future product development and improvement. The aim of this study is therefor to provide information about how medical solutions companies can reduce the enviromental impacts of drapes and gowns, as well the health impacts of drapes.

1.5 The studied products

The drape is used on patients during different surgical interventions in order to facilitate technical support to the staff such as absorption of liquids, as well as creating a sterile field for a surgical procedure to contribute to a reduction of the wound contamination and of the post-operative wound infection rate. It is comprised of the parts listed in Table 1 and is also illustrated schematically in Figure 2. The gown is used on personnel when performing different surgical interventions in order to maximize protection against contamination of the surgical wound. It is a standard single layer textile product, which today consists of wood pulp and polyester.

Table 1. Parts of the drape and their material description. PE=polyethylene.

ID	Name	Material description
1	Top layer	Chembond non-woven
2	PE film	Impermeable layer
3	Comfort layer	Spunbound non-woven
4	Skin adhesive	Glue technomelt
5	Patch	Non-woven
6.1	Lamination adhesive	Hot melt glue
6.2	Patch adhesive	Glue artimelt
6.3	Release liner film	Protect skin adhesive

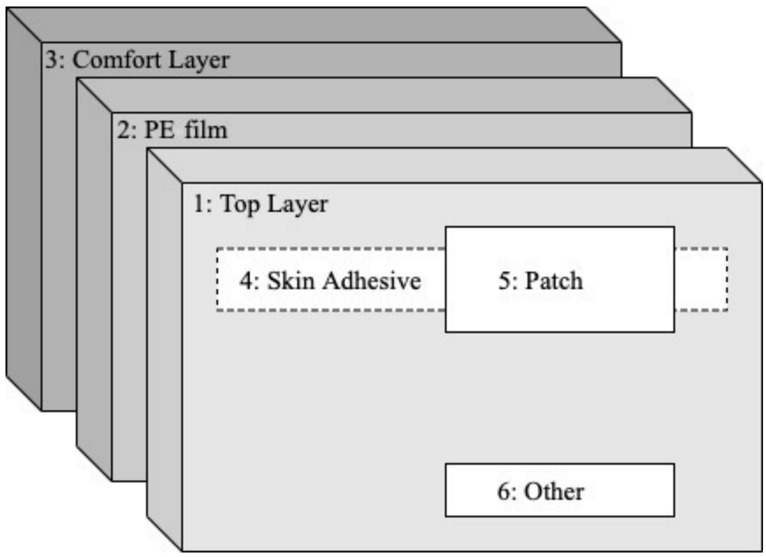

Figure 2. Schematic picture of the layers of the drape.

2. Goal and Scope Definition

In this chapter, the goal and scope of the LCA study are described, which sets the frame for the LCA study.

2.1 Goal of the study

The goal of the LCA are twofold:

1. to identify opportunities for lowering environmental impacts related to the drape and the gown.
2. to identify opportunities for improving the net human health impacts of the drape.

Although these goals might be of interest to several different actors, the main intended audience of the study are medical solutions companies providing drapes and gowns as part of their product portfolio.

2.2 Scope of the study

In this study, it is the main layers of the two products that are under investigation: the top layer (ID: 1), the PE film (ID: 2) and the comfort layer (ID: 3) of the drape, and the single layer of the gown (see Figure 2 for a clarification of the ID numbers). The scenarios have been chosen together with Mölnlycke Healthcare AB, where scenario D1 and G1 constitutes the current product materials composition of the drape and gown, respectively, i.e. what they consist of today. All parts of the production are the same besides the materials varied in the different scenarios. The assessment scenarios for the drape are shown in Table 2, and the scenarios chosen for the gown are shown in Table 3. In scenario D2 for the drape, the top layer is changed from viscose to polypropylene (PP). In scenario D3, the fossil PE film is replaced with a bio-based PE film. The bio-based raw material used for the PE-film in this scenario is sugar cane. In scenario D4 the comfort layer, which only function is to provide amenity towards the patient and does not affect the main function of preventing contamination, is removed.

In scenario G2 of the gown, primary polyester is replaced by recycled polyester. In scenario G3, the whole material is changed to PP with a surface weight of 40 g/m^2 and in scenario G4, the whole material is instead changed to PP with a surface weight of 35 g/m^2.

Table 2. Assessment scenarios for the drape. PE=polyethylene, PP=polypropylene.

Scenario	PE film: Fossil	PE film: Bio	Top layer: Viscose	Top layer: PP	Comfort layer
D1	X		X		X
D2	X			X	X
D3		X	X		X
D4	X		X		-

Table 3. Assessment scenarios for the gown. PP=polypropylene.

Scenario	Wood pulp	Polyester	Recycled polyester	PP (40 g/m^2)	PP (35 g/m^2)
G1	50%	50%			
G2	50%		50%		
G3				X	
G4					X

2.2.1 Type of LCA and main data sources

The performed LCAs are attributional, with as focus on describing the relevant physical flows to and from the life cycles of the drape and the gown (Finnveden et al., 2009). Modelling and impact calculations are performed in the open-source software OpenLCA (version 1.10.2), using mainly life cycle inventory data from the Ecoinvent database (version 3.7) and additional data provided by Mölnlycke Health Care AB.

2.2.2 Functional Unit

The functional unit for the drape is set to one piece (i.e. item or product) of drape. The functional unit of the gown is set to 1 m^2.

2.2.3 Impact Categories

The chosen impact categories are all part of the ReCiPe 2016 package of impact assessment methods (Huijbregts et al., 2016):

- Fossil resource scarcity
- Freshwater ecotoxicity
- Freshwater eutrophication
- Global warming
- Land use
- Water consumption

These midpoint impact categories represent represent a wide range of different environmental issues. In particular, some of them are often high for fossil-based products (e.g. global warming), while some are often high for bio-based products (e.g. land use). This set of impact categories will thus probably enable the identification of tradefoffs between fossil- and bio-based products. Note, however, that there might be considerable correlation between several of the midpoint impact categories, as shown by e.g. Steinmann et al. (2016).

In addition to the midpoint indicators, disability-adjusted life years (DALY) is used as endpoint indicator for human health in order to assess the net health impacts of the drape (Arvidsson et al., 2018).

2.2.4 System boundaries

Figure 3 shows a flow chart for the processes and materials of the product life cycle for the drape. The raw materials originate mainly from France, Belgium, the Netherlands, Spain and Germany. The assembly of the final product takes place in Waremme, the Netherlands.

Figure 4 shows a flow chart for the processes and materials of the product life cycle for the gown. It assumed that all materials originate from China, while the data used for the raw materials is of average global data. For detailed information, see Section 3.

The products generate no impacts during their use phase (apart from positive health impacts), and the transports after the assembly are the same regardless of chosen scenario. All known emissions to soil, air and water are included – regardless of geographical location.

Production and maintenance of personnel, production equipment and other capital goods related to the products are excluded from the study, unless part of the background system data obtained from the Ecoinvent database (see Section 3.1.1 for the drape and 3.2.1 for the gown). The study does not include packaging, sterilization or waste treatment of the two products.

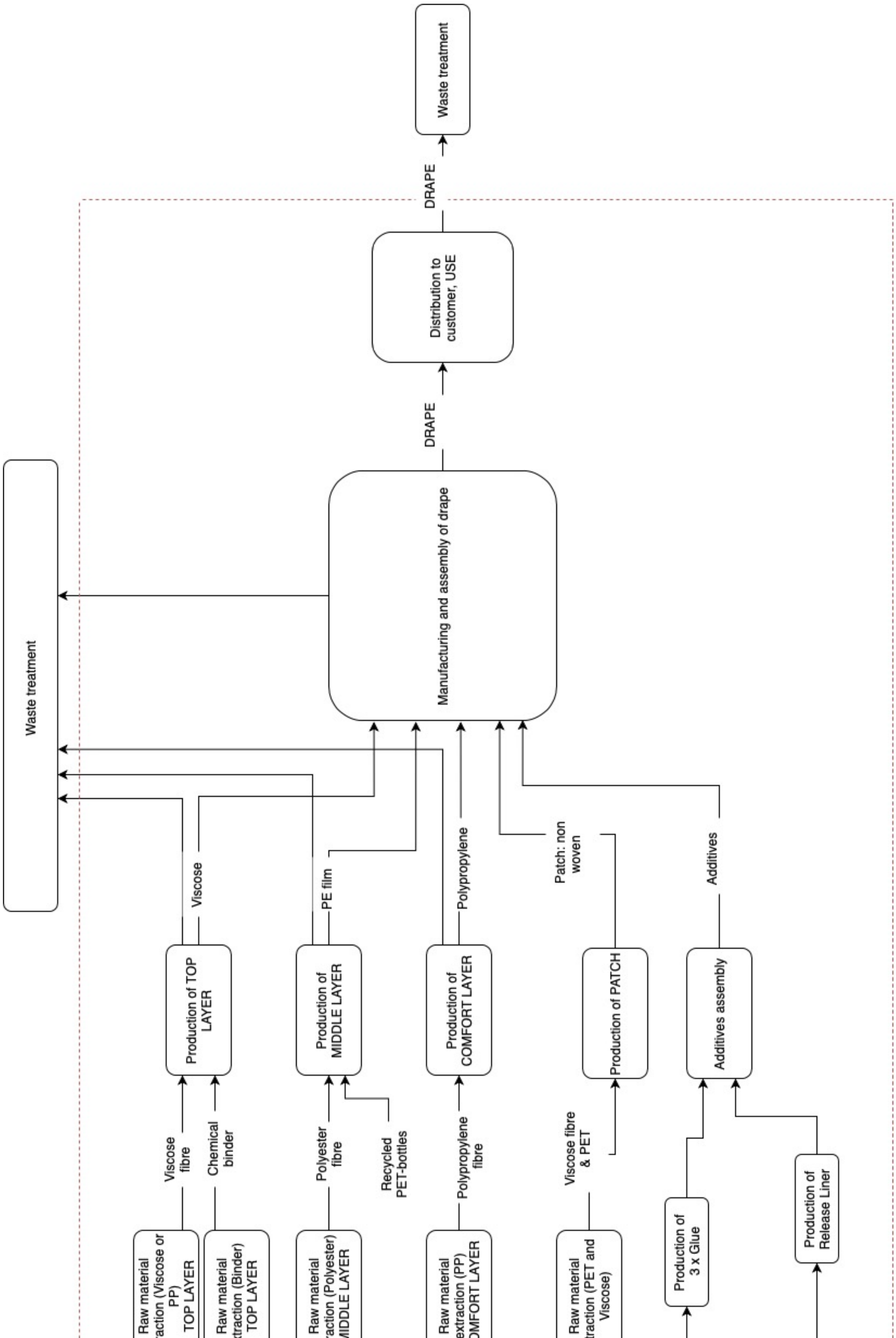

Figure 3. Flowchart for the drape. The dashed box represents the system boundary. PE=polyethylene, PP=polypropylene, PET=Polyethylene terephthalate.

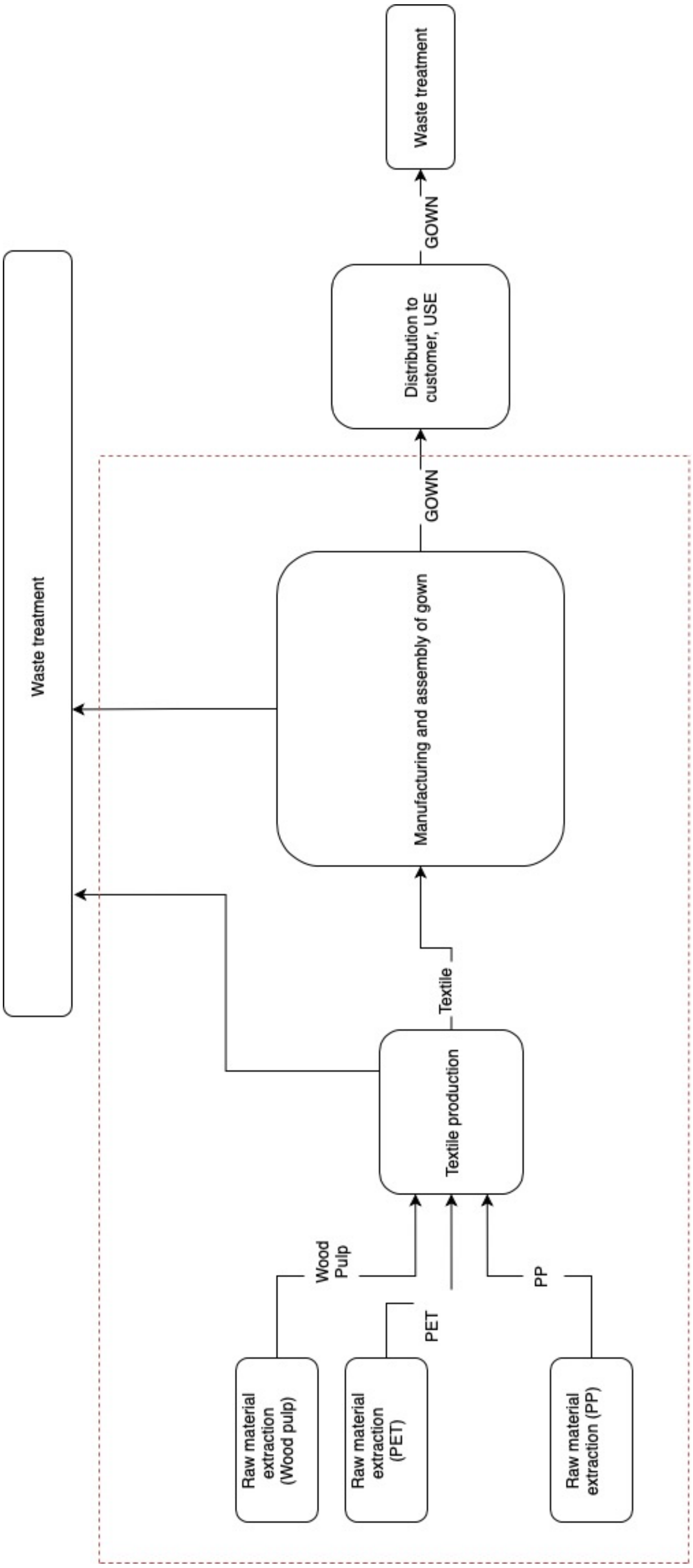

Figure 4. Flowchart for the gown. The dashed box represents the system boundary. PP=polypropylene, PET=Polyethylene terephthalate.

2.2.5 Delimitations and general assumptions

Due to lack of time and data, several assumptions have been required. Some of the more major ones are mentioned here:

- When switching materials in the different scenarios, it is always assumed that the same amount of the new material is needed even though it could potentially differ due to different technical performances.

- There are two available datasets for pigments in the Ecoinvent database (version 3.7), namely production of titanium dioxide (TiO_2) and carbon black. The products under investigation are green and blue, but no datasets matching these colors have been found. Therefore, a 50/50% mixture of the two available pigments (TiO_2 for white and carbon black for black) has been applied as a "proxy pigment". Considering that netiher TiO_2 nor carbon black have very high impacts from production (e.g. cumulative energy demand <100 MJ/kg), this might be an underestimation.

- All suppliers have reported transport distances for their raw materials, apart from the material in the comfort layer of the drape. The supplier has, however, reported that the material is sourced from within the EU. Therefore, an assumption of a medium distance of 1 000 km has been applied.

- All truck transports of materials are modelled as Euro 6 trucks with a 16-32 metric ton payload capacity. Euro 6 is the most current European vehicle emission standard for exhaust emissions.

- Due to very limited availabilty of data for the gown, it is assumed that the same type and amount of energy per functional unit is required in the processes of material production regardless of raw material used in the processes.

- Transports for the gown have not been included unless part of the background system data obtained from the Ecoinvent database and is then part of the results linked to each material selection in the scenarios. This is because the location of the possible future production sites are unknown.

3. Inventory analysis

The inventory analysis for the drape is presented in Section 3.1, while the inventory analysis for the gown is presented in Section 3.2.

3.1 The Drape

The inventory analysis of the drape can be divided into two sections: production of input materials (described in Section 3.1.1) as well as production, assembly and use of the drape (described in Section 3.1.2).

3.1.1 Input materials

Declaration of the input material used for the functional unit of the drape can be seen in Table 4. The data collected for the top layer (ID: 1), PE film (ID: 2), comfort layer (ID: 3) and the patch (ID: 5) are product specific while generic data has been applied to the remaining materials.

In many cases, the production system datasets selected logically represent a generic global or rest-of-the-world production of the material in question, e.g. the dataset “fibre production, viscose | fibre, viscose | Cutoff, U – GLO” for the material viscose. However, for some materials, the background production system dataset selection is less straight forward and therefore warrant more detailed explanations. Regarding the selection of datasets for pigments production, see Section 2.2.5. Regarding the bio-based PE film (ID: 2), three datasets have been used, where two of them originate from Ecoinvent: production of ethanol from sugar cane and production of LDPE from ethylene. However, no dataset representing the production of ethylene from ethanol is available in the Ecoinvent dataset. Therefore, a dataset for the production of ethylene from ethanol was obtained from a study investigating this specific process, conducted by Liptow & Tillman (2012).

As proxy process for the production of hydrogenated hydrocarbon resin used in the adhesives (ID: 5, 6.1, 6.2), epoxy resin production was selected from the Ecoinvent database. Although epoxy is not a pure hydrocarbon, it is mainly hydrocarbon-based and has a wide range of uses among adhesives (Abbey, 2010). Unfortuntately, no other, more suitable dataset could be identified, neither in the Ecoinvent database nor in any other available database. Therefor the chosen dataset “epoxy resin production, liquid | epoxy resin, liquid | Cutoff, U – RER” is assessed to be the most representative dataset in the Ecoinvent database.

Regarding the mineral oil and polybutene (ID: 6.1), it was approximated as mineral oil only. Since mineral oil consists of highly refined liquid paraffin, a paraffin production dataset from the Ecoinvent database was chosen for the modeling of the mineral oil’s upstream impacts.

Table 4. Material declaration and chosen datasets, mainly from the Ecoinvent database (version 3.7). PP=polypropoylene, PE=polyethylene, PET=polyethylene terephthalate, LDPE=low density polyethylene, LLDPE=linear low density polyethylene.

ID	Input materials	Total share of mass [%]	Supplier location	Dataset(s)
1: Top Layer (Viscose)	Viscose	25.1	50% (NL), 50% (FR)	fibre production, viscose | fibre, viscose | Cutoff, U - GLO
	Ethylene Vinyl Acetate polymer			ethylene vinyl acetate copolymer production | ethylene vinyl acetate copolymer | Cutoff, U - RER
	Pigments			50% carbon black production | carbon black | Cutoff, U - GLO
				50% market for titanium dioxide | titanium dioxide | Cutoff, U - RER
1: Top Layer (PP)	PP	25.1	GLO	market for textile, non woven polypropylene | textile, non-woven polypropylene | Cutoff, U - GLO
	Ethylene Vinyl Acetate polymer			ethylene vinyl acetate copolymer production | ethylene vinyl acetate copolymer | Cutoff, U - RER
	Pigments			50% carbon black production | carbon black | Cutoff, U - GLO
				50% market for titanium dioxide | titanium dioxide | Cutoff, U - RER
2: PE film	LDPE	41.4	(BE)	polyethylene production, low density, granulate | polyethylene, low density, granulate | Cutoff, U - RER
	LLDPE			polyethylene production, linear low density, granulate | polyethylene, linear low density, granulate | Cutoff, U - RER
	Pigments			50% carbon black production | carbon black | Cutoff, U - GLO
				50% market for titanium dioxide | titanium dioxide | Cutoff, U - RER
2: PE film (bio-based)	LDPE (Sugar cane)	41.4	(BR)	Sugarcane to ethanol: sugarcane processing, modern annexed plant | ethanol, without water, in 95% solution state, from fermentation | Cutoff, U – BR Ethanol to ethylene: Liptow & Tillman (2012), data from their Table 2 Ethylene to LDPE: polyethylene production, low density, granulate | polyethylene, low density, granulate | Cutoff, U – RER
	Pigments			50% market for titanium dioxide | titanium dioxide | Cutoff, U - RER
				50% carbon black production | carbon black | Cutoff, U - GLO
3: Comfort Layer	PP Fibre	10.5	(ES)	market for textile, non woven polypropylene | textile, non-woven polypropylene | Cutoff, U - GLO
4: Patch	Viscose	7.7	(ES)	fibre production, viscose | fibre, viscose | Cutoff, U - GLO
	Pigments			50% carbon black production | carbon black | Cutoff, U - GLO
				50% market for titanium dioxide | titanium dioxide | Cutoff, U - RER
	PET fibres (30%)			polyethylene terephthalate production, granulate, bottle grade | polyethylene terephthalate, granulate, bottle grade | Cutoff, U - RER

5: Skin Adhesive	Hydrogenated hydrocarbon resin	2.2	(SE)	epoxy resin production, liquid | epoxy resin, liquid | Cutoff, U - RER
	Styrene-isoprene block copolymers			acrylonitrile-butadiene-styrene copolymer production | acrylonitrile-butadiene-styrene copolymer | Cutoff, U - RER
	Paraffin oil			paraffin production | paraffin | Cutoff, U - RER
6.1: Lamination Adhesive	Hydrogenated hydrocarbon resin	4.4	(IT)	epoxy resin production, liquid | epoxy resin, liquid | Cutoff, U - RER
	Styrene-isoprene block copolymers			acrylonitrile-butadiene-styrene copolymer production | acrylonitrile-butadiene-styrene copolymer | Cutoff, U - RER
	Mineral oil + polybutene*			paraffin production | paraffin | Cutoff, U - RER
6.2: Patch Adhesive	Polyolefin	1.6	(CH)	polypropylene production, granulate | polypropylene, granulate | Cutoff, U - RER
	Hydrocarbon resin			epoxy resin production, liquid | epoxy resin, liquid | Cutoff, U - RER
	Mineral oil			paraffin production | paraffin | Cutoff, U - RER
6.3: Release Liner Film	Paper	7.1	(ES)	paper production, woodfree, uncoated, at integrated mill | paper, woodfree, uncoated | Cutoff, U - RER
	PE			packaging film production, low density polyethylene | packaging film, low density polyethylene | Cutoff, U - RER
	Silicone			silicone product production | silicone product | Cutoff, U - RER

* Input approximated as 100% mineral oil.

3.1.2 Production, assembly and use

Table 5 consists of specific production data for the layers of the drape and their assembly collected from producers. The drape is assembled in Waremme, Belgium. Table 6 consists of specific data on transportation collected from the suppliers, specifically transportation distances to Waremme for all input materials and the respective modes of transport. Table 7 shows a scenario assumed for the transport of the drape from Waremme to Stockholm, where it is assumed to be used.

Table 5. Modelling data for production of the layers and their assembly, specific energy data.

ID	Input	Approximate amount	Unit	Dataset(s)
1: Top Layer	Electricity	3E-04	kWh/g product	market for electricity, medium voltage | electricity, medium voltage | Cutoff, U - FR
	Natural gas	3E-05	kWh/g product	market group for heat, district or industrial, natural gas | heat, district or industrial, natural gas | Cutoff, U - RER
2: PE-film	Electricity	5E-05	kWh/g product	market for electricity, medium voltage | electricity, medium voltage | Cutoff, U - BE
3: Comfort Layer	Electricity	2E-03	kWh/g product	market for electricity, medium voltage | electricity, medium voltage | Cutoff, U - ES
	Natural gas	7E-06	kWh/g product	market group for heat, district or industrial, natural gas | heat, district or industrial, natural gas | Cutoff, U - RER
4: Patch	Electricity	3E-03	kWh/g product	market for electricity, medium voltage | electricity, medium voltage | Cutoff, U - ES

	Natural gas	1E-02	kWh/g product	market group for heat, district or industrial, natural gas | heat, district or industrial, natural gas | Cutoff, U - RER
Assembly	Electricity	7E-03	kWh/g product	market for electricity, medium voltage | electricity, medium voltage | Cutoff, U - BE

Table 6. Transport distances and modes of transport to Waremme, Belgium, for assembly.

ID	Distance from – to	Distance [km]	Vehicle	Dataset
1	Bailleul (FR) – Waremme (BE)	215	Truck	transport, freight, lorry 16-32 metric ton, EURO5 | transport, freight, lorry 16-32 metric ton, EURO5 | Cutoff, U – RER
1	Cuijk (NL) – Waremme (BE)	175	Truck	transport, freight, lorry 16-32 metric ton, EURO5 | transport, freight, lorry 16-32 metric ton, EURO5 | Cutoff, U – RER
2	(BE) – Waremme (BE)	20	Truck	transport, freight, lorry 16-32 metric ton, EURO5 | transport, freight, lorry 16-32 metric ton, EURO5 | Cutoff, U – RER
3	Tarragona (ES) – Waremme (BE)	1430	Truck	transport, freight, lorry 16-32 metric ton, EURO5 | transport, freight, lorry 16-32 metric ton, EURO5 | Cutoff, U – RER
4	(SE) – Waremme (BE)	1522	Truck	transport, freight, lorry 16-32 metric ton, EURO5 | transport, freight, lorry 16-32 metric ton, EURO5 | Cutoff, U – RER
		20	Ferry	transport, freight, sea, ferry | transport, freight, sea, ferry | Cutoff, U – GLO
5	Mildenau (DE) – Waremme (BE)	696	Truck	transport, freight, lorry 16-32 metric ton, EURO5 | transport, freight, lorry 16-32 metric ton, EURO5 | Cutoff, U – RER
6.1	(IT) – Waremme (BE)	850	Truck	transport, freight, lorry 16-32 metric ton, EURO5 | transport, freight, lorry 16-32 metric ton, EURO5 | Cutoff, U – RER
6.2	(CH) – Waremme (BE)	592	Truck	transport, freight, lorry 16-32 metric ton, EURO5 | transport, freight, lorry 16-32 metric ton, EURO5 | Cutoff, U – RER
6.3	(ES) – Waremme (BE)	1179	Truck	transport, freight, lorry 16-32 metric ton, EURO5 | transport, freight, lorry 16-32 metric ton, EURO5 | Cutoff, U – RER

Table 7. Transport of the drape from Waremme, Belgium, to Stockholm, Sweden.

Distance from – to	Distance [km]	Vehicle	Dataset
Waremme (BE) – Karvina (CZ) – Landskrona (SE) – Stockholm (SE)	2863	Truck	transport, freight, lorry 16-32 metric ton, EURO5 | transport, freight, lorry 16-32 metric ton, EURO5 | Cutoff, U – RER
	20	Ferry	transport, freight, sea, ferry | transport, freight, sea, ferry | Cutoff, U – GLO

3.2 The Gown

The inventory analysis of the gown can be divided into two sections: production of input materials (described in Section 3.2.1) as well as production and assembly of the gown (described in Section 3.2.2). Note that transports have not been included unless part of the background system data obtained from the Ecoinvent database and is then part of the results linked to each material selection in the scenarios.

3.2.1 Input materials

Declaration of the input material used for the functional unit of the gown can be seen in Table 8. Note that the modeling of the recycled polyester is performed in a simplified way. Generally, the modeling of the 50% recycled polyester in scenario G2 could e.g. include the replacement of the primary polyester with a flow of recycled polyester, which can be referred to as a recycled content approach (Frischknecht, 2010). However, there is no dataset for recycling of polyester in the Ecoinvent database. Therefore, the primary polyester production dataset was modified by removing the burden of raw material extraction and used as proxy dataset for the recycled polyester. This simplified approach resembles a closed-loop modeling of recycling (Frischknecht, 2010), with the assumption that the recycling process has similar impacts as the production process and that negligible degradation of the polyester occurs between the cycles.

Table 8. Material declaration and chosen datasets from the Ecoinvent database (version 3.7).

Scenario	Input materials	Total share of mass [%]	Dataset
G1	Wood pulp	50	sulfate pulp production, from softwood, unbleached | sulfate pulp, unbleached | Cutoff, U - RoW
	Polyester	50	market for textile, non woven polyester | textile, non-woven polyester | Cutoff, U - GLO
G2	Wood pulp	50	sulfate pulp production, from softwood, unbleached | sulfate pulp, unbleached | Cutoff, U - RoW
	Recycled Polyester	50	market for textile, non woven polyester | textile, non-woven polyester | Cutoff, U - GLO *
G3	PP	100	market for textile, non woven polypropylene | textile, non-woven polypropylene | Cutoff, U - GLO
G4	PP	100	market for textile, non woven polypropylene | textile, non-woven polypropylene | Cutoff, U - GLO

*Modelled without the burden of the raw material extraction.

3.2.1 Production and assembly

The current supplier of polypropylene has delivered specific data on material production. For the assembly process, data was instead obtained from the study by Roos et al. (2019), specifically their dataset “Garment making: cutting, sewing”. This data on assembly of the materials was then used on all scenarios regardless of production site and materials and is presented in Table 9.

Table 9. Modelling data for production of the textile material and assembly, specific energy data.

Process	Input	Approximate amount	Unit	Dataset(s)
Production of material	Electricity	2	kWh/kg product	market group for electricity, medium voltage | electricity, medium voltage | Cutoff, U - GLO
	Natural gas	0.1	kWh/kg product	market group for heat, district or industrial, natural gas | heat, district or industrial, natural gas | Cutoff, U - GLO
Assembly*	Electricity	0.2	kWh/kg product	market group for electricity, medium voltage | electricity, medium voltage | Cutoff, U - GLO

* Data obtained from Roos et al. (2019)

4. Impact assessment

The environmental impact results for the chosen impacts categories of the study are presented in Section 4.1 and 4.2 for the drape and the gown, respectively. Dominance analyses are further performed and shown in Section 4.1.1 and 4.2.1.

4.1. Impacts of the drape

The results from the assessment of the drape can be seen in Table 10. The contributions can be seen in detail in Appendix I, Table 20.

Table 10. Results from the impact assessment of the drape.

Impact Assessment	**Fossil Resource Scarcity** (kg oil-eq)	**Freshwater ecotoxicity** (kg 1,4-DCB)	**Freshwater eutrophication** (kg P-eq)	**Global warming** (kg CO_2-eq)	**Land Use** (m^2 crop-eq)	**Water consumption** (m^3)
D1	1.21E-01	6.03E-03	4.76E-05	2.23E-01	2.06E-02	3.33E-03
D2	1.33E-01	5.44E-03	4.23E-05	2.19E-01	1.07E-02	2.68E-03
D3	8.98E-02	6.34E-03	5.11E-05	2.10E-01	5.50E-02	3.50E-03
D4	1.09E-01	5.40E-03	4.25E-05	2.07E-01	2.03E-02	3.14E-03

The result of the endpoint impacts assessment evaluating the human health impacts can be seen in Figure 5. The aggregated health impacts are comprised of contributions from:

- Fine particulate matter formation
- Global warming, Human health
- Human carcinogenic toxicity
- Human non-carcinogenic toxicity
- Ionizing radiation
- Ozone formation, Human health
- Stratospheric ozone depletion
- Water consumption, Human health

The non aggregated values can be seen in Appendix I, Table 21.

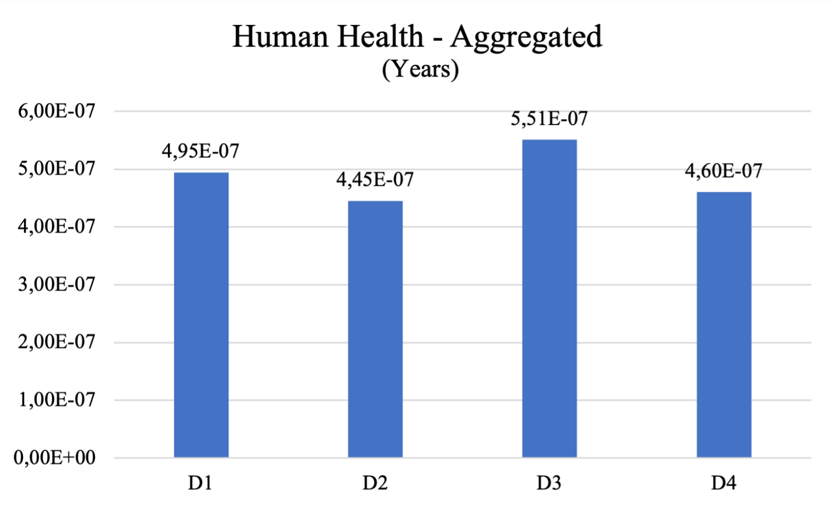

Figure 5. Results from the human health impact assessment of the drape for the scenarios D1-D4.

As can be seen in Figure 5, the negative health impacts of the drape from emissions to the environment is approximately 4 to 5.5 $\times 10^{-7}$ years/drape. As comparison, previous studies report that one disposable drape reduces the risk of surgical site infection (SSI) by 0.46% to 11.5% (Keiser et al., 2018). Another study report that that the average number of years lost per SSI is 2.5 years, specifically in the Netherlands (Koek et al., 2019). In the lower case, a drape thus bring a 0.46% probablility of avoiding 2.5 years lost, i.e. $0.0046\times 2.5=0.0115$ years. In the higher case, a drape brings a 11.5% probability of avoiding 2.5 years lost, i.e. $0.115\times 2.5=0.288$ years. In both cases, these avoided negative health impacts of a drape, which can be seen as positive health impacts from using a drape, are several orders of magnitude higher than the negative health impacts from emissions to the environment as shown in Figure 5.

4.1.1 Dominance analysis

Figure 6 shows that the majority of the contribution to the global warming from all scenarios are the top layer, followed by the PE film. Notably, the global warming results are very similar for all scenarios.

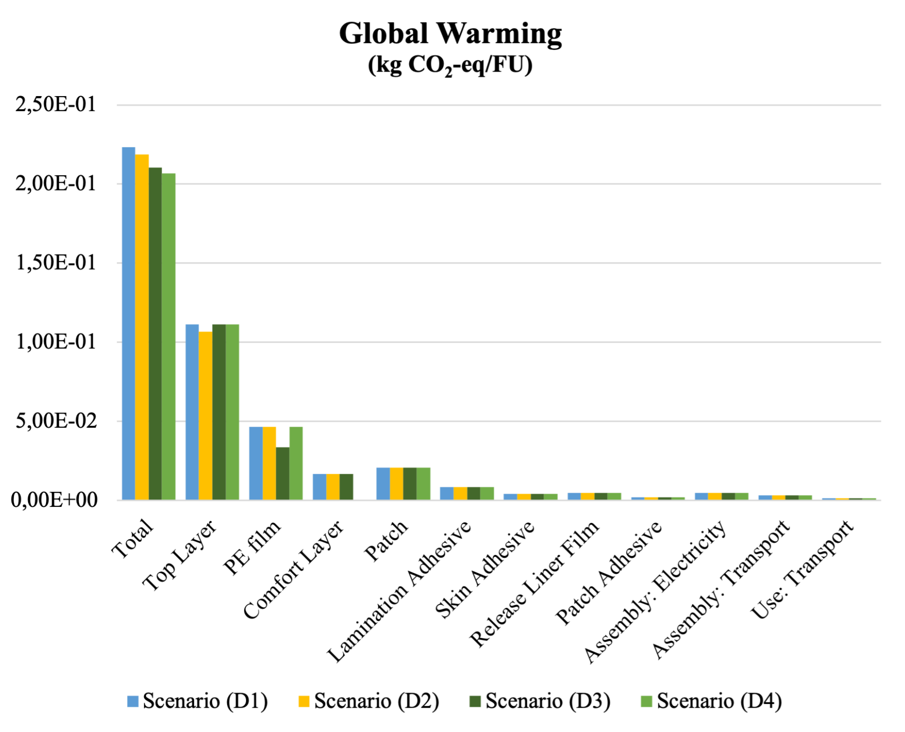

Figure 6. Contributions to the impact category global warming for the drape.

Figure 7 shows that the majority of the contribution to the fossil resource scarcity from all scenarios are the top layer. Scenario D2 results in a high contribution from the switch of material of the top layer, while scenario D3 shows a significant reduction regarding the PE film, making the comfort layer a larger contributor than the PE film. This is because of the shift from fossil to bio-based feedstock in the PE film as per scenario D3. Again, however, all scenarios give total results in the same order of magnitude.

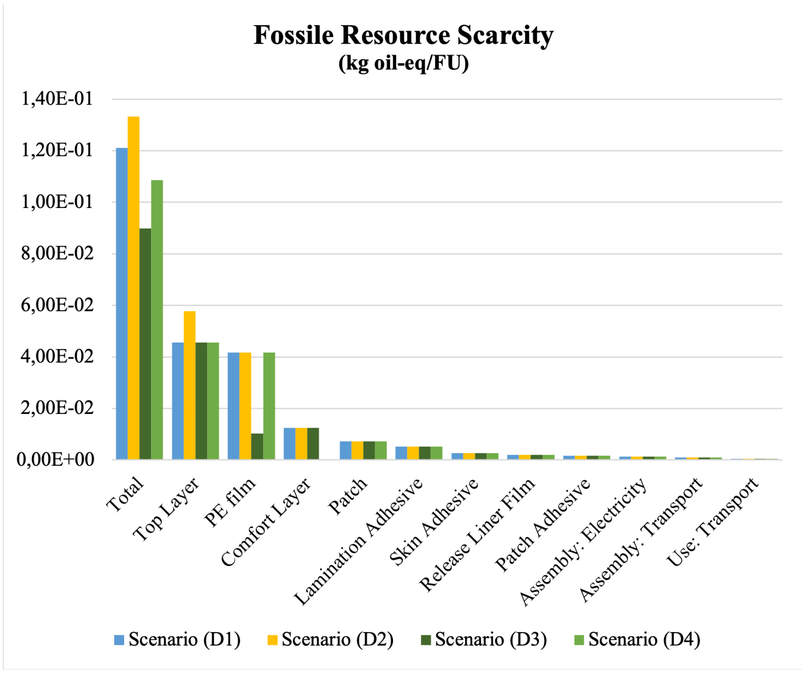

Figure 7. Contributions to the impact category fossile resource scarcity for the drape.

Figure 8 shows that the majority of the contribution to the freshwater eutrophication from all scenarios are the top layer followed by the PE film, besides in Scenario D2 where it is the opposite. The patch is also here a bigger contributor to the impact category than the comfort layer. All four scenarios give very similar total results.

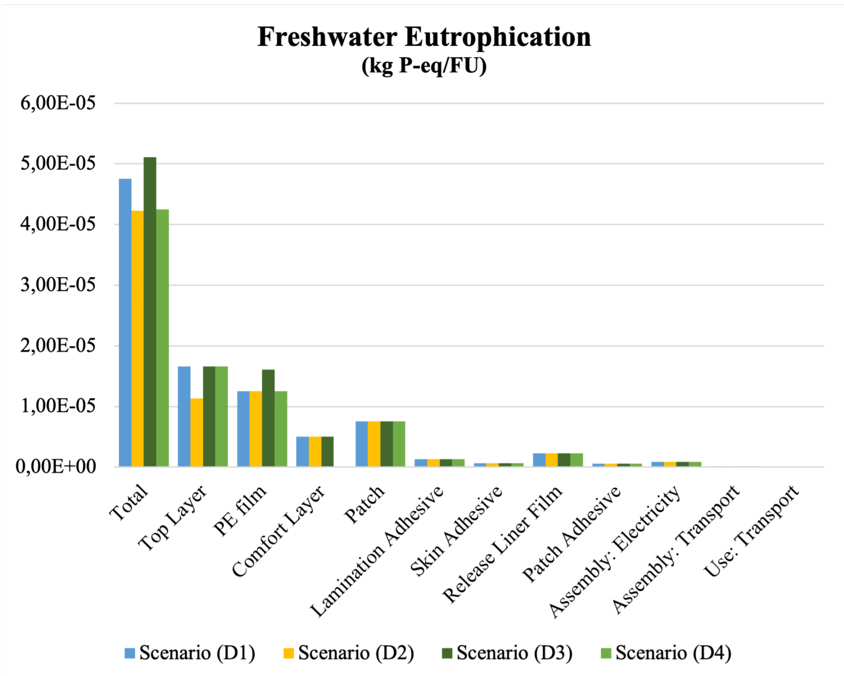

Figure 8. Contributions to the impact category freshwater eutrophication for the drape.

Figure 9 shows that the majority of the contribution to the freshwater ecotoxicity from all scenarios are the top layer followed by the PE film, besides in scenario D2 where it is the opposite. The patch is also here a bigger contributor to the impact category than the comfort layer. Also for this impact category, the total results are very similar between the scenarios.

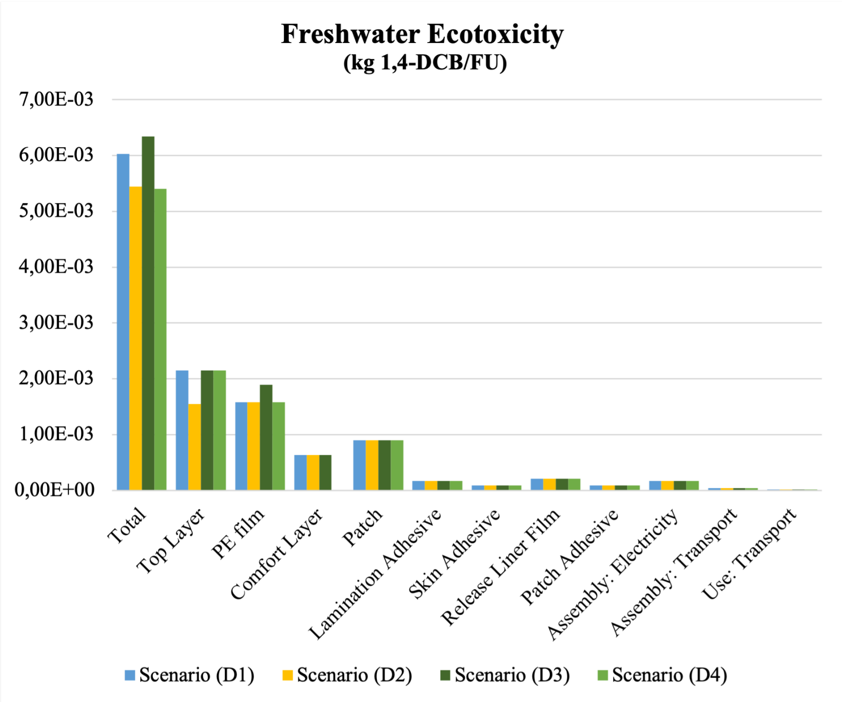

Figure 9. Contributions to the impact category freshwater ecotoxicity for the drape.

Figure 10 shows that the majority of the contribution to the land use is the top layer for scenarios D1, D3 and D4, while the majority of the contribution to the impacts in scenario D2 results from the PE film. This is because of the larger amounts of land required for the sugar cane cultivation in the bio-based PE film. In this impact category, the patch is contributing more than the comfort layer. For the land use impact category, there is a clearer difference between the results of the different scenarios, with scenario D3 giving the clearly highest impacts.

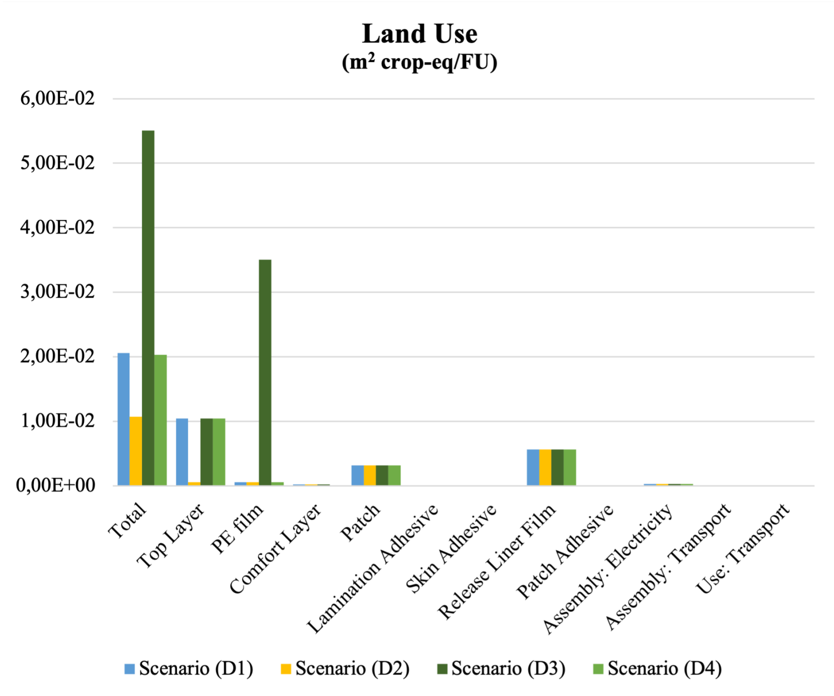

Figure 10. Contributions to the impact category land use for the drape.

Figure 11 shows that the majority of the contribution to the water consumption is the top layer for scenarios D1, D3 and D4 while the majority of the contribution to the impacts in scenario D2 is almost equal for the top layer and the (bio-based) PE film. The total water consumption is very similar in all scenarios.

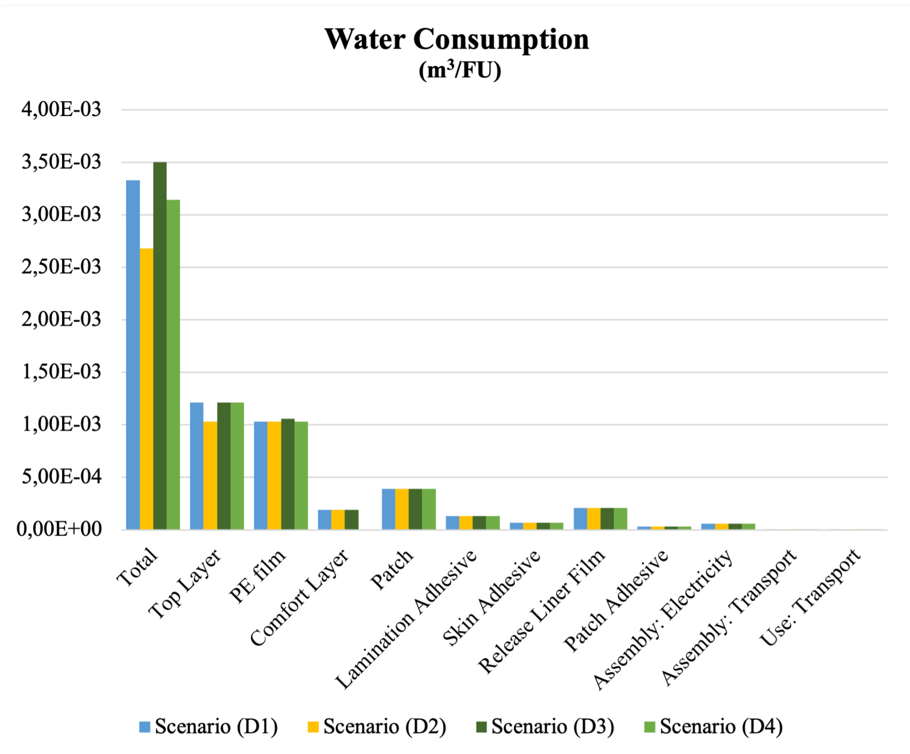

Figure 11. Contributions to the impact category water consumption for the drape.

4.2. Impacts of the gown

The results from the assessment of the gown can be seen in Table 11. The contributions can be seen in detail in Appendix II, Table 22.

Table 11. Results from impacts assessment of the gown.

Impact Assessment	Fossil Resource Scarcity (kg oil-eq)	Freshwater ecotoxicity (kg 1,4-DCB)	Freshwater eutrophication (kg P-eq)	Global warming (kg CO_2-eq)	Land Use (m^2 crop-eq)	Water consumption (m^3)
G1	1.09E-01	1.04E-02	1.10E-04	2.81E-01	5.11E-02	3.72E-03
G2	4.38E-02	5.41E-03	6.90E-05	1.53E-01	4.91E-02	1.89E-03
G3	9.34E-02	5.31E-03	6.19E-05	1.64E-01	2.25E-03	1.62E-03
G4	8.18E-02	4.65E-03	5.42E-05	1.44E-01	1.97E-03	1.42E-03

The results from the impacts assessment evaluating the human health impacts can be seen in Figure 12. The aggregated value is comprised of the following midpoint impact categories:

- Fine particulate matter formation
- Global warming, Human health
- Human carcinogenic toxicity
- Human non-carcinogenic toxicity
- Ionizing radiation
- Ozone formation, Human health
- Stratospheric ozone depletion
- Water consumption, Human health

The non aggregated values can be seen in Appendix II, Table 23. Unfortunately, no data on the positive health impacts of using gowns during sergery has been found. Therefore, no comparison between positive and negative health impacts can be performed for the gown. Such as comparison is therefore instead recommended in future studies.

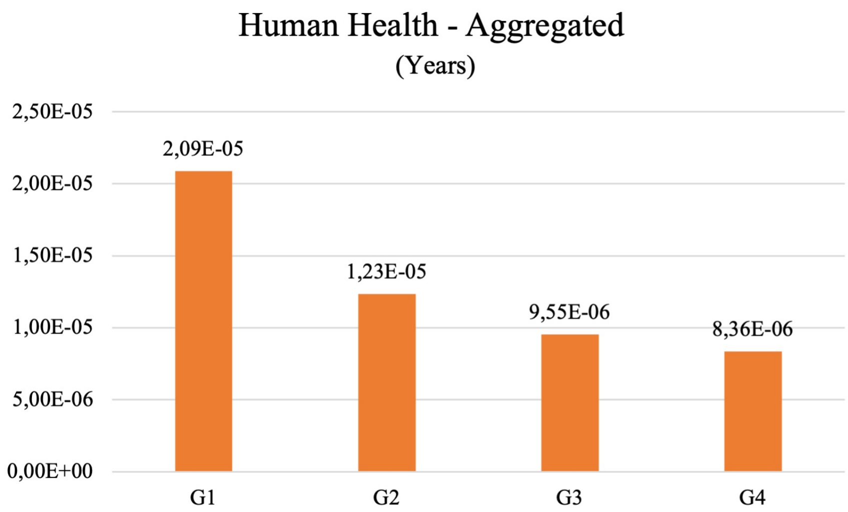

Figure 12. Results from the human health impact assessment of the gown for scenarious G1-G4.

4.2.1. Dominance analysis

The majority of the contribution to the global warming from all scenarios is from the raw material production (polyester or PP), see Figure 13. The electricity used in the treatment from the producers of the main materials has a big impact as well. Regarding the wood pulp/polyester scenario G1, it is clear that the biggest contribution comes from the polyester. By using recycled polyester, as in scenario G2, the largest contributor then instead becomes the electricity usage in the production. All three scenarios involving changes (G2-G4) give approximately half as high global warming impacts as scenario G1.

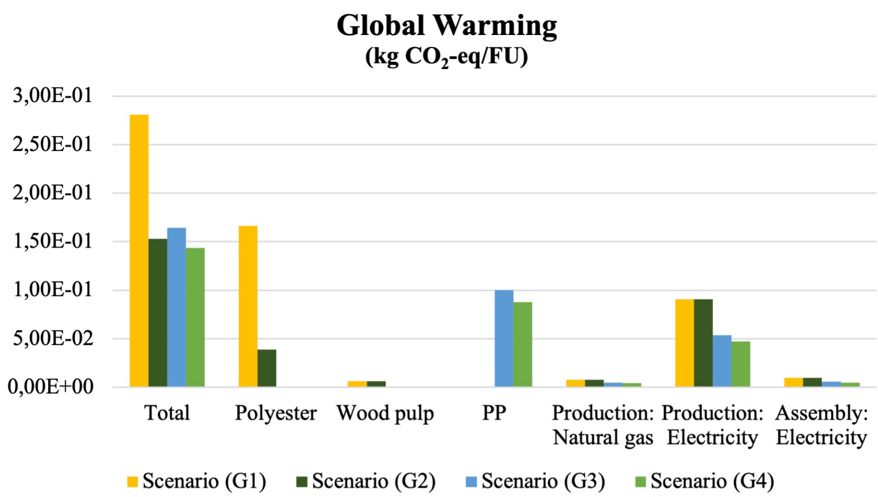

Figure 13. Contributions to the impact category global warming for the gown.

Figure 14 shows that the contribution to the fossil resource scarcity is dominated by the raw material production (polyester or PP), besides in scenario G2, where the recycled polyester gives a significant reduction in contribution and the electricity usage in the production instead becomes the largest contributor. In particular scenario G2 shows low impacts to fossil resource scarcity.

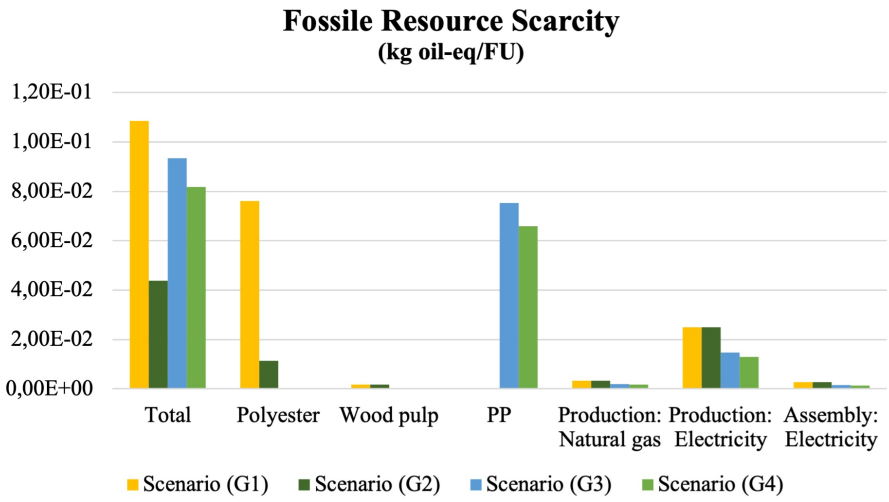

Figure 14. Contributions to the impact category fossil resource scarcity for the gown.

Figure 15 shows that the largest contribution to the freshwater eutrophication comes from the electricity from the production of the materials and the raw material production (polyester or PP). Again, all scenarios involving changes (G2-G4) show about half as high impacts as scenario G1.

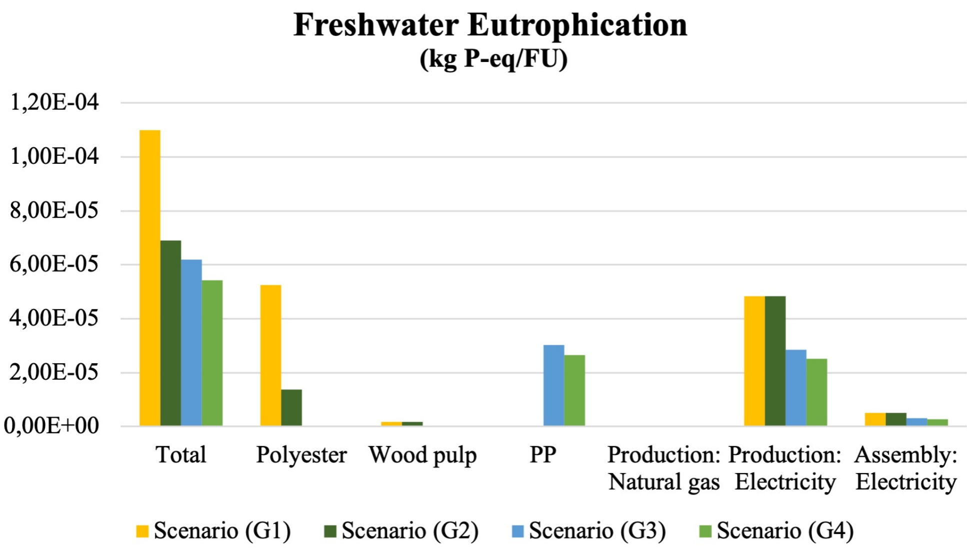

Figure 15. Contributions to the impact category feshwater eutrophication for the gown.

Figure 16 shows that the largest contribution to the freshwater ecotoxicity comes from the electricity from the production of the materials and the raw material production (polyester and PP). Again, all scenarios involving changes (G2-G4) show about half as high impacts as scenario G1.

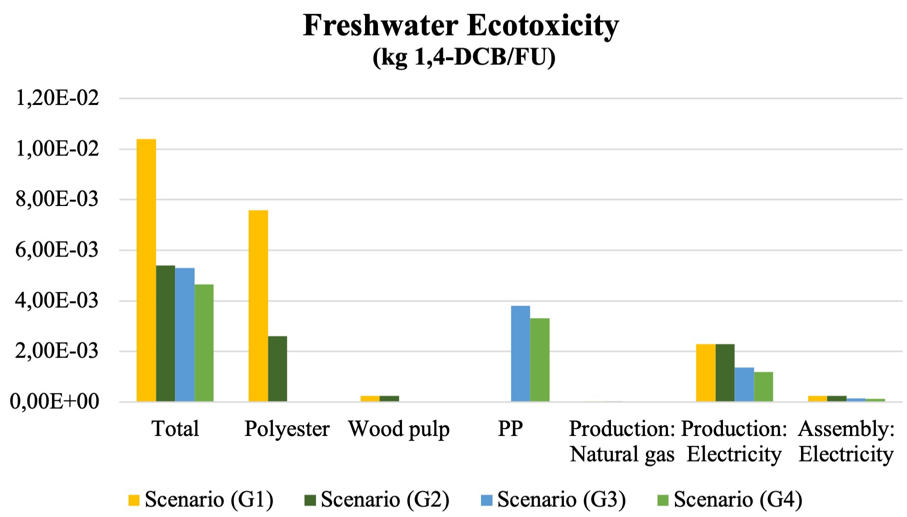

Figure 16. Contributions to the impact category feshwater ecotoxicity for the gown.

Figure 17 shows that when considering the land use impact category, wood pulp is a very large contributor in scenario G1 and G2. Thus, these two scenarios show clearly highest total land use impacts as well.

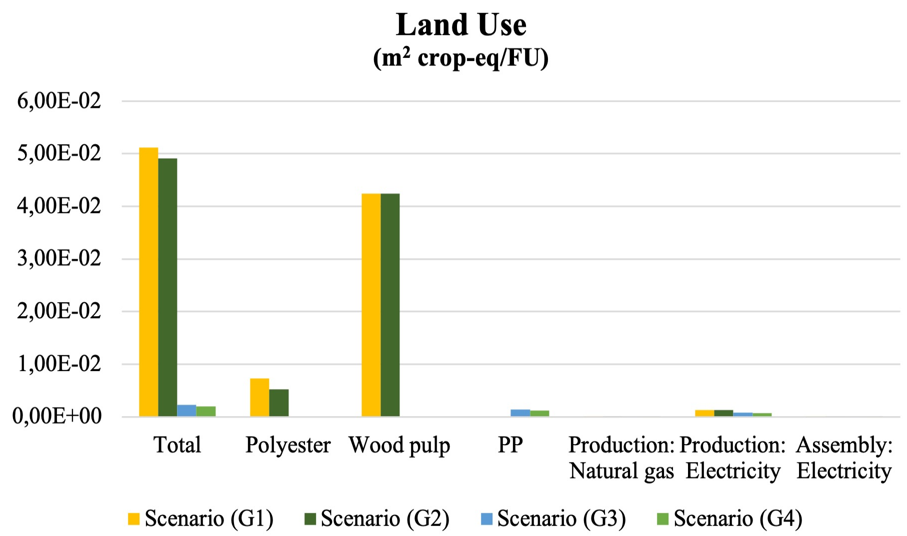

Figure 17. Contributions to the impact category land use for the gown.

Figure 18 shows that the largest contributor to the water consumption in all scenarios is from the raw material production (polyester or PP). The electricity used in the treatment from the producers of the main materials has a big impact as well, while the electricity usage in the assembly off less relevance. Regarding the wood pulp/polyester scenario G1, it is clear that the biggest contribution comes from the polyester. By using recycled polyester, scenario G2, the largest contributor then becomes the electricity usage in the production. Again, all scenarios involving changes (G2-G4) show about half as high impacts as scenario G1.

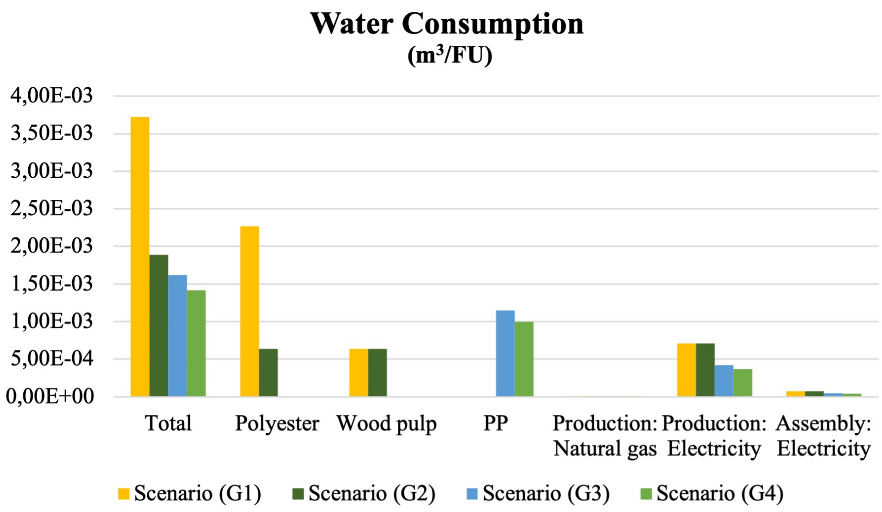

Figure 18. Contributions to the impact category water consumption for the gown.

5. Interpretation

Table 18 and 19 contains the potential increases or reductions in environmental impacts from the material changes in the scenarios for the drape and gown, respectively.

Table 18. Changes in impacts with scenarios D2-D4 for the drape.

Impact category	D2	D3	D4
Fossil resource scarcity	10%	-26%	-10%
Freshwater ecotoxicity	-10%	5%	-10%
Freshwater eutrophication	-11%	8%	-11%
Global warming	-2%	-6%	-7%
Land use	-48%	168%	-1%
Water consumption	-20%	5%	-6%
Human health	-10%	11%	-7%

Scenario D2 suggests that a shift from a top layer of viscose to PP enables an improvement of only 2% for global warming. The other impact categories show lager reductions, and the scenario reduces land use impacts with 48%. On the downside, the fossil resource scarcity increases with 10% which can be explained by the shift from the wood based raw material viscose to the fossil-based PP.

Scenario D3, which contains the shift from fossil to bio-based PE film, results in the best improvement in the category fossil resource scarcity and a slightly lower impact in the global warming category. A downside to keep in mind is a considerably increased land use that comes with the sugar cane use. For some other impact categories, specifically freshwater ecotoxicity and eutrophication, there are also slight increases in impacts.

Scenario D4 suggests that a removal of the comfort layer results in an overall decrease in the order of 10% for five of the impact categories (fossil resource use, freshwater eutrophication, global warming and water consumption). For land use, the reduction in impact is negligible.

This analysis shows that there is no unambiguously preferable scenario for the drape. Scenario D2 is best for land use but worst for fossil resource scarcity. For scenario D3, the opposite is true. Scenario D4 constitutes somewhat of a middle ground, with reductions in all impact categories, but only marginally (between 1 and 10%). Overall, there thus seems to be a trade-off between either reducing land use (by switching to PP as in scenario D2) and reducing fossil resource scarcity and global warming (by switching to bio-based PE film as in scenario D3). It should be noted that considering the overall uncertainties in an LCA study, for example linked to the limitations listed in Section 2.2.5, reductions/increases of ±10% should not be overemphasized.

When considering the human health impacts scenario D2 shows most potential with a reduction of 10%. Scenario D3 suggests that the switch to a bio-based PE film increases the impacts in the human health category by 10%, while a removal of the comfort layer give a reduction of 7%. But because of the very small numbers in all scenarios, it does not make that much of a difference when also considering the positive contribution from the usage, see Section 4.1.

Table 19. Changes in impacts with scenarios G2-G4 for the gown.

Impact Category	G2	G3	G4
Fossil resource scarcity	-60%	-14%	-25%
Freshwater ecotoxicity	-48%	-49%	-55%
Freshwater eutrophication	-37%	-44%	-51%
Global warming	-45%	-42%	-49%
Land use	-4%	-96%	-96%
Water consumption	-49%	-56%	-62%
Human health	-41%	-54%	-60%

Scenario G2 suggests that significant reductions can be obtained when switching to recycled polyester. The impact category land use is the only one with changes below 10%, which is expected since polyester is made from fossil resources which generally do not require much land during their production.

The scenarios with PP, G3 and G4, result in considerable (>20%, often >50%) improvements throughout all impact categories.

6. Conclusions and recommendations

The changes in impacts that comes with the material changes in the scenarios suggests that there are several opportunities for lowering the impacts of the two surgical products studied.

Regarding the drape, in scenario D2, the switch from viscose to polypropene presents good opportunities for lowering the land use, but only a very small reduction of the global warming impacts and an increase in fossil resource scarcity. That scenario thus results in a trade-off between a reduction of land use and fossil resources. Scenario D3, the switch to a bio-based PE film, presents the most interesting results if global warming and fossil resources are considered most important, but leads to a considerable increase in land use. Again, there is thus a trade-off between global warming and fossil resources on the one hand, and land use on the other. The removal of the comfort layer in scenario D4 results in minor improvements only. There is thus no unambiguously preferable scenario for the drape. Therefore, additional, possibly more radical changes might need to be investigated instead in order to identify actions that might lead to clearer reductions in environmental impacts.

Regarding human health impacts of the drape, it is clear that the drape is a net positive contributor to the human health regardless of the chosen scenario. The negative health impacts from emissions to the environment as obtained from the LCA are very small compared to the positive contribution from the usage reported in previous studies.

Regarding the gown, all scenarios involving changes show considerable reductions in environmental impacts. Based on the findings in this study, implementation of one or more of the materials assessed in the scenarios for the gown is thus recommended. In addition, more detailed assessments with improved and more case-specific data are recommended for the gown. It is also recommended that future studies should involve a more in dept analysis and modelling of the recycled polyester, possibly using different approaches to model recycling (Ekvall et al., 1997; Frischknecht, 2010). At last, an investigation of the positive contributions to human health from using a gown is also recommended in order to be able to conduct a comparison between positive and negative health impacts of the gown in a similar way as is done for the drape in this study.

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Appendix I – Drape: Impact assessment results

Table 20. Results from the impact assessment of the drape for scenario D1-D4.

D1		Fossil resource scarcity (kg oil-eq)	Freshwater ecotoxicity (kg 1,4-DCB)	Freshwater eutrophication (kg P-eq)	Global warming (kg CO_2-eq)	Land use (m^2 crop-eq)	Water consumption (m^3)
ID	Total	1.21E-01	6.03E-03	4.76E-05	2.23E-01	2.06E-02	3.33E-03
1	Top Layer	4.57E-02	2.15E-03	1.66E-05	1.11E-01	1.05E-02	1.21E-03
2	PE film	4.17E-02	1.58E-03	1.25E-05	4.67E-02	5.70E-04	1.03E-03
3	Comfort Layer	1.26E-02	6.30E-04	5.06E-06	1.67E-02	2.30E-04	1.90E-04
5	Patch	7.32E-03	9.00E-04	7.52E-06	2.07E-02	3.19E-03	3.90E-04
6.1	Lamination Adhesive	5.17E-03	1.70E-04	1.29E-06	8.63E-03	5.59614E-5	1.30E-04
4	Skin Adhesive	2.63E-03	8.57E-05	6.46E-07	4.39E-03	2.79E-05	6.81E-05
6.3	Release Liner Film	2.05E-03	2.10E-04	2.32E-06	4.73E-03	5.64E-03	2.10E-04
6.2	Patch Adhesive	1.65E-03	8.64E-05	5.73E-07	2.15E-03	2.98E-05	3.09E-05
	Assembly: Electricity	1.39E-03	1.70E-04	9.06E-07	4.97E-03	3.10E-04	6.01E-05
	Assembly: Transport	1.03E-03	4.11E-05	1.40E-07	3.20E-03	5.47E-05	3.27E-06
	Use: Transport	5.15E-04	2.05E-05	6.99E-08	1.60E-03	2.74E-05	1.64E-06

D2		Fossil resource scarcity (kg oil-eq)	Freshwater ecotoxicity (kg 1,4-DCB)	Freshwater eutrophication (kg P-eq)	Global warming (kg CO_2-eq)	Land use (m^2 crop-eq)	Water consumption (m^3)
ID	Total	1.33E-01	5.44E-03	4.23E-05	2.19E-01	1.07E-02	2.68E-03
1	Top Layer	5.77E-02	1.55E-03	1.13E-05	1.07E-01	5.80E-04	1.03E-03
2	PE-film	4.17E-02	1.58E-03	1.25E-05	4.67E-02	5.70E-04	1.03E-03
3	Comfort Layer	1.26E-02	6.30E-04	5.06E-06	1.67E-02	2.30E-04	1.90E-04
5	Patch	7.32E-03	9.00E-04	7.52E-06	2.07E-02	3.19E-03	3.90E-04
6.1	Lamination Adhesive	5.17E-03	1.70E-04	1.29E-06	8.63E-03	5.59614E-5	1.30E-04
4	Skin Adhesive	2.63E-03	8.57E-05	6.46E-07	4.39E-03	2.79E-05	6.81E-05
6.3	Release Liner Film	2.05E-03	2.10E-04	2.32E-06	4.73E-03	5.64E-03	2.10E-04

6.2	Patch Adhesive	1.65E-03	8.64E-05	5.73E-07	2.15E-03	2.98E-05	3.09E-05
	Assembly: Electricity	1.39E-03	1.70E-04	9.06E-07	4.97E-03	3.10E-04	6.01E-05
	Assembly: Transport	1.03E-03	4.11E-05	1.40E-07	3.20E-03	5.47E-05	3.27E-06
	Use: Transport	5.15E-04	2.05E-05	6.99E-08	1.60E-03	2.74E-05	1.64E-06
D3		**Fossil resource scarcity** (kg oil-eq)	**Freshwater ecotoxicity** (kg 1,4-DCB)	**Freshwater eutrophication** (kg P-eq)	**Global warming** (kg CO_2-eq)	**Land use** (m^2 crop-eq)	**Water consumption** (m^3)
ID	Total	8.98E-02	6.34E-03	5.11E-05	2.10E-01	5.50E-02	3.50E-03
1	Top Layer	4.57E-02	2.15E-03	1.66E-05	1.11E-01	1.05E-02	1.21E-03
2	PE-film	1.04E-02	1.89E-03	1.61E-05	3.36E-02	3.50E-02	1.06E-03
3	Comfort Layer	1.26E-02	6.30E-04	5.06E-06	1.67E-02	2.30E-04	1.90E-04
5	Patch	7.32E-03	9.00E-04	7.52E-06	2.07E-02	3.19E-03	3.90E-04
6.1	Lamination Adhesive	5.17E-03	1.70E-04	1.29E-06	8.63E-03	5.59614E-5	1.30E-04
4	Skin Adhesive	2.63E-03	8.57E-05	6.46E-07	4.39E-03	2.79E-05	6.81E-05
6.3	Release Liner Film	2.05E-03	2.10E-04	2.32E-06	4.73E-03	5.64E-03	2.10E-04
6.2	Patch Adhesive	1.65E-03	8.64E-05	5.73E-07	2.15E-03	2.98E-05	3.09E-05
	Assembly: Electricity	1.39E-03	1.70E-04	9.06E-07	4.97E-03	3.10E-04	6.01E-05
	Assembly: Transport	1.03E-03	4.11E-05	1.40E-07	3.20E-03	5.47E-05	3.27E-06
	Use: Transport	5.15E-04	2.05E-05	6.99E-08	1.60E-03	2.74E-05	1.64E-06
D4		**Fossil resource scarcity** (kg oil-eq)	**Freshwater ecotoxicity** (kg 1.4-DCB)	**Freshwater eutrophication** (kg P-eq)	**Global warming** (kg CO_2-eq)	**Land use** (m^2 crop-eq)	**Water consumption** (m^3)
ID	Total	1.09E-01	5.40E-03	4.25E-05	2.07E-01	2.03E-02	3.14E-03
1	Top Layer	4.57E-02	2.15E-03	1.66E-05	1.11E-01	1.05E-02	1.21E-03
2	PE film	4.17E-02	1.58E-03	1.25E-05	4.67E-02	5.70E-04	1.03E-03
3	COMFORT	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Patch	7.32E-03	9.00E-04	7.52E-06	2.07E-02	3.19E-03	3.90E-04

6.1	Lamination Adhesive	5.17E-03	1.70E-04	1.29E-06	8.63E-03	5.59614E-5	1.30E-04
4	Skin Adhesive	2.63E-03	8.57E-05	6.46E-07	4.39E-03	2.79E-05	6.81E-05
6.3	Release Liner Film	2.05E-03	2.10E-04	2.32E-06	4.73E-03	5.64E-03	2.10E-04
6.2	Patch Adhesive	1.65E-03	8.64E-05	5.73E-07	2.15E-03	2.98E-05	3.09E-05
	Assembly: Electricity	1.39E-03	1.70E-04	9.06E-07	4.97E-03	3.10E-04	6.01E-05
	Assembly: Transport	1.03E-03	4.11E-05	1.40E-07	3.20E-03	5.47E-05	3.27E-06
	Use: Transport	5.15E-04	2.05E-05	6.99E-08	1.60E-03	2.74E-05	1.64E-06

Table 21. Results from the human health impact assessment of the drape for scenario D1-D4.

Impact assessment: Human Health	**D1**	**D2**	**D3**	**D4**
Fine particulate matter formation	1.99E-07	1.59E-07	2.65E-07	1.88E-07
Global warming. Human health	2.34E-07	2.31E-07	2.20E-07	2.16E-07
Human carcinogenic toxicity	3.13E-08	3.00E-08	3.33E-08	2.89E-08
Human non-carcinogenic toxicity	2.17E-08	1.79E-08	2.45E-08	1.98E-08
Ionizing radiation	2.25E-10	2.21E-10	2.55E-10	2.15E-10
Ozone formation. Human health	4.55E-10	4.31E-10	5.09E-10	4.14E-10
Stratospheric ozone depletion	5.71E-11	5.04E-11	1.82E-10	5.46E-11
Water consumption. Human health	7.39E-09	5.96E-09	7.45E-09	6.97E-09
Total - Aggregated	4.95E-07	4.45E-07	5.51E-07	4.60E-07

Appendix II – Gown: Impact assessment results

Table 22. Results from the impact assessment of the drape for scenario G1-G4.

G1	Fossil resource scarcity (kg oil-eq)	Freshwater ecotoxicity (kg 1,4-DCB)	Freshwater eutrophication (kg P-eq)	Global warming (kg CO_2-eq)	Land use (m^2 crop-eq)	Water consumption (m^3)
Total	1.09E-01	1.04E-02	1.10E-04	2.81E-01	5.11E-02	3.72E-03
Polyester	7.61E-02	7.58E-03	5.25E-05	1.66E-01	7.25E-03	2.27E-03
Wood pulp	1.62E-03	2.40E-04	1.71E-06	6.01E-03	4.24E-02	6.40E-04
PP	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Production: Natural gas	3.29E-03	2.69E-05	1.14E-07	7.91E-03	1.11E-05	9.47E-06
Production: Electricity	2.49E-02	2.30E-03	4.83E-05	9.07E-02	1.34E-03	7.10E-04
Assembly: Electricity	2.64E-03	2.40E-04	5.13E-06	9.63E-03	1.40E-04	7.59E-05
G2	**Fossil resource scarcity** (kg oil-eq)	**Freshwater ecotoxicity** (kg 1,4-DCB)	**Freshwater eutrophication** (kg P-eq)	**Global warming** (kg CO_2-eq)	**Land use** (m^2 crop-eq)	**Water consumption** (m^3)
Total	4.38E-02	5.41E-03	6.90E-05	1.53E-01	4.91E-02	1.89E-03
Polyester	1.13E-02	2.60E-03	1.38E-05	3.87E-02	5.22E-03	6.40E-04
Wood pulp	1.62E-03	2.40E-04	1.71E-06	6.01E-03	4.24E-02	6.40E-04
PP	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Production: Natural gas	3.29E-03	2.69E-05	1.14E-07	7.91E-03	1.11E-05	9.47E-06
Production: Electricity	2.49E-02	2.30E-03	4.83E-05	9.07E-02	1.34E-03	7.10E-04
Assembly: Electricity	2.64E-03	2.40E-04	5.13E-06	9.63E-03	1.40E-04	7.59E-05
G3	**Fossil resource scarcity** (kg oil-eq)	**Freshwater ecotoxicity** (kg 1,4-DCB)	**Freshwater eutrophication** (kg P-eq)	**Global warming** (kg CO_2-eq)	**Land use** (m^2 crop-eq)	**Water consumption** (m^3)
Total	9.34E-02	5.31E-03	6.19E-05	1.64E-01	2.25E-03	1.62E-03
Polyester	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Wood pulp	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PP	7.52E-02	3.80E-03	3.03E-05	1.00E-01	1.36E-03	1.15E-03
Production: Natural gas	1.97E-03	1.61E-05	6.82E-08	4.73E-03	6.62E-06	5.66E-06
Production: Electricity	1.47E-02	1.36E-03	2.85E-05	5.35E-02	7.90E-04	4.20E-04
Assembly: Electricity	1.56E-03	1.40E-04	3.02E-06	5.67E-03	8.38E-05	4.46E-05
G4	**Fossil resource scarcity** (kg oil-eq)	**Freshwater ecotoxicity** (kg 1,4-DCB)	**Freshwater eutrophication** (kg P-eq)	**Global warming** (kg CO_2-eq)	**Land use** (m^2 crop-eq)	**Water consumption** (m^3)
Total	8.18E-02	4.65E-03	5.42E-05	1.44E-01	1.97E-03	1.42E-03
Polyester	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wood pulp	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PP	6.58E-02	3.32E-03	2.65E-05	8.76E-02	1.19E-03	1.00E-03
Production: Natural gas	1.73E-03	1.41E-05	5.98E-08	4.15E-03	5.81E-06	4.97E-06
Production: Electricity	1.29E-02	1.19E-03	2.50E-05	4.70E-02	7.00E-04	3.70E-04
Assembly: Electricity	1.36E-03	1.30E-04	2.64E-06	4.96E-03	7.34E-05	3.90E-05

Table 23. Results from the human health impact assessment of the drape for scenario G1-G4.

Impact assessment: Human Health	**G1**	**G2**	**G3**	**G4**
Fine particulate matter formation	3.42E-07	2.17E-07	1.82E-07	1.60E-07
Global warming, Human health	3.51E-06	1.91E-06	2.05E-06	1.80E-06
Human carcinogenic toxicity	5.62E-06	3.57E-06	2.05E-06	1.80E-06
Human non-carcinogenic toxicity	1.14E-05	6.62E-06	5.26E-06	4.61E-06
Ionizing radiation	5.49E-10	3.74E-10	3.23E-10	2.83E-10
Ozone formation, Human health	7.10E-10	3.99E-10	3.74E-10	3.28E-10
Stratospheric ozone depletion	1.03E-09	1.55E-10	1.08E-10	9.45E-11
Water consumption, Human health	8.25E-09	4.19E-09	3.60E-09	3.15E-09
Total	2.09E-05	1.23E-05	9.55E-06	8.36E-06

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