REDUCING SINGLE-USE MATERIALS IN MEDICINE AND HEALTHCARE

An exploratory study on sustainability of commonly used materials in hospitals

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The photographs used in the report serve as representations of the medical items. The footage has been obtained through purchase, and in cases where it was not available, proprietary photographs were used.

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Finally, we particularly appreciate the efforts of David van der Ha at the start of the study.

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GLOSSARY

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<tr><td>A0</td><td>Value "A"/"A0" (disinfection value)
A0 is a physical parameter denoting the inactivation of microorganisms. The concept of A0 is intended to allow equivalent disinfection efficiencies to a reference time/temperature to occur at other disinfection temperatures.
Corresponding time in seconds at a temperature of 80 °C to achieve a given disinfecting effect. If the temperature is 80 °C and the Z value is equal to 10, the term "A0" is used.
Richtwaarden voor temperatuur en inwerkingstijd voor thermische desinfectie<table><tr><th rowspan="2">Temperatuur
in C°</th><th colspan="2">$A_0 = 600$</th><th colspan="2">$A_0 = 3\,000$</th></tr><tr><th>Tijd in seconden</th><th>Tijd in minuten</th><th>Tijd in seconden</th><th>Tijd in minuten</th></tr><tr><td>80</td><td>600</td><td>10</td><td>3 000</td><td>50</td></tr><tr><td>90</td><td>60</td><td>1</td><td>300</td><td>5</td></tr><tr><td>93</td><td>30</td><td>0,50</td><td>150</td><td>2,5</td></tr></table>(Hoge Gezondheidsraad 2023)</td></tr>
<tr><td>ABS</td><td>Acrylonitrile Butadiene Styrene (type of fossil plastic)</td></tr>
<tr><td>Attributional LCA</td><td>See LCA</td></tr>
<tr><td>Blue water</td><td>Fresh surface and groundwater; the water in freshwater lakes, rivers and aquifers</td></tr>
<tr><td>Blue water footprint</td><td>Volume of surface and groundwater consumed as a result of the production of a good or service. Consumption refers to the volume of freshwater used and then evaporated or incorporated into a product. It also includes water abstracted from surface or groundwater in a catchment and returned to another catchment or the sea. It is the amount of water abstracted from groundwater or surface water that does not return to the catchment from which it was withdrawn.</td></tr>
<tr><td>Circular economy</td><td>The production and consumption of existing materials and products as long as possible by extending the life cycle of products through sharing, leasing, reusing, repairing, refurbishing and recycling.</td></tr>
<tr><td>Cogeneration</td><td>Combined Heat and Power (CHP), simultaneously produced using a single (fossil or renewable) fuel engine.</td></tr>
<tr><td>Consequential LCA</td><td>See LCA</td></tr>
<tr><td>Cradle-to-grave</td><td>Approach that considers impacts at each stage of a product's life-cycle, from the time natural resources are extracted from the ground and processed through each subsequent stage of manufacturing, transportation, product use, and ultimately, disposal</td></tr>
<tr><td>Critical item</td><td>Item/device in contact with sterile tissue or bloodstream (Spaulding Classification)</td></tr>
<tr><td>DALY</td><td>Disability-adjusted life years</td></tr>
<tr><td>DKK</td><td>Danish Krone</td></tr>
<tr><td>EO</td><td>Ethylene oxide</td></tr>
<tr><td>EO SU</td><td>Ethylene oxide single-use</td></tr>
<tr><td>ERCP</td><td>Endoscopic retrograde cholangiopancreatography</td></tr>
<tr><td>EU</td><td>Europe</td></tr>
<tr><td>FAMHP</td><td>Federal Agency for Medicines and Health Products</td></tr>
<tr><td>GHG</td><td>Greenhouse gas</td></tr>
<tr><td>HDPE</td><td>High density polyethylene</td></tr>
<tr><td>HMW</td><td>Hazardous Medical Waste</td></tr>
<tr><td>LCA</td><td>Life cycle analysis - Life cycle assessment
An Attributional LCA (ALCA) estimates what share of the global environmental burdens belongs to a product.
A Consequential LCA (CLCA) gives an estimate of how the global environmental burdens are affected by the production and use of a product.</td></tr>
<tr><td>LCC</td><td>Life cycle costing study</td></tr>
<tr><td>LCIA</td><td>Life cycle impact assessment</td></tr>
<tr><td>LDPE</td><td>Low density polyethylene</td></tr>
<tr><td>LLDPE</td><td>Linear low-density polyethylene</td></tr>
<tr><td>LMA</td><td>Laryngeal mask airway</td></tr>
</table>

Medical device	Any instrument, apparatus, appliance, software, implant, reagent, material or other article intended by the manufacturer to be used, alone or in combination, for human beings for one or more of the following specific medical purposes: a) diagnosis, prevention, monitoring, prediction, prognosis, treatment or alleviation of disease, b) diagnosis, monitoring, treatment, alleviation of, or compensation for, an injury or disability, c) investigation, replacement or modification of the anatomy or of a physiological or pathological process or state, d) providing information by means of in vitro examination of specimens derived from the human body, including organ, blood and tissue donations, and which does not achieve its principal intended action by pharmacological, immunological or metabolic means, in or on the human body, but which may be assisted in its function by such means. The following products shall also be deemed to be medical devices: – devices for the control or support of conception; – products specifically intended for the cleaning, disinfection or sterilisation of medical devices. (Hoge Gezondheidsraad 2023) (MDR 2017/745) **In this report the term "medical device" has been used in a broader sense than the definition mentioned above. The term was also used as a synonym encompassing all categories of medical items or medical materials**
NHMW	Non-hazardous medical waste
Non-critical	Item/device in contact with intact skin (Spaulding classification)
OR	Operating room
PDT	Percutaneous dilatational tracheostomy
PE	Polyethylene
PET	Polyethylene terephthalate
PLA	Polylactic acid
PP	Polypropylene
PPE	Personal protective equipment
PVC	Polyvinylchloride
ReCipe	ReCipe is a method for the impact assessment (LCIA) in an LCA. Life cycle impact assessment (LCIA) translates emissions and resource extractions into a limited number of environmental impact scores by means of mid-and endpoint indicators. ReCiPe calculates: 18 midpoint indicators and 3 endpoint indicators (human health damage, ecosystem damage and resource depletion)
RU	Reusable
SDG	Sustainable development goal
Semi-critical	Item/device in contact with mucous membranes or non-intact skin (Spaulding classification)
SMMS	Spunbond/ Meltblown/Meltblown/Spunbond
SMS	Spunbond/Meltblown/Spunbond
Spaulding classification	A classification for cleaning, disinfection or sterilisation of items and devices which is based on the degree of risk involved during use
SU	Single-use
SU ABS	Single-use containing fossil plastics acrylonitrile butadiene styrene
SUD	Single-use device
SU PLA	Single-use containing biobased plastic polylactic acid
TMR	Total material required. TMR is defined as the total mass of resource flows needed for the production of a given good or performing a service caused by economic and non-economic activities, which includes hidden flows arising from non-economic activities such as waste disposal, as well as direct and indirect flows from economic activities. Although TMR does not indicate environmental impacts directly, it can be considered as indicative of the 'potential' impacts from the total mass of natural resources.
VAT	Value added tax
WHO	World Health Organisation

EXECUTIVE SUMMARY

Over the past decades the use of single-use materials in medicine and healthcare has increased considerably. Single-use materials were considered advantageous for - amongst others - the safety of care, the low cost per item, and the permanent availability. Environmental implications were seldom questioned. Currently, the unlimited use of single-use materials in medicine and healthcare became a leading topic in discussions on sustainability in healthcare. To date, such discussions are led by limited evidence. Therefore this project aimed to strengthen the body of knowledge on whether it is beneficial to replace single-use medical materials by reusable ones. This study aims to investigate possibilities and alternatives for to use of single-use materials in medicine and healthcare, in line with the principles of the circular economy and taking into account the constraints associated with each solution, such as safety, efficiency and cost. Thereby offering evidence-based guidance to policymakers and healthcare facilities (hospitals) in determining on whether to use single or reusable materials in medicine and healthcare for a number of items. The initiative for this project has been taken by the Directorate-General for the Environment of the Federal Public Service (FPS) Health, Food Chain Safety and Environment and was executed by the Ghent University Hospital.

An exploratory study on environmental sustainability of commonly used materials in hospitals was performed in four consecutive steps:
1) In order to substantiate and refine the study, literature data on sustainability of single-use and reusable medical devices were studied. 2) In order to further focus the study, current consumption of single-use materials was explored from 12 Belgian hospitals. 3) A selection of five single-use medical items and their reusable alternatives were studied on four parameters, namely environmental sustainability, safety, costs and efficiency. 4) A Life Cycle Analysis (LCA) was performed to evaluate the environmental impact of single-use compared to reusable vaginal specula.

The literature review revealed that most studies focused on one single item and were often LCA's whereby the environmental impact and costs of different scenarios replacing reusable medical devices by single-use equipment were compared. The literature search identified medical devices varying from examination devices (e.g. laryngoscope, cystoscopes), laparoscopic devices (e.g. trocars, surgical staplers), aiding devices (e.g. surgical scissors, medical blue wraps), clothing and linens (e.g. surgical gown) to other medical devices (sharps containers). For most medical devices existing studies demonstrated that using a reusable alternative is more environmental friendly than disposable equivalents (for example, surgical staplers, reusable packing options, sharps containers; surgical and isolation gowns). The financial cost is also lower than for the single-use alternative (for example, scissors). Conflicting or inconclusive evidence was found for trocars, laryngoscopes and flexible endoscopes. For laryngoscopes, the energy mix used in a country has a significant impact on the conclusions concerning environmental impact.

A hospital survey on the consumption of single-use materials was extracted from procurement data of 12 Belgian hospitals (four Walloon, six Flemish and two hospitals from Brussels-Capital region; eight general hospitals and four university hospitals). Data were aggregated on the type of single-use medical devices most frequently used, and on the consumption in relation to the cost. A large variation in consumption between hospitals became apparent. It was important to reflect on both, items with high consumption rates, as well as on a diversity in the circular processes needed for reuse. Several circular processes were detected: sterilisation or high level disinfection, thermal disinfection or low level disinfection, laundry process, and change of item/device. This led to the selection of five single-use medical devices of relevance to explore the replacement by reusable alternative: kidney trays, blankets, vessel sealing devices, cover caps for thermometers and vaginal specula. Pragmatically, in light of available project time and budget, one LCA was carried out. The other four items were compared on life cycle stages and the carefully studied literature data combined with own observations lead to valid general conclusions.

The selected single-use medical items and their reusable alternatives were studied related to four parameters: environmental sustainability, safety, costs and efficiency. Sustainability used data for raw materials, manufacturing, transport, (re)use, end-of-life (waste), and carbon footprint. Safety focused on infection prevention and occupational safety. Costs focused on costs for purchase, reuse, waste elimination or recycling. Efficiency focused on availability, handling, and time consumption for (re)use. By taking these parameters into account, a balanced conclusion could be drawn for kidney trays, blankets, vessel sealing devices, and cover caps for thermometers. For example, based on the available data, it seems that reusable kidney trays are more environmentally friendly. However, the method of disinfection has also an

environmental impact as well as a large impact on cost. The safety is comparable, whereas the efficiency might be in favour of the single-use kidney tray based on the time consumption.

To evaluate the environmental sustainability of single-use compared to reusable vaginal specula, a life cycle analysis (LCA), cradle-to-grave, was performed according to well established methodology and guidelines (ISO 14040/14044 guidelines, modelled using SimaPro 9.4.0.2). The ecoinvent database (version 3.8) was used to retrieve secondary data. The functional unit was one pelvic examination by a stainless steel reusable, or by three types of single-use specula, of which one containing fossil plastics, one containing biobased plastic, and one containing two types of fossil plastics and sterilised using ethylene oxide (EO). The primary outcome was global warming impact, with total greenhouse gases expressed as carbon dioxide equivalents ($kgCO_2eq$). The secondary outcome was the environmental impact representing damage to human health, ecosystems and resource scarcity.
From global warming perspective the most favourable option is the use of a stainless steel reusable speculum producing 78% less greenhouse gas (GHG) emissions than a single-use speculum from fossil plastic, 65% less emissions than a single-use biobased plastic speculum, and 74% less emissions than an EO sterilised single-use speculum consisting of two types of fossil plastic. Emissions from reusables were largely due to packaging and, to a lesser extent the reprocessing (treatment) of the specula, whereas emissions from single-use alternatives were mainly due to raw materials and manufacturing, incineration at the end of life, and packaging.

From an environmental perspective and for costs, mixed pictures were obtained. Reusable equivalents of most devices are favourable, although it cannot be decided with certainty if reusable laryngoscopes, trocars, flexible endoscopes are more or less beneficial for the environment than their single-use equivalents due to conflicting evidence in literature. Single-use devices are more expensive although the impact on costs should be interpretated with caution since far less data were available. From a safety perspective, the single-use and reusable devices are equal. Concerning efficiency, referring to availability, handling, and time consumption for (re)use, the results are in favour of the single-use devices. The most trustworthy conclusion can be done for the LCA study on vaginal specula. From a sustainability perspective, the use of stainless steel reusable specula is most favourable.
Finally, whatever technique is used, destruction of solid medical waste is not easy and requires great attention from economical, ecological and healthcare perspective. All efforts to minimize the need for incineration or any other technique are highly welcomed to obtain the sustainable development goals, particularly those goals on responsible consumption and production. Equally important are the WHO recommendations on a revised management of medical waste.

In summary, using reusable or hybrid systems can help to meet environmental targets as well as reduce financial costs. Although results were robust with regard to several modelling scenarios, optimizing sterilisation processes remains an area of concern to minimize the environmental impact and specifically the impact on human health. By using research triangulation, the main findings allow the most balanced conclusions possible in the complex field of environmental sustainability. The results of this project helped to demonstrate the applicability of the methods and stimulate further research of the sustainability aspects specifically in hospitals and in the healthcare sector in general.

Recommendations for hospitals, companies, regulatory bodies and waste/recycling departments have been made and are summarized below.

1. Recommendations for hospitals

a) Include validated sustainability requirements in the procurement process of medical material
b) Give appropriate weight to sustainability characteristics in the decision process for procurement of medical material in addition to costs, logistics, etc.
c) Inform companies that sustainability will be integral part of the decision process during procurement of medical material
d) Convince the users within the hospital of remanufactured medical material on the quality of this material
e) Further diversify the waste streams as to optimise the possibility of recycling
f) Set up activities and take initiatives to develop the fundamentals and practical applications of sustainability among all employees in the hospital

2. Recommendations for companies

a) Provide purchasers with information allowing to decide on sustainability quality to medical material
b) Adapt construction methods and raw material as to respond to higher sustainability quality of the goods

3. Recommendations for regulatory bodies

a) Review legal obligations necessary for reusing medical material after remanufacturing
b) Review legal obligations for waste selection based on scientific evidence
c) Set up projects to study sustainability of medical material using sophisticated and science based methods
d) Set up a list of validated criteria helping all stakeholders to decide on the quality of the variables within sustainability research. This is imperative for the procurement departments of hospital (see 1a & 1b)

4. Recommendations for waste/recycling departments within the hospital and waste treatment organizations

a) Contribute to the optimization of the waste handling processes from practical point of view in collaboration with the medical department of the hospital (health care personal, prevention department, infection prevention department, sterilization department, etc.)

5. Recommendations for further research

a) Compare sustainability through life cycle analysis (and life cycle cost studies) of several disinfection methods
b) Compare sustainability through life cycle analysis (and life cycle cost studies) of single-use and reusable surgical sets/instruments handled by in-house sterilisation department or external sterilisation company
c) Compare sustainability through life cycle analysis (and life cycle cost studies) of single-use and reusable kidney trays, including the various types disposal (maceration/waste/recycling) and disinfection methods (see also 5a)
d) Design and test reusable textiles as alternative for single-use items (such as isolation gowns, surgical caps, bibs,…) and compare sustainability through life cycle analysis (and life cycle cost studies) of both

The results of this project demonstrated clearly that decisions on whether to use single-use or reusable devices within a hospital cannot be taken light heartedly. Instead, detailed analysis of literature data coupled with meticulous observations at the work floor are necessary. Only in this way evidence based advice is possible and this is needed to convince the users to change their habits. In this respect, this project was an excellent exercise and the conclusions confirm this statement.

1 INTRODUCTION

1.1 Situating the project in an historical context

This project is situated in the broad context of circular economy. In the second half of last century, society evolved quickly from a society in despair after the war into wealthy society characterised as a throwaway society. At first this attitude concerned simple and cheap material used within a daily context but later also more complex and more expensive devices were similarly used for a limited time and considered as easily expendable and destructible. The attempts to refurbish material was considered useless with arguments as high costs, unlimited supply of raw basic material, etc. It was pure consumerism: make-take-throw away.

Since the 1990's, however, people realised that this attitude was leading to a number of societal problems that were not considered before: huge waste production, growing shortness of natural resources, increasing costs, etc. Hence, a tendency to reverse the consumerism became more prominent and new working definitions were introduced, "circular economy" being the most used. The "make-take-throw way" slogan was replaced by the 3R "reduce-reuse-recycle" or even the 6R "reuse, recycle, redesign, remanufacture, reduce, recover" slogans (Winans et al. 2017). The evolution from the throwaway economy into a circular economy is nicely described by Winans et al.(2017).

The healthcare profession has not escaped from this evolution and a lot of throwaway materials were introduced in medical care some decades ago. Single-use devices (SUD) in Western health routine care practice included needles, tubing, syringes, bandages, etc. and this has been very advantageous for the safety of the individual patients and for avoiding cross-contamination among patients (Costa and Costa 2021). The overall characteristics of this group of material are low cost per item, use in massive amounts, technically uncomplicated, mostly small and made of low-costs basic raw material and after use frequently contaminated with patients body fluids such as blood, saliva or other excretions. No one questions the validity and irreplaceability of these SUD's. Last decade, however, we witnessed the appearance of other SUD medical devices which do not correspond to these criteria and are much more complex such as staplers, laparoscopic instruments often containing expensive components eventually composed of high-costs raw materials: batteries, sensors, miniaturized camera's, etc. (Grantcharov et al. 2019; Pandey and Vora 2019; Guzzo et al. 2020).

The decision to use SUD's for a particular medical intervention is almost always guided by the ultimate argument stressed by the manufacturers i.e. the written guarantee of sterility and thereby assuring patient safety which is from legal point of view, very attractive for healthcare organizations (Hailey et al. 2008; Popp et al. 2010). Collateral advantages are the nearly permanent availability of the material, the easiness of use and the reliability during the procedure; questions on costs or the implications for the environment were seldomly put forward with some exceptions (Monmousseau et al. 2021).

After the 2015 declaration on sustainability and the formulation of the sustainability goals – in particular SD goal 12 - the use of SUD's was questioned (Guzzo et al. 2020). The criteria such as environmental burden through the waste and the costs were weighted against the advantages of the SUD's. Hence, the quest to reconsider the unlimited use of single-use material became an important and leading theme in discussions on sustainability in healthcare.

1.2 Introduction on medical waste

Medical waste in the context of this project, contains any material used during diagnosis, treatment and care for patients in a hospital and eventually discarded after use. This material might be dangerous (e.g. contaminated with pathogens, containing sharps or carrying the residues of chemicals) and this is identified in Europe as EWC/EURAL Code 18.01.03. If not dangerous (e.g. packaging materials) it is identified in Europe as EWC/EURAL Code 18.01.04 and considered comparable to household waste (Hossain et al. 2011).

The elimination of dangerous medical waste is in Europe mostly obligatory by incineration. Of note is the fact that the destruction of dangerous medical waste is between three and ten times more expensive than the destruction of non-dangerous waste. In this project we focus on solid medical waste. Whatever technique is used, destruction of medical waste is not easy and requires great attention from economical, ecological and

healthcare perspective. All efforts to minimize the need for incineration or any other technique are highly welcome (Hassan and Shareefdeen 2022).

Solid medical waste is subject of an ongoing discussion both in the scientific and lay press, related to its impact on the environment, on public health and on costs for destruction. In the last decade, these fragmented discussions focus on a new point of interest, i.e. sustainability. Although sustainability and sustainable development goals and the corresponding targets are deeply embedded in societal problems like poverty and hunger (SDG 1 and 2), and in environmental and climate related problems (SDG's 6. 7. 11, 13, 14 and 15), sustainable development goal 12 is on sustainable consumption and production with the defined related subjects: chemicals and waste. Hence, the activities on the management of waste in general and hospital waste in particular should be interpreted against a background of sustainability. In this document we want to report on our attempts to comply with the SDG's as far as solid medical waste is concerned (Sachs 2012; Sachs et al. 2019).

Second and very recently, the world was confronted with a devastating pandemic caused by the SARS-Cov-2 virus, causing the COVID-19 disease. It is an understatement that the COVID-19 pandemic has shaken the entire world in many aspects: societal, physical and mental healthcare organization, economics, logistics, etc. to name the most visible or at the forefront of discussions. Less visible but equally important are the questions related to the management of the huge volume of medical waste and solid medical waste in particular. Although the waste during the pandemic contained in majority light weighted personal protection equipment (gloves, aprons…..) the question to reconsider the disposal of medical waste went far beyond this and referred to the whole of basic considerations related to medical waste (Fraeyman et al. 2022). The WHO is even calling for an urgent need to improve waste management systems (WHO 2018, 2022).

In this manuscript we describe our efforts to construct a scientifically sound basis in order to be able to decide on whether single-use or reusable devices should be used in hospitals. The project developed basically in four steps, starting from a survey of the available literature data. This was followed by an overview of most used medical devices in twelve hospitals (78 items) and narrowing down this high amount of information to one device (vaginal specula) for which a detailed life cycle analysis was performed and to four devices for which literature data related to aspects of sustainability were collected. For the latter, a conservative conclusion and for the specula, a scientifically based conclusion on the sustainability properties is possible. Details of the four steps are described in the method section.

The results of this project should demonstrate the applicability of the methods and stimulate further research of the sustainability aspects, specifically in hospitals and in general in the healthcare sector.

2 EXPLORATION OF EXISTING EVIDENCE AND PRACTICES ON SUSTAINABILITY OF SINGLE-USE AND REUSABLE MEDICAL DEVICES

2.1 Literature

2.1.1 Goal

In order to inform, substantiate, refine and focus the study, the literature on sustainability of single-use and reusable medical devices was explored.

2.1.2 Methods

A literature database was constructed from references in The Medline and ISIWeb of Science databases from January 2010 to July 2022. Keywords were Life Cycle Assessment, LCA, Reusables, Single-use Devices, Disposable Equipment, Waste Management, Medical Waste, Environmental Sustainability and Sterilization. Relevant references within the database were included. Articles with a main focus on developing regions and countries were excluded. Reference lists of included studies, reports and related reviews were examined and gray literature was checked to identify any additional relevant studies.
Specific to LCA's, the HealthcareLCA Database was screened to identify additional studies between April 2022 and July 2023 (Drew and Rizan 2022).

Only of those items for which at least two LCA's were available were included in the literature review. Thus, studies on, for example, blood pressure cuffs (Sanchez et al. 2020), disinfection cloths (Maloney et al. 2022) or dental burs (Unger and Landis 2014) were not included in the literature review below.

The literature search identified articles in a range of medical devices varying from examination devices (e.g. laryngoscope, cystoscopes), laparoscopic devices (e.g. trocars, surgical staplers) aiding devices (e.g. surgical scissors, medical blue wrap), clothing and linens (e.g. surgical gowns) to other medical devices (sharps containers). Some of these devices are described hereafter in detail.

The studies describing an LCA were synthetised in evidence tables. The evidence tables describing the LCA methodology and an evidence table with the results were included in Appendices 9.1 & 9.2.

Grade quality and risk of bias were not determined due to the breadth of the review, the qualitative synthesis of results and the need for a pragmatic approach.

2.1.3 Results

2.1.3.1 Laryngoscopes

Laryngoscopes are designed for visualisation of the vocal cords and for placement of tube into the trachea under direct vision. It consists of a handle and a blade. Blades are available in different sizes to be used according to the age of the patients (Health Care Without Harm Europe 2021a).

Example of laryngoscope blade

The environmental impact of single-use and reusable laryngoscopes (blades and/or handles) was compared in two studies (McGain et al. 2017; Sherman et al. 2018) (See Table 1 and Appendices 9.1 & 9.2).

Sherman et al. (2018) considered the environmental impact and cost throughout the life cycle of reusable and single-use rigid laryngoscopes using a cradle-to-grave life cycle assessment (LCA) and life cycle costing (LCC) method. The study revealed that reusable laryngoscopes produced fewer environmental emissions, and are significantly cheaper.
Depending on the cleaning strategy, reusable **handles** produced the least CO_2 when high level disinfection was performed, followed by low level disinfection, and produced the most CO_2 in case of steam sterilisation. Using single-use laryngoscope blades resulted in approximately 25 times more emissions than the use of a reusable handle treated with high level disinfection (Sherman et al. 2018).

Similar results were found for the laryngoscope **blades.** Blades are semi-critical items that need a minimum of high level disinfection. Depending on the cleaning strategy, reusable **blades** produced the least CO_2 when high level disinfection was performed, and increased by 400% in case of steam sterilisation. The latter is standard practice in Belgian hospitals. Single-use **blades** produced approximately 40-50% more CO_2 than a reusable blade treated with steam sterilisation (Sherman et al. 2018).

Contrary to Sherman et al. (2018), the study of McGain et al. (2017) found that replacing reusable by single-use laryngoscope blades would decrease emissions. McGain et al. (2017) modelled the environmental and financial costs of different scenarios of replacing reusable anaesthetic equipment (circuits, face masks, laryngeal mask airways, direct and video-laryngoscope blades and handles) with single-use variants. The authors defined five different scenarios, scenario 1 using reusable anaesthetic equipment; scenario 2 using disposable anaesthetic equipment but retaining reusable direct laryngoscope handles and reusable video-laryngoscopes; scenario 3 replacing all reusable with single-use anaesthetic equipment; scenario 4 identical to scenario 1 but replacing only reusable with single-use face masks; and scenario 5 identical to scenario 1 but replacing only reusable with single-use direct laryngoscope blades.
The authors found that converting from single-use to reusable equipment in Australia would result in an increase of CO_2 emissions from 9%. The switch from single-use to reusable laryngoscope **blades** increased CO_2 emissions, due to the energy mix used in Australia.
Of note, in the UK or a European country the power mix is principally sourced from renewables, whereas in the US natural gas is the most important source. Both differ from the Australian power mix, which is principally based on coal. In the study of Mc Gain et al. (2017), converting from single-use to reusable anaesthetic equipment reduced CO_2 emission by 84% in UK/Europe and by 48% in the USA.
Replacing reusable direct laryngoscope blades with single-use would create an additional cost of AUD$9690 for one hospital over one year (McGain et al. 2017).

Table 1: Summary LCA's on laryngoscopes

Reference	Objective LCA	Functional unit	Results
McGain et al. (2017, Australia)	Environmental impact and costs of different scenarios replacing RU anaesthetic equipment by SU equipment	Use of breathing circuits, face masks, laryngeal masks airways and laryngoscope handles and blades, and video-laryngoscopes at one hospital over one year	Global warming: Scenario 1 (all reusable equipment) – Scenario 5 (replacement of reusable with single-use blades) = 5575 (S1) – 6763 (S5) = - 1 188 kg CO_2eq/year. Water depletion: 82.2 (S1) -69.7 (S5)= 12.5 kilolitres/year
Sherman et al. (2018, US)	Environmental impact and costs comparing SU and RU metal and plastic laryngoscope handles and blades	1 handle and 1 blade for a single patient encounter	Global warming **Handles** RU with HLD: 0.06 kg CO_2eq/use RU with LLD: 0.08 kg CO_2eq/use RU with STZ: 0.23 kg CO_2eq/use SU plastic: 1.41 kg CO_2eq/use SU metal: 1.60 kg CO_2eq/use **Blades** RU with HLD: 0.06 kg CO_2eq/use RU with STZ: 0.22 kg CO_2eq /use SU plastic: 0.38 kg CO_2eq /use SU metal: 0.44 kg CO_2eq /use

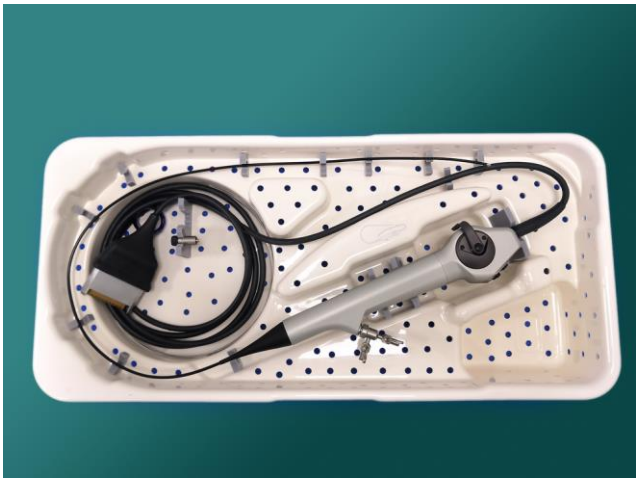
RU: reusable, SU: single-use, HLD: high level disinfection, LLD: low level disinfection, STZ: steam sterilisation,

In summary, the level of disinfection and the energy mix (source) had a significant impact on the produced emissions and is country-dependent. Whereas in the US and Europe (more renewable and gas sourced) the use of reusable laryngoscope blades or anaesthetic equipment would lead to lower emissions compared to single-use, this was not the case in Australia (brown coal sourced).
Both studies found that reusable laryngoscope blades, or laryngoscopes were less costly than single-use alternatives.

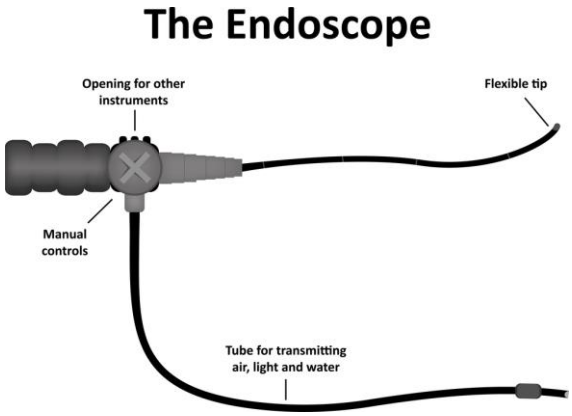
2.1.3.2 Flexible endoscopes

Flexible endoscopes are complex medical devices used to visualise the inside of various body cavities. Generally, it consists of a long, thin, flexible tube carrying a light and camera. Examples include a bronchoscope, which examines the interior of the bronchi, a cystoscope, which examines the urinary tract, an ureteroscope, which examines the ureters and a duodenoscope, which examines the duodenum, bile duct and pancreas and is also used during endoscopic retrograde cholangiopancreatography (ERCP).

Information was found for cystoscopes (Kemble et al. 2022; Hogan et al. 2022; Baboudjian et al. 2022); ureteroscopes (Davis et al. 2018; Sørensen and Grüttner 2018; Duijndam 2022; Bringier et al. 2023), bronchoscopes (Sørensen and Grüttner 2018; Duijndam 2022; Bringier et al. 2023) and duodenoscopes (Le et al. 2022) (See Table 2: Summary LCA's on and Appendices 9.1 & 9.2). Finally, the cost of single-use and reusable bronchoscopes (Videau et al. 2017; Sohrt et al. 2018; Bringier et al. 2023) and cystoscopes (Boucheron et al. 2022) was evaluated.



Example of a flexible ureteroscope



Example of a flexible endoscope

Hogan et al. (2022) and Baboudjian et al. (2022) concluded that the carbon footprint of a single-use cystoscope was significantly lower than the multiple use (See Table 2, See Appendices 9.1 & 9.2). The manufacturing impact of the reusable cystoscope was significantly lower than of the single-use, while the sterilisation impact of the reusable cystoscope was significantly larger. Also the impact of waste to landfill was significantly higher for the reusable flexible cystoscope.
Baboudjian et al. (2022) found, taking difference in lifespan and in disinfection procedure into account, that the single-use cystoscope reduced several parameters of environmental effects between 33 and 71% compared to the reusable cystoscope (See Table 2). Similar to Hogan et al. (2022), this study revealed that the disinfection procedure of the reusable cystoscope had a significant higher environmental impact than the use of a single-use cystoscope.
On the contrary, Kemble et al. (2023) concluded that the environmental impact of a reusable flexible cystoscope was considerably lower than of a single-use flexible cystoscope (See Table 2). This LCA showed that the main contribution to the carbon footprint of a reusable cystoscope was the energy consumption of the reprocessing process and of a single-use scope it was the manufacturing.

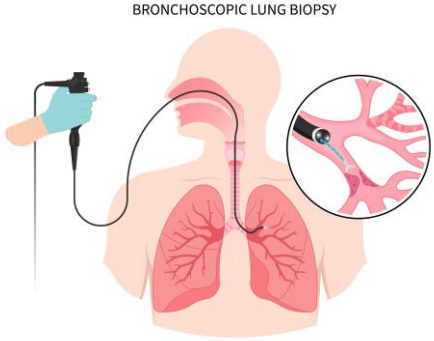
Table 2: Summary LCA's on flexible endoscopes

Reference	Objective LCA	Functional unit	Results
Badoudjian et al. (2022, France)	To compare the life cycle of RU and SU flexible cystoscopes	SU: one cystoscope RU: reprocessing a cystoscope one time	Global warming SU: 2.06 kgCO_2eq vs RU: 3.08 kgCO_2eq Mineral resource depletion SU: 25.03 MJ vs RU: 49.92 MJ Ecotoxicity SU: 1.07 kg1.4Beq vs RU: 2.20 kg1.4 DBeq Acidification SU: 0.011 kgSO_2eq vs RU: 0.037 kgSO_2eq Eutrophication SU: 0.003 kg PO_4eq vs RU: 0.005 kg PO_4eq
Bringier et al. (2023, France)	To compare the environmental impact of SU vs RU bronchoscopes for difficult tracheal intubations	2000 uses of a flexible intubation bronchoscope *(RU: assuming lifespan of 2000 uses)*	Global warming SU: 7.8 t CO_2eq vs RU: 5.8 t CO_2eq SU: production: 86.1%, packaging, 5.9%, transport: 3.1%, use: 0%, waste: 5.4.% RU: production: 0.2%, packaging, 0%, transport: 0.2%, use: 77.3%, waste: 26.3%
Davis et al. (2018, Australia)	To compare environmental impact of SU with RU flexible ureteroscopes	Use of one ureteroscope *(RU: assuming lifespan of 180 uses and repairs after 16 uses)*	Total global warming SU: 4.43 kgCO_2eq vs RU: 4.47 kgCO_2eq Manufacturing SU: 3.83 kgCO_2eq vs RU: 0.06 kgCO_2eq Sterilisation RU: 3.95 kgCO_2eq Repair RU: 0.45 kgCO_2eq
Duijndam (2022, The Netherlands)	To investigate environmental impact of a SU and a RU flexible intubation scope (bronchoscope).	450 uses of flexible intubation bronchoscopes *(RU: is validated for 450 uses)*	Climate change SU: 1230 kgCO_2eq vs RU: 1120 kgCO_2eq No absolute figures on the impact per life cycle phases, only graphs.
Hogan et al. (2022, Denmark)	To compare the carbon footprint of SU with RU cystoscopes	Use of one cystoscope *(RU: based on a lifespan 7 year with 1220 uses)*	Solid waste SU: 622 g vs RU: 671.5 g Total global warming SU: 2.41 kgCO_2eq vs RU: 4.23 kgCO_2eq Manufacturing SU: 1.34 kgCO_2eq vs RU:0,013kgCO_2eq Sterilisation SU: 0,3 kg CO_2eq vs RU: 3,5 kgCO_2eq Incineration SU: 0,61 kgCO_2eq vs RU: 0.52 kgCO_2eq Landfill SU: 0.11 kgCO_2eq vs RU: 0.22 kgCO_2eq
Kemble et al. (2023, US)	To compare the carbon footprint of SU and RU flexible cystoscopes	One use of cystoscope *(RU: assuming lifespan of 3920 uses)*	Total global warming potential: SU: 2.40 kgCO_2eq vs RU: 0.53 kgCO_2eq Manufacturing SU: 1.37 kgCO_2eq + 0.22 kgCO_2eq (packaging) + 0.3 kgCO_2eq (sterilisation) RU: 0.002 kgCO_2eq Reprocessing RU: 0.20 (reprocessing) + 0.005 (repackaging) + 0.3 (PPE) + 0.02 (repair) kgCO_2eq; new reprocessor RU: total 1.04 kgCO_2eq
Le et al. (2022, US)	To compare environmental and human health effects of SU and RU duodenoscopes.	One ERCP procedure *(RU: assuming lifespan of 650 uses)* SU, RU and RU with disposable endcap	Total global warming potential SU1*: 36.3 kg CO_2 eq , SU2*: 71.5 kg CO_2eq RU: 1.53 kg CO_2 eq RU + disposable endcap: 1.54 kg CO_2 eq Raw material + manufacturing SU1 – SU2: 91-96% of total impact GWP Use RU: electricity: 62% of total impact GWP, cleaning & disinfection: 26% of total impact Disposal SU1- SU2: 3-5% of total impact GWP
Sørensen and Grüttner (2018, Denmark)	To compare CO_2- equivalent emissions and resource consumption from a SU to a RU bronchoscope	SU: use of one bronchoscope RU: reprocessing one bronchoscope	Total global warming potential SU: 1.6 kg CO_2eq vs RU: 2.9 kg CO_2eq Energy consumption SU: 29 MJ vs RU: 48 MJ Scarce resources consumption SU: 2,1 DKK vs RU: 2,7 DKK

SU: single-use; RU: reusable; ERCP: endoscopic retrograde cholangiopancreatography procedure; GWP: global warming potential, DKK: Danish Kron
SU1 and SU2*: because of lack of data on the composition of SU, the authors modelled a lower bound SU scenario (scenario 1 = same % of electronics as the RU) and an upper bound scenario (scenario 2 = same mass of electronics as the RU).*

According to Davis et al. (2018), the environmental impact of single-use and reusable flexible ureteroscopes was comparable (See Table 2). The main impact for the single-use scope was generated by the manufacturing, whereas for the reusable ureteroscope it was caused by the sterilisation process. Important to note is that ureteroscopes have a quite high breakage rate. They frequently require repairs which has an additional impact (Davis et al. 2018).

For bronchoscopes, the results of Sørsensen and Grüttner (2018) are considered (See Table 2). The results were based on one cleaned bronchoscope, including per cleaning procedure needed materials (cloth, 3 disinfection wipes, transport container liner, brushes, syringe, disinfection products; energy washing and drying) and thereby using one set of personal protective equipment (PPE) (gown, gloves, shoe covers, face shield, …). Under these working conditions, reusable bronchoscopes had comparable or higher material and energy consumption as well as CO_2 emissions and values for resource consumption compared to single-use bronchoscopes. However as the LCA was only partial, the results should be treated with care (Sørensen and Grüttner 2018).



Example of a bronchoscope

Two more recent LCA's suggest that the utilisation of a reusable flexible video endoscope results in a lower carbon footprint compared to a single-use flexible video endoscope. These studies indicate a reduction of 8.6% (Duijndam 2022) and 25.7% (Bringier et al. 2023) respectively (See Table 2). In both studies, the production and manufacturing of materials for the single-use bronchoscope accounted for the largest emissions, while the disinfection process contributed significantly to the environmental impact of the reusable flexible video endoscope.

Analogous results were found in a study on duodenoscopes (Le et al. 2022). This study compared a single-use duodenoscope with a reusable duodenoscope with and without a disposable protective cap (See Table 2). Reusable duodenoscopes pose an increased risk of contamination due to their complex design with multiple channels and small openings, making cleaning and disinfection challenging. When taking this into account in the sensitivity analysis, the human health burden associated with single-use duodenoscopes is found to be comparable to that of reusable duodenoscopes (Le et al. 2022).

The results are up to a certain level conflicting because authors included different processes within the LCA's. At the one hand, there was the impact of the manufacturing procedure of both types of equipment, which is or is not in balance with the disinfection procedure of the reusable item and this balance is different for the different endoscopes and local habits of disinfection. This evidently leads to conflicting results obscuring straightforward conclusions.

As far as the costs of endoscopes is concerned, some information is available (See Table 3). The costs for a single-use cystoscope and a reusable cystoscope were comparable. The cleaning and disinfection process of reusable cystoscopes accounted for a significant portion of the total cost (Boucheron et al. 2022).
Regarding bronchoscopes, Videau et al. (2017) and Bringer et al (2023) calculated that the overall cost of using a reusable bronchoscope was lower compared to a single-use bronchoscope (Videau et al. 2017; Bringier et al. 2023). However, based on a combination of data from a literature research and a questionnaire, Sohrt et al. (2018) found a considerably higher average total cost for reusable bronchoscopes compared to single-use bronchoscopes (Sohrt et al. 2018). Conflicting results are most likely due to differences in methodology.

Table 3: Summary cost studies on flexible endoscopes

Reference	Objective Cost study	Method	Results
Bringier et al. (2023, France)	Overall cost for the hospital	Life cycling costing (LCC) 2000 uses of a flexible intubation bronchoscope (200/year)	Total cost RU: €170 000, based on: -Purchase + service costs: €7160 + €2314/year -Cleaning/reprocessing: equipment: €55/procedure, personnel cost: €17.5/1.5h SU: €450 000, based on: -Purchase cost: €225/ bronchoscope -Waste: €700/tonne (HMW)
Boucheron et al. (2022, France)	To quantify costs associated with a disposable and reusable flexible cystoscopy	Micro-costing approach: - RU: purchase cost of cystoscopes+ towers, maintenance contracts, reprocessing costs, transport, sterilisation equipment+consumables, microbiological test, professional charges, administrative and structural cost (electricity, water,…) - SU: purchase cost of cystoscopes (cost monitor was incorporated into the purchase price of SU scope) Costs were calculated per procedure	RU: €195.65 -Purchase/amortisation: €55.56 -Maintenance/repair: €32.94 -Reprocessing consumables: €39.61 -Reprocessing professional costs: €34.18 -Reprocessing administrative/structural: €32.61 -Microbiological tests: €0.75 SU: €192
Videau et al. (2017, France)	To present a minimisation-cost analysis to compare reusable and single-use fiberscopes (bronchoscopes)	Minimisation cost analysis based on an amortisation over 5 years - RU: purchase cost, maintenance cost, disinfection costs - SU: purchase and disposal costs	RU: €208 - Investment: fibroscopes, washing machine: €69.6 - Maintenance:: €79 - Consumables: €31.6 - Microbiological analyses: €3.02 - Waste disposal:€0.2 - Personnel cost: €25 SU: €264
Sohrt et al. (2018, Denmark)	To calculate cost of using single-use or reusable bronchoscopes per percutaneous dilatational tracheostomy (PDT)	- Systematic literature search on costs - Questionnaire to gather data in 366 hospitals in the US, UK and Germany regarding repair rates and costs for reusable bronchoscopes	RU: $US 406 - Purchase: $US 135 - Reprocessing: $US 123 - Repair: €148 SU: $US 249

SU: single-use; RU: reusable

In summary, it cannot be decided with certainty if reusable cystoscopes, ureteroscopes or bronchoscopes are more or less beneficial for the environment than their single-use equivalents. Additionally, the cost studies gave conflicting results.

2.1.3.3 Trocars

A trocar (or trochar) is a device that is inserted into the abdomen during laparoscopic surgery, as access for other instruments, such as laparoscopic stapler/cutter, clip applier and scissors. Trocars also allow gas or fluid from cavities within the body to escape.

Example of single-use trocars

Example of reusable trocars

Several manuscripts addressed the ecological impact of surgical procedures using trocars (Unger and Landis 2016; Rizan and Bhutta 2022; Boberg et al. 2022) (See Table 4 and Appendices 9.1 & 9.2).

Unger and Landis (2016) performed an LCA and life cycle cost analysis including processes for seven medical devices, more specifically a deep vein thrombosis compression sleeve, a pulse oximeter, a ligasure (vessel sealing device), an harmonic scalpel, an endoscopic trocar, an arthroscopic shaver, and a scissor tip. Driven by the high consumption of trocars compared to the other devices, the use of trocars (single-use and reusable devices) had the second highest total environmental contribution of the seven devices under study. When comparing the relative global warming and human health impacts (impact per device) for the seven analysed devices, the compression sleeve and ligasure are the devices with the highest environmental impacts, while the ultrasonic scalpel was consistently third and the endoscopic trocar was consistently fourth (Unger and Landis 2016).
The authors found that reprocessing those devices for reuse slightly reduced global warming impacts, but concurrently exacerbates human health impacts (i.e., carcinogenic, non-carcinogenic, respiratory effects) due to suboptimal reprocessing inputs. If those reprocessing inputs, such as the use of ethylene oxide, water and electricity were optimised, the use of reusable devices offers overall benefits concerning global warming, human health, and economic benefits compared to single-use (Unger and Landis 2016).
In two recent studies single-use trocars used for laparoscopic procedures were suggested to have a higher environmental impact compared to hybrid trocars containing both reusable and single-use parts for laparoscopic cholecystectomies in a UK setting (Rizan and Bhutta 2022), as well as compared to the reusable trocar systems for laparoscopic procedures in Sweden (Boberg et al. 2022). Both studies found robust results of decreased environmental impacts favouring (partly) reusable trocar systems over single-use systems. Boberg et al. (2022) found that single-use trocars had a 182% higher impact on resources, 379% higher impact on climate change, and an 83% higher impact on ecosystem quality than the reusable trocars. Rizan and Bhutta (2022) found a carbon footprint of 27% per operation using four laparoscopic hybrid trocars compared to its single-use alternative, so almost four times lower (Rizan and Bhutta 2022).

Table 4: Summary LCA's on trocars

Reference	Objective LCA	Functional unit	Results
Boberg et al. (2022, Sweden)	To compare environmental impacts of a single-use, a mixed, and a reusable trocar system for laparoscopic cholecystectomy	500 uses of single-use, reusable, and mixed (SU and reusable) trocar systems	SU trocars – 182% higher impact on resources – 379% higher impact on climate change 83% higher impact on ecosystem compared to RU trocars
Rizan and Bhutta (2022, UK)	To compare the environmental life cycle cost of hybrid and single-use instruments (trocar) for laparoscopic cholecystectomy	Number of 3 types of instruments required to perform one laparoscopic cholecystectomy (=2 small diameter ports, 2 large diameter ports, 1 laparoscopic scissor, and 1 laparoscopic clip applier)	Hybrid 933g CO_2eq /4 trocars Human health: 1.67e^{-6}. DALY Ecosystem: 3.67e^{-9} species. yr Resources: US $ 0.0853 SU 3495g CO_2eq/4 trocars Human health: 6.13e^{-6} DALY Ecosystem: 1.36e^{-9} species.yr

			Resources: US $ 0.344473
Unger and Landis (2016, US)	To model the environmental impacts of varying levels of reprocessing at Phoenix Baptist Hospital in Phoenix, Arizona	Seven medical devices: – deep vein thrombosis compression sleeve, – pulse oximeter, – ligasure, – harmonic scalpel, – endoscopic trocar, – arthroscopic shaver and – scissor tip (=the number of medical devices needed to fulfil the reprocessed device supply chain requirements of the hospital)	No absolute nor relative figures on outcome measures were included in the manuscript (only graphs)

RU: reusable, SU: single-use; DALY: disability-adjusted life years

Even in scenarios of high reprocessing inputs, the financial benefits of reprocessing outweighed the single-use supply chains in the study of Unger and Landis (2016). A finding that was confirmed by Boberg et al. (2022) where reusable trocar systems were approximately half as expensive as the single-use systems (€17360 and €18560 versus €37600, respectively for 500 uses), and Rizan and Bhutta (2022) were the cost of hybrid trocars was 58% compared to single-use ones (GBP £59 vs £102 for one laparoscopic intervention) (Rizan and Bhutta 2022; Boberg et al. 2022).

In summary, conflicting results were found. Using reusable or hybrid systems can help to meet environmental targets as well as reduce financial costs. Although results were robust with regard to several modelling scenarios, optimising sterilisation processes remains an area of concern to minimise the environmental impact and specifically the impact on human health.

2.1.3.4 Laparoscopic stapler, cutter, clip applier and scissors

These sophisticated instruments for laparoscopic procedures, often involving the separation or removal of tissue, require the approximation of the cut edges or tissue to close the wound. Modern surgical stapling systems are available in a diverse range of forms and incorporate various features depending on the surgical application. Each surgical stapler contains a power handle (including battery) which is held by the surgeon, an adapter fixed to the power handle, and a disposable cartridge holder which houses the staples (Meissner et al. 2021). Laparoscopic scissors are used to cut tissue, such as fibrotic or calcified tissue, sutures, and occasionally tissue containing staples. Laparoscopic clip appliers are utilized to ligate tubular structures during laparoscopic and other procedures. They are available in various lengths and diameters and for use with various sized clips.

Example of laparoscopic scissors

Example of a surgical stapler

Two studies (Meissner et al. 2021; Rizan and Bhutta 2022) were suitable for inclusion. Another LCA comparing 2 single-use staplers (Freund et al. 2022) was not included because it did not provide a comparison with a reusable stapler.

Rizan and Bhutta (2022) evaluated very comprehensively the environmental impact of single-use and hybrid (containing both reusable and single-use parts) laparoscopic clip appliers and scissors as part of their study on laparoscopic cholecystectomies (See also Trocars). This LCA determined an 83% reduction in carbon footprint per operation for a reusable clip applier compared to its single-use equivalent, and a 66% reduction for laparoscopic scissors compared to its single-use equivalent (See Table 5). The majority of the carbon footprint of single-use instruments was due to raw material extraction and manufacturing, followed by transportation and waste. For hybrid instruments, single-use parts and disinfection of reusable components were a major contributor to the carbon footprint. Using the hybrid laparoscopic scissors and clip appliers substantially reduced the impact categories (See Table 5) (Rizan and Bhutta 2022).

Table 5: Summary LCA on laparoscopic scissors and clip applier

Reference	Objective LCA	Functional unit	Results
Rizan and Bhutta (2022, UK)	To compare the environmental life cycle cost impact of hybrid and single-use laparoscopic instruments (focus on scissors and clip applier) used for a laparoscopic cholecystectomy	Number of 3 types of instruments required to perform one laparoscopic cholecystectomy: Focus on 1 laparoscopic scissor *(Hybrid: assuming lifespan reusable components of 500 reuses)* Focus on laparoscopic clip applier *(Hybrid: assuming lifespan reusable components of 500 reuses)*	**Laparoscopic scissor** Total global warming SU: 1138 gCO_2eq vs Hybrid: 378 gCO_2eq -Manufacturing SU: 660 gCO_2eq vs Hybrid 232 gCO_2eq (SU parts), 1.27 gCO_2eq (RU parts) -Transportation SU: 324 gCO_2eq -Decontamination Hybrid: 79 gCO_2eq -Waste SU: 154 gCO_2eq Human health SU: 2.90.e^{-6} DALY vs Hybrid: 1.28 e^{-6} DALY Ecosystem: SU: 5.22 e^{-9} species.yr vs Hybrid 1.84 e^{-9} species.yr Resources SU: US $ 0.1176 vs Hybrid: US $ 0.0314 **Laparoscopic clip applier** Total global warming SU 2559 gCO_2eq vs Hybrid 445 gCO_2eq -Manufacturing SU: 1342 gCO_2eq vs Hybrid 112 gCO_2eq (SU parts), 4,37 gCO_2eq (RU parts) -Transportation SU: 923 gCO_2eq -Decontamination Hybrid: 247 gCO_2eq -Waste SU: 294 gCO_2eq Human health SU: 6.30.e^{-6}. DALY vs Hybrid: 1.09 e^{-6}. DALY Ecosystem SU: 1.24 e^{-9} species.yr vs Hybrid:1.96 e^{-8} species.yr Resources SU: US $ 0.2944 vs Hybrid: US $ 0.0464

SU: single-use; RU: reusable; DALY: disability-adjusted life years

In the study of Meissner (2021), the total material requirement (TMR) approach was applied. TMR is based on the concept of material input per service and is a metric which reflects all abiotic and biotic material as well as the moved soil needed to manufacture a product or perform a service. The use of air and water in the manufacturing process is not taken into account in this metric. The TMR approach is different from an LCA given that it considers a narrower range of environmental impacts focusing on quantifying the material needs (Meissner et al. 2021).

Shifting from a single-use to a reusable stapler resulted in a total waste reduction for laparoscopic sleeve gastrectomy by 40%, for laparoscopic gastric bypass of 70% and for video-assisted thoracoscopy lobectomy by 62% (See Table 6). In all three surgical procedures, the TMR was reduced by over 90% when switching from single-use to reusable stapler, suggesting that over 90% of total raw material inputs can be saved by converting to reusable staplers. Meissner et al. (2021) concluded that for each surgical procedure evaluated, switching from single-use to reusable staplers facilitates a significant reduction in total surgical waste and the total material requirement.

Table 6: Summary study on surgical stapler

Reference	Objective study	Method	Results
Meissner et al. (2021, Germany)	To evaluate the waste prevention potential and extended resources use of RU versus SU powered surgical stapling systems.	Calculation for 3 surgical procedures (laparoscopic sleeve gastrectomy, laparoscopic gastric bypass, and video-assisted thoracoscopic (VATS) lobectomy) of: - Total waste (disassembling both systems) per surgery - Extended resource use (Total Material Required (TMR)) per surgery	Total waste -Sleeve gastrectomy SU: 0.72 kg vs RU: 0.43 kg -Gastric bypass: SU: 1.38 kg vs RU: 0.41 kg -VATS lobectomy: SU: 1.39 kg vs RU: 0.53 kg kg TMR -Sleeve gastrectomy SU: 329 kg vs RU: 27 kg -Gastric bypass: SU: 633 kg vs RU: 25 kg -VATS lobectomy: SU: 633 kg vs RU: 34 kg

SU: single-use; RU: reusable; VATS: video-assisted thoracoscopy TMR: total material required

In summary, it can be concluded that the use of reusable laparoscopic stapler, cutter, scissors and clip applier devices are more environmentally friendly than the use of their single-use equivalents.

2.1.3.5 Surgical scissors

Surgical scissors are not only used during surgery, but also in other departments of a hospital, including general and surgical wards, laboratories, and outpatient clinics. They make up a relevant share of the production volume of surgical instrument suppliers, as well as of the number of instruments that need to be sterilised (Ibbotson et al., 2013).

Example of surgical scissors

The environmental impact of single-use and reusable surgical scissors was compared in two studies (Ibbotson et al. 2013; Rizan et al. 2022a).

Ibbotson et al (2013) compared the impacts and total cost throughout the life cycle (called “total cost of ownership”) for reusable stainless steel scissors with single-use scissors made of either stainless steel or fibre-reinforced plastic. The overall impacts of the single-use steel product exceeded those of the two others by 80 % for single-use plastic scissors and by 99 % for reusable steel scissors. Differences in total cost of ownership revealed significant economic advantages of reusable stainless steel scissors compared to both type of single-use scissors. An economic break-even analysis revealed that the payback period of the reusable stainless steel scissors is valid at 19 use cycles when compared with the plastic single-use scissors and at 25 use cycles when compared with the stainless steel single-use scissors. The authors concluded that using reusable stainless steel scissors was the most eco-efficient choice (Ibbotson et al., 2013).

Rizan et al (2022) focused on the environmental impact and financial cost of repairing surgical scissors in 3 scenarios, no repair (lifespan of 40 uses), onsite repair (hospital) and offsite repair. Repairing surgical scissors rather than replacing them with a new pair can reduce environmental and financial cost. Emissions were reduced by 20% through use of onsite repair every 40 uses instead of replacement, and by 19% through use of offsite repair every 40 uses. The use phase, and more specifically decontamination, impacted the carbon footprint across all baseline scenarios. Life cycle cost was GBP £1.43 per use of reusable scissors, and when repaired either on- or offsite this decreased by 32% to GBP £0.97 per use (Rizan et al. 2022a).

Detailed results of both studies were included in Table 7 and Appendices 9.1 & 9.2.

Surgical scissors as part of laparoscopic devices were described elsewhere (See 2.1.3.4).

Table 7: Summary LCA's on surgical scissors

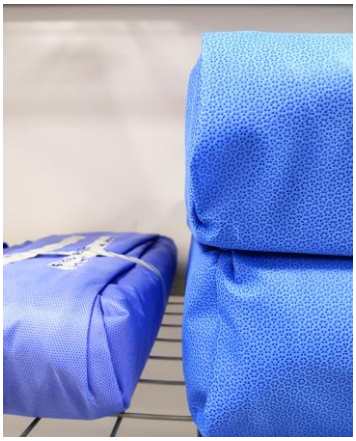
Reference	Objective LCA	Functional Unit	Results
Ibbotson et al. (2013, Germany)	To evaluate the environmental impact and total cost of ownership (customer perspective) comparing SU scissors of stainless steel, SU scissors of fibre-reinforced plastic and RU stainless steel	4500 use cycles of surgical scissors during 18 years	Impact RU stainless steel scissors: 11 times lower for the plastic SU scissors 52 times lower than stainless steel SU scissors
Rizan et al. (2022, UK)	To evaluate the environmental impact and financial cost of repairing surgical scissors for 3 scenarios: no repair, onsite (hospital) and offsite	One use of a reusable surgical scissor (type 17-cm, straight Mayo reusable; manufactured in Germany and used in the UK)	Global warming 70.3 g CO_2eq/use Onsite repair: 56.3 g CO_2eq/use Offsite repair: 57 g CO_2eq/scissor use

SU: single-use; RU: reusable

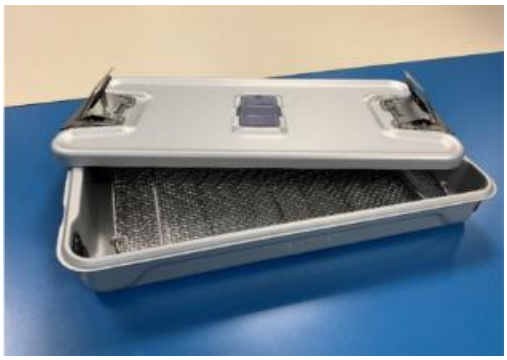
In summary, using reusable stainless steel scissors was more beneficial for the environment and financial cost compared to their single-use alternatives. Repairing surgical scissors (onsite and offsite), rather than replacing them with a new pair, reduces environmental and financial cost.

2.1.3.6 Medical blue wrap

It is of utter importance that medical devices used in the OR (operating room) are completely sterile. Therefore, blue wrap (sterilisation wrap) or sterilization containers are typically used. Blue wrap is a multilayer non-woven packaging material made from polypropylene supplied as sheets. Surgical instrument nets are wrapped in two sheets of blue wrap (Friedericy et al. 2022; Hoge Gezondheidsraad 2023).



Example of blue wrap



Example of rigid sterilization container (Friedericy et al. 2022)

The environmental impact of single-use packaging for sterilisation of surgical instruments and reusable sterilisation containers was compared in two cradle-to-grave LCA's (Stiegler et al. 2016; Friedericy et al. 2022), while Friedericy et al. (2022) also studied the cradle-to-cradle or recycling option (See Table 8 and Appendices 9.1 & 9.2). The processes and cost of alternative packaging options were analysed by Krohn et al. (2019).

Stiegler et al. (2016) demonstrated that the reusable aluminium containers had approximately half of the greenhouse gas emissions impact compared to the disposable polypropylene blue wraps annually (See Table 8). For both alternatives, the use phase had the largest environmental impact of all phases, due to the large amount of energy consumption during sterilisation and decontamination process.
Correspondingly, according to Friedericy et al. (2022) the use of a rigid aluminium sterilisation container gave a reduction of 85% in carbon footprint compared to the use of blue wrap. The reusable container had 84.5% less impact in eco-costs. An ecological advantage already occurred after 98 use cycles while the rigid containers are used up to 5000 times. (Friedericy et al. 2022).

Table 8: Summary LCA's on blue wrap

Reference	Objective LCA	Functional unit	Results
Friedericy et al. (2021, The Netherlands)	- To compare environmental impact of SU and RU sterilisation packaging for surgical instruments - To investigate environmental break-even point of use-cycles	Sterile packaging of a standard format instrument tray for 5000 sterilisation cycles	Global warming potential – SU incineration: 1869 $kgCO_2$ eq – RU landfill: 285 $kgCO_2$ eq Eco-costs: – SU incineration: €669 – RU landfill: €104 Break-even point (SU incineration-RU landfill) – Carbon footprint: 98 use-cycles – Eco-cost: 67 use cycles
Stiegler et al. (2016, US)	To compare SU polypropylene blue wraps and RU aluminium containers	Sterilisation protection for 100 surgical toolsets used 365 times per year over 10 years	Global warming potential SU: 823 000 $kgCO_2$eq RU: 377 000 $kgCO_2$eq - Manufacturing: SU: 22.2% of total impact RU: 1.6% of total impact - Use: SU: 77.3% of total impact RU: 97.5% of total impact - End-of-Life: SU: 2.5% of total impact RU: 0.9% of total impact

SU: single-use; RU: reusable

The cost of four (2 reusable and 2 disposable) different packaging options of sterile medical devices was analysed by Krohn et al. (2019) (See Table 9). The results of the analysis revealed that 'the sterile container without inner wrap' was the most cost-effective alternative per use. Under numerous (33) scenarios (concerning personnel cost, material and special costs, changes in usage and extreme scenarios), the sterile container without inner wrap remained most cost-effective. The two sheets sterilisation option brought about the highest costs in most cases. This is due to the higher process times and thus higher personnel costs. The authors remarked that each central sterilisation department should analyse its own situation, requirements and circumstances (Krohn et al. 2019).

Table 9: Summary cost study on blue wrap

Reference	Objective Cost study	Method	Results
Krohn et al. (2019, Germany)	To analyse and compare processes and costs of 4 packaging alternatives	- Defining main and sub-processes directly related to the packaging options - Time measurements - Distribution fitting (time consumption and costs) and simulation for all sub-process	- Sterile container without inner wrap:€2.05 - Sterile container with inner wrap: €3.24 - Two sheets non-woven sterilization wrap: € 3.87 - One-step non-woven sterilization wrap (made of two sheets): €3.44

In summary, both LCA studies have clearly demonstrated that the use of reusable containers are beneficial to the environment compared to the use of disposable blue wrap. The cost study was also in favour of a reusable packaging option.

2.1.3.7 Sharps containers

Sharps containers provide safe disposal of syringes, needles and other small sharps. In Belgium, it is currently not allowed to use reusable sharps containers (FAGG-AFMPS 2022). Waste containers are in the top 20 contributors to the supply chain carbon footprint in the UK (NHS 2017). Single-use containers are used once and the intact container and contents are incinerated. Replacing disposable by reusable alternatives has been investigated in the UK where companies processing reusable sharps containers are present.. Reusable containers, certified for a specific number of uses, are being transported to a processing plant, automatedly decanted of its contents, robotically cleaned, decontaminated, and quality checked (Grimmond et al. 2021).

Example of reusable sharps container

The environmental impact of the supply of reusable versus single-use sharps containers was compared in three cradle-to-grave LCA studies in the US and UK (See Table 10 and Appendices 9.1 & 9.2) (Grimmond and Reiner 2012; McPherson et al. 2019; Grimmond et al. 2021).
Replacing single-use sharps containers by reusables reduced GHG (greenhouse gas) emission between 65% to 83% depending on the lifespan of the reusable containers. Furthermore, converting from single-use to reusable eliminated tonnes of plastic cardboard, depending on the size of institutions involved in the study.

Table 10: Summary LCA's on sharp containers

Reference	Objective LCA	Functional unit	Results
Grimmond et al. (2021, UK)	To evaluate the environmental impact, expressed as global warming potential in metric **tons** of carbon dioxide equivalent ($MTCO_2eq$), of replacing SU SC by RU SC	Total fill line litres (FLL) of sharps containers needed to dispose of sharps for 1-year period in 40 trusts	Global warming potential Reduction of 3267.4 $MTCO_2eq$ SU SC: 3896.4 $MTCO_2eq$ RU SC (lifespan of 18 years): 628.9 tonnes CO_2eq + elimination of 900.8 tonnes plastic (landfill + incineration), 132.5 tonnes cardboard.
Mc Pherson et al. (2019, US)	To evaluate the environmental impact, expressed as greenhouse gas emissions in metric t**ons** of carbon dioxide equivalent ($MTCO_2eq$), of RU SC and SU SC	Total of single-use and reusable sharps containers, needed to dispose of sharps for 1-year period in 5 hospitals	Global warming potential Reduction of 162.$MTCO_2eq$ SU SC:248.6 $MTCO_2eq$ RU SC (lifespan of 26.4 years): 86.20 $MTCO_2eq$ + reduction of 50.2 tons plastic (31.8 landfill + 18.4 incineration), and 8.1 tons cardboard
Grimmond and Reiner (2012, US)	To evaluate the environmental impact, expressed as global warming potential (GWP), of replacing SU SC by RU SC in metric tons (MTCO2eq)	Not reported	Global warming potential Reduction of 127 $MTCO_2eq$ SU SC:139.1 $MTCO_2eq$ RU SC (lifespan of 39.6 years): 25.1 $MTCO_2eq$ + reduction of 30.9 tons of plastic and 5.0 tons of cardboard from landfill

SU SC: single-use sharps container; RU SC: reusable sharps container; MTCO2eq metric tonnes carbon dioxide equivalent

In summary, all three studies have clearly demonstrated that the use of reusable sharps containers is beneficial to the environment compared to the use of single-use sharps containers.

2.1.3.8 Surgical gown, isolation gown, coverall

Surgical gowns, isolation gowns and coveralls are medical textiles which can be woven, knitted, braided, or consists of non-woven structures, depending on the application. It can include both, natural and synthetic fibres (Health Care Without Harm Europe 2021b; Martínez-Barbosa and Moreno-Corral 2022). Surgical gowns serve a critical role in infection prevention (Overcash 2012). They protect patients from microbial contamination by surgical personnel and protect perioperative personnel from microorganisms and contamination related to the patient's body fluids. Isolation gowns also have a critical role in infection prevention by protecting healthcare workers and patients from the transfer of microorganisms and body fluids in isolation settings. Finally, a coverall can be used as a type of isolation gown which was often used in the corona pandemic. Cleanroom coveralls are also used in e.g. pharmaceutical industry when cleanroom standards are required.

Overcash (2012) performed a literature review on reusable and single-use perioperative textiles, including surgical gowns and surgical drapes. Six life cycle studies were included, dating from 1993 to 2011. The author concluded that reusable surgical textiles offer substantial sustainability benefits over single-use products in terms of natural resource energy by 200 to 300%, water footprint by 250 to 330%, carbon footprint by 200 to 300%, volatile organics, solid wastes by 750%, and instrument recovery. All other factors such as cost, protection, and comfort were relatively similar (Overcash 2012).

Example of a reusable surgical gown

Example of a single-use surgical gown

Example of a single-use isolation gown

In more recent studies, single-use and reusable **surgical gowns** were evaluated using a cradle-to-grave LCA (Vozzola et al. 2020; Bijleveld and Uijttewaal 2022) (See Table 11, See Appendices 9.1 & 9.2). In the study of Vozzola et al. (2020), the surgical gown was defined as single-piece, long-sleeved, size extra-large with AAMI (Association for the Advancement of Medical Instrumentation's) Level 3 barrier protection rating. Global warming was substantially lower (66%) for the reusable gowns than for the single-use gowns (See Table 11)**.** The laundry procedure accounted for 50% of the GHG emissions for the reusable surgical gowns. Furthermore, the use of reusable gowns reduced also natural resource energy consumption (64%), blue water consumption (83%), and solid waste generation (84%). Bijleveld and Uijtewaal (2022) compared two

types of reusable and two types of single-use surgical gowns. The environmental impact of the reusable surgical gowns was considerably lower than the impact of the single-use gowns (See Table 12). For reusable surgical gowns, packaging and washing in particular have a large share in climate impact and for single-use gown the production of the gown had the largest impact.
Comparable to the literature review of Overcash et al. (2012), these study results showed that selection of reusable surgical gowns rather than disposable gowns was more favourable (Vozzola et al. 2020).

Example of a single-use coverall

Using an identical methodology, the same authors also investigated the environmental impact of reusable and disposable **isolation gowns** and **cleanroom coveralls** (Vozzola et al. 2018a, b). The isolation gown was defined as a single-piece, long sleeved, extra-large or one-size -fits-most garment with AAMI Level 1 barrier protection rating (See Table 11). The gown manufacturing and delivery life cycle steps had a huge impact on the environmental indicator for single-use isolation gowns. On the other hand, for reusable gowns the laundry procedures had the largest impact. The results also showed that selection of reusable gowns rather than disposable gowns reduced natural resource energy consumption (28%), GHG emissions (30%), water consumption (41%) and solid waste generation (93%).
A cleanroom coverall was defined as a single-piece, long-sleeve extra-large zip up garment, excluding a hood, gloves, or booties. Two single-use and one reusable coverall were examined.
The reusable cleanroom coverall showed also substantial improvement over both single-use coveralls in all environmental impact categories (See Table 11). The improvements over the single-use HDPE (high density polyethylene) coverall and the single-use SMS PP coverall were respectively 34% and 59% lower process energy, 23% and 56% lower natural resource energy, 27% and 57% lower GHG emissions, and 73% and 77% lower water consumption. Between the two single-use cleanroom coveralls, the flash spunbonded HDPE coverall shows a considerable environmental improvement over the SMS PP coverall.

Table 11: Summary LCA's on medical textiles

Reference	Objective LCA	Functional unit	Results
Bijleveld and Meis (2022, The Netherlands)	To compare environmental impacts of RU and SU surgical gowns	1 use of surgical gown - RU1: 100% polyester with C6 fluorcarbonfinish - RU2: 100% polyester - SU1: 90-95% SMMMS PP, 5-10% other (PET, cellulose) - SU2: 86-99% SMMMS PP, 1-14% non-woven PET)	No absolute figures are given, only graphs.
Vozzola et al. (2018a, US)	To compare the environmental impact of RU and SU cleanroom coveralls	1000 uses of a cleanroom coverall *(50 uses before discarding was used resulting in manufacture and disposal*	Global warming – RU: 517 $kgCO_2eq$ – SU HDPE: 712 $kgCO_2eq$ – SU SMS PP: 1220 $kgCO_2eq$ Process energy – RU: 4560 MJ

		of 20 gowns for 1000 uses) *(60% was laundered to cleanroom standards and 40% as laundered and sterilized)* - SU: spunbonded high density polyethylene (HDPE) - SU: spunbond-meltblown-spunbond polypropylene (SMS PP) - RU: woven polyethylene terephthalate (PET)	– SU HDPE: 6930 MJ – SU SMS PP: 11100 MJ Natural resource energy – RU: 8380 MJ – SU HDPE:10900 MJ – SU SMS PP:19200 MJ Water consumption – RU: 80.7 kg – SU HDPE: 304 kg – SU SMS PP: 345 kg Solid waste – RU: 10.2 kg – SU HDPE: 171 kg – SU SMS PP: 238 kg
Vozzola et al. (2018b, US)	To compare environmental impacts of RU and SU isolation gowns	1000 uses of isolation gown *(60 uses before discarding the RU gown resulting in manufacture and disposal of 16,7 gowns for 1000 uses)* – SU:non-woven polypropylene – RU: primarily woven polyester fabric	Global warming – SU: 310 kgCO2eq vs RU: 218 kgCO_2eq Global warming – SU manufacturing: 300 kgCO_2eq – RU laundry: 146 kgCO_2eq Natural resource energy – SU: 5150 MJ vs RU: 3712 MJ – Manufacturing SU: 4996 MJ – Laundry RU: 2538 MJ Water consumption – SU: 74.6 kg vs RU: 43.8 kg – Manufacturing SU: 74.6 kg – Laundry RU: 8.71 kg Solid waste SU: 63.4 kg vs RU 0.41-4.42 (depending on 100% or 0% recycling)
Vozzola et al. (2020, US)	To evaluate environmental impacts of RU and SU surgical gowns	1000 uses of surgical gown *(60 uses before discarding the RU gown resulting in manufacture and disposal of 16,7 gowns for 1000 uses)* – SU: non-woven polyester (non-critical zone OR), PP (critical zone OR); – RU: woven PET in non-critical zone and knit PET in critical zone	Global warming – SU: 1636 kgCO_2eq vs RU: 557 kgCO_2eq Laundry global warming – RU: 278 kgCO_2eq Natural resource energy – SU: 26289 MJ vs RU: 9396 MJ Water consumption – SU: 1097 kg vs RU: 185 kg Solid waste - SU: 265 kg vs RU 35.5–43.4 kg (depending on 100% or 0% recycling)

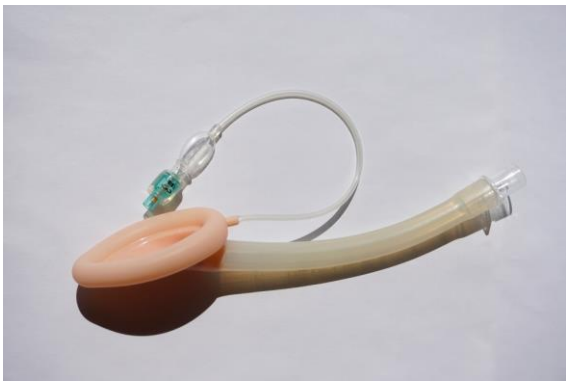
SU: single-use; RU: reusable; HDPE: high-density polyethylene, PP: polypropylene, PET: polyester, SMMMS: spunbond, meltblown, meltblown, meltblown, spunbond; OR: operating room

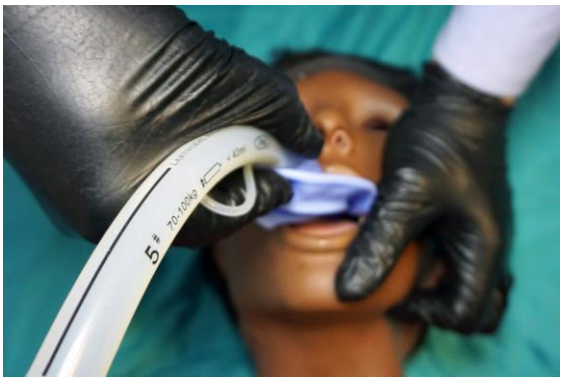
In summary, the studies demonstrated that reusable gowns/coveralls are more environmentally friendly than single-use equivalents.

2.1.3.9 Laryngeal mask airway

A laryngeal mask airway (LMA) is a supraglottic airway device which is used temporarily to maintain an open airway during anaesthesia or as an urgent life-saving measure in a patient with a difficult or obstructed airway. An LMA consists of an airway tube and an elliptical mask cuff and is designed to sit in the patient's hypopharynx and cover the supraglottic structure (Liang 2019; Simon and Torp 2023).

The environmental impact of single-use and reusable LMA's was compared in two cradle-to-grave LCA's using a similar methodology (See Table 13 and Appendices 9.1 & 9.2) (Eckelman et al. 2012; Liang 2019). The results of both studies showed that reusable LMA's had fewer negative environmental effects. In the study by Eckelman et al. (2012), the production of PVC (polyvinylchloride), the main component of single-use LMA's, accounted for the largest source of GHG emissions (23%). For reusable LMA's, natural gas production and incineration for steam generation in the autoclave constituted the largest source of emissions (77%). Similarly, Liang (2019) concluded that for the single-use LMA's, PVC production was the major contributor to the environmental burden, while for reusable LMA's, the use phase, specifically the manual cleaning and soaking process (before automated cleaning), was the main source of environmental impact.





Example of a laryngeal mask airway

Table 12: Summary LCA's on laryngeal mask airways

Reference	Objective LCA	Functional unit	Results
Eckelman et al (2012, US)	To compare the environmental and human health impact of SU and RU laryngeal mask airway	40 uses of a laryngeal mask airway	Global warming potential – SU: 11.3 $kgCO_2eq$ o Production + polymerisation PVC: 23% o Polycarbonate production: 14% o Transportation via truck: 15% o Thermoforming: 13% o Waste disposal: 11% – RU: 7.4 $kgCO_2eq$ o Natural gas production + combustion to produce steam for the autoclave: 77% Scenario analyses – RU: fully loaded autoclave (10 pieces): 5.6 $kgCO_2eq$ – RU: individual autoclave: 37 $kgCO_2eq$ – RU: autoclave efficiency +10%: 6.8 $kgCO_2eq$ – RU: 10 reuses: 11.4 $kgCO_2e$ – SU: transport by air: 20.5 $kgCO_2eq$
Liang (2019, Sweden)	To compare the environmental impact of SU and RU laryngeal mask airway	40 uses of a laryngeal mask airway	No absolute figures are given, only graphs. Comparative analysis of the single-use and reusable LMA for 3 endpoints (human health, ecosystems and resources): reusable LMA has less than 40% impact burdens compared to the single-use LMA

SU: single-use, RU: reusable, LMA: laryngeal mask airway; PVC: polyvinyl chloride

In summary, the findings of both studies indicate that reusable laryngeal mask airway are more environmentally friendly compared to single-use laryngeal mask airway.

3 STAKEHOLDERS

3.1 Goal

By consulting stakeholders, information on current (best) practices and challenges in reducing, reusing and recycling of medical items and devices was collected.

3.2 Overview consulted stakeholders

Hospitals, departments	– Sustainability coordinators (Ghent University Hospital, AZ Maria Middelares) – Working group single-use Ghent University Hospital – Central sterilisation Ghent University Hospital – Infection Prevention and Control Department Ghent University Hospital – Surgery Ghent University Hospital – Best practices hospitals from hospital websites
Purchase departments	– Procurement central Charleroi MercurHosp - Mutualisation Hospitalière – Purchase department Ghent University Hospital
Companies	– GreenCycl (https://greencycl.org) o Circular and economically sustainable solutions for healthcare: consulting, collection, sterilisation, design, production and recycling. – Vanguard (https://www.vanguard.de) o Medical remanufacturing: restores a used medical device to “as new” functional and safety standard with matching warranty. – Sterima (https://www.sterima.be/nl) o Sterilisation services for hospitals and medical companies in the Benelux – Renewi (https://www.renewi.com) o Waste management and recycling

Relevant information from the stakeholder interviews and visits was included in the analysis of the items, LCA and recommendations (See Chapters 5, 6 and 7).

4 HOSPITAL SURVEY: CONSUMPTION AND COST OF SINGLE-USE MATERIALS

4.1 Goal

The goal of the hospital survey was to identify the five most relevant single-use medical devices with possible environmentally sustainable and/or circular alternatives based on consumption rates and/or cost rates in Belgian hospitals.

4.2 Methods

4.2.1 Design

A cross-sectional multi-centre study was performed. Data were collected between August and November 2022.

4.2.2 Setting

Hospital participation was requested on behalf of the Directorate-General for the Environment of the Federal Public Service (FPS) Health, Food Chain Safety and Environment. An email invite was sent by the FPS to the CEO of the Belgian hospitals requesting participation (See Appendix 9.3: Invitation letter French-language and Invitation letter Dutch-language). The study was also announced during a national meeting of the BVZD-ABDH (Belgian Association of Hospital Managers) on circularity and sustainability in healthcare on June 21th of 2022. All Belgian hospitals, including general and university hospitals (N=103), and psychiatric hospitals (N = 59), were invited to share information about the procurement of single-use medical items and devices. No reminders were sent by the FPS, but requests for further information were replied by the FPS or by the researchers of Ghent University Hospital. Hospitals that responded positively were given further instructions for participation and a template to encourage uniformity of data entry. Hospitals who responded positively to the initial call, but did not provided procurement data by the end of September, received two reminders (one by telephone and one by mail).

4.2.3 Data collection: hospital survey procurement lists

To gain insight into the type of single-use medical devices most frequently used or with the highest cost per item, a hospital survey requesting procurement lists was conducted. Following data were requested for all medical single-use devices purchased by pharmacy and procurement department of the participating hospitals:

- Name of the medical device purchased by pharmacy and procurement department
- Manufacturer
- Number of packing units ordered per year
- Number of items per packing unit
- Purchase price per packing unit (excl. VAT)
- Optional parameters, if available, such as weight/volume.

Procurement data of the year 2019, the last full year before the COVID-19 pandemic, were requested. The hospital situation during the COVID-19 pandemic was considered not representative for the study.

Participants obtained the certainty of anonymisation when analysing their data (See also 4.2.5: Ethical considerations).

4.2.4 Processing procurement lists

4.2.4.1 Consumption of single-use medical items and devices

Data were processed uniformly for each hospital separately: 1) sorted by consumption (amount), 2) related items were added up (e.g. same item but from different companies, different size) and 3) consumption per item per bed (licensed beds) per hospital per year was calculated.

Medical devices indicated by the FAMHP (Federal Agency for Medicines and Health Products) during the COVID-19 crisis that they should not be reused (due to their complexity) were excluded (See Appendix 9.4). In conjunction with this, items beyond the scope of the project due to safety (for example needles), complexity (for example glucose sticks), availability of alternatives (for example blood tubes) were excluded. The FPS steering committees with delegates of several departments of the FPS monitored the project and advised the focus on items with the potential of more sustainable alternatives. A non-limitative list of excluded items is provided in Appendix 9.5.

The selection process from all items to the final five items for further research is detailed in the result section.

4.2.4.2 Cost of single-use medical devices

Similar to the list of items with high consumption rates, we aimed to compose a list of high cost items. Since hospitals were not eager to share their prices, and the most expensive items were rarely included in the provided lists, cost data could not be similarly processed.
For a selected amount of items, purchase costs were based on publicly available pricelists of three suppliers.

4.2.5 Ethical considerations

A data transfer protocol between the participating hospitals and Ghent University Hospital was developed to ensure confidentiality. All data provided by the hospitals will only be used for data processing within this research project and will be handled confidential. In processed and aggregated form, the data may be part of future scientific publications.

4.3 Results

4.3.1 Participating hospitals

Twenty-three hospitals responded to the initial call of the FPS to participate in the study. Eleven hospitals provided procurement data lists. Upon completion of the initial data collection period, one additional hospital provided purchasing amounts based on a shortlist of items. In total, data from 12 hospitals were synthetised, of which four Walloon hospitals, six Flemish hospitals and two hospitals from Brussels-Capital region. Eight hospitals were general hospitals, the remaining four were university hospitals.

Of these twelve hospitals, nine provided procurement data lists from the requested year 2019, one provided data from 2021 and two from a part (nine or ten months) of 2022. For the latter group, the data were recalculated to full-year amounts.

Five hospitals were willing to report purchase cost in addition to consumption figures, of which one provided cost data from 2022. All hospitals provided partial procurement data, with missing data on procurement figures on regularly used single-use medical devices (See Table 13). An overview of the type of provided data of the participating hospitals can be found in Appendix 9.6.

None of the participating hospitals provided data on the optional parameters, as weight or volume of the single-use medical items and devices.

Table 13: Overview of type of provided data of the participating hospitals

Region	Number of participating hospitals % (n)	Hospitals providing procurement data /with cost data % (n) – Cost %(n)	Hospitals providing pharmacy data/ with cost data # % (n) – Cost %(n)	Hospitals providing surgery equipment data (laparoscopic devices/catheters…)/with cost data # % (n) – Cost %(n)
Brussels	16.7 (2)	8.3 (1) / 0.0 (0)	8.3 (1) / 0.0 (0)	0.0 (0)/ 0.0 (0)
Wallonia	33.3 (4)	33.3 (4)/ 25.0 (3)	25.0 (3) /16.7(2)	0.0 (0)/ 0.0 (0)
Flanders	50.0 (6)	50.0 (6)/ 16.7 (2)	50.0 (6)/ 16.7 (2)	16.7 (2)/8.3 (1)

4.3.2 Procurement data

4.3.2.1 Longlist of single-use medical devices

The twenty highest-scoring items in terms of consumption for each hospital were included in a list (hereafter referred to as "longlist"). Consumption rate of items emerging in one hospital's procurement top 20, but not in another hospital's procurement top 20 were specifically searched for and, if available, completed in the longlist. The longlist ended up containing a total of 78 medical single-use materials.

Categories were created based on the process needed for reuse. Following categories were identified:

- Sterilisation or high level disinfection
  - Small medical devices
  - Operating room (OR) equipment, such as laparoscopic and other surgical equipment
- Thermal disinfection (TD) or low level disinfection (LLD)
- Laundry process
- Change of item/device (alternative needed)/ Change of composition (/ Change of behaviour) [1]

Each item was assigned one of these categories. The full longlist of items with categories is included in Appendix 9.7.

A more complete list consisting of the highest-scoring items per hospital based on cost per item expressed as cost per bed per year could not be compiled due to missing cost data (>50% of hospitals), and missing data on single-use surgical equipment (>90% of hospitals).

For illustrative purposes only, graphs of consumption in relation to cost (catalogue price and/or real hospital prices) were added to the report. An example of a hospital was included where amounts and costs of single-use medical devices including all departments (central purchase department, pharmacy and surgical equipment) were available (Appendix 9.8). Due to the limitations of the data collection, results including cost data should be interpreted with caution.

4.3.2.2 From longlist to shortlist

Pragmatically, in light of available project time and budget, the five most relevant items for further research were chosen, using following steps (See Figure 1). Firstly, a shortlist was created by selecting 28 items from the longlist. Secondly, items were sorted based on reprocessing categories and finally for each reprocessing category, one item was selected. A detailed description of those three steps is provided below.
The first step was creating a shortlist of 28 items (See Table 14), compiled from the longlist, and based on following criteria (and listed in Figure 1):

- Consumption rate/bed/year (thermometer caps, kidney trays)
- Cost/item (vessel sealer)
- Feasibility (such as countering shift from reusable to single-use alternative) (vaginal speculum, patient blanket)
- Volume/item (patient blanket)
- Safety (kidney tray, vaginal speculum, patient blanket)
- Sustainability (high ecological impact when disposed as waste) (vessel sealer)
- Literature/Stakeholders input/Focus of project

[1] Items in the category "Change of behavior" were not included as this was not the scope of the study (more sustainable alternatives for single-use medical devices)

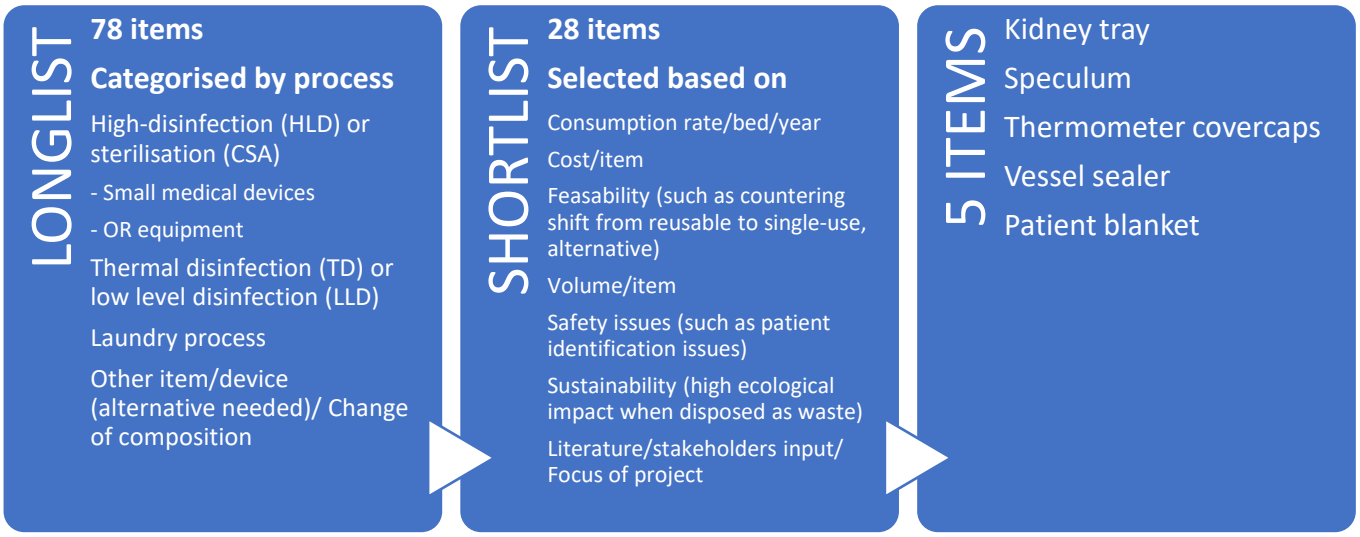


Figure 1: Steps followed to identify the five single-use items for further research

Secondly, items were sorted based on the circular process needed for reuse as reflected in Table 14.

Table 14: Shortlist of items

ITEM	CIRCULAR PROCESS NEEDED
MEDICATION CUPS	TD
BASINS/KIDNEY TRAY	TD
NEEDLE BINS	TD/ CHANGE OF ITEM OR DEVICE
GARROT	TD/ CHANGE OF ITEM OR DEVICE
DENTAL JAR	TD/HLD
LID FOR DRINKING CUP	TD
COVERCAPS FOR TEMPERATURE MEASUREMENT	CHANGE OF ITEM OR DEVICE
STERILISATION DRAPES ABSROBERENDE VELLEN/LINER	LAUNDRY/ STERILISATION
SURGICAL AND OTHER CAPS	LAUNDRY
BREAST(FEEDING) COMPRESS	LAUNDRY
SHEETS EXAMINATION TABLES	LAUNDRY
GOWN (NS) (ISOLATION)	LAUNDRY
SURGICAL GOWN (S)	LAUNDRY/ STERILISATION
BIB	LAUNDRY
PROTECTIVE COVER MATRESS	LAUNDRY
WASH CLOTH	LAUNDRY
DIAPERS (BABY)	LAUNDRY
INCONTINENCE SHEETS	LAUNDRY
TROLLEY COVERS	LAUNDRY
BLANKET	LAUNDRY
MILK BOTTLES	STERILISATION
BRUSH ENDOSCOPIC VALVES	STERILISATION
SPECULUM	STERILISATION
SCISSORS (STERILE)	STERILISATION
LARYNGOSCOOPBLADES	STERILISATION
TROCAR	STERILISATION (OR EQUIPMENT)
VESSEL SEALING	STERILISATION (OR EQUIPMENT)
BLOODPRESSURE CUFS	CHANGE OF ITEM OR DEVICE

The large variations in consumption between hospitals and the lack of data on certain items is illustrated in Appendix 9.9 (each hospital is represented by another colour). Data on some of the items were only provided by one or two hospitals, whereas, from logical reasoning in care provision, it is used by (almost) all hospitals, for example incontinence materials.

Because of this limitation, it was not deemed appropriate to rely solely on the quantities received from the hospitals, but other criteria were also considered (as listed to compile the shortlist and in Figure 2). For illustrative purposes only, a graphic overview of the median consumption-rates (amount/bed/year for 2019) of the 28 highest scoring items was provided in Figure 2.

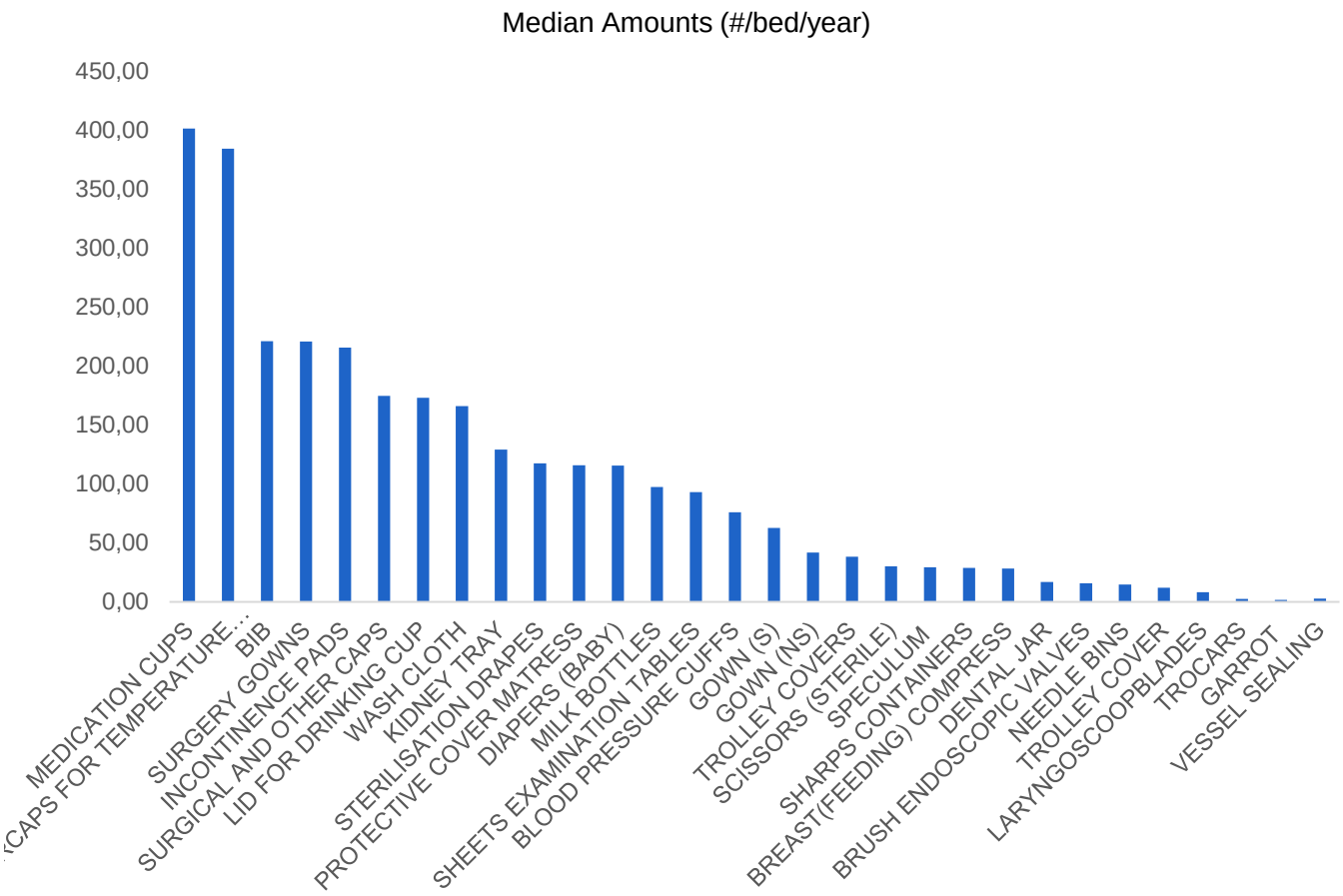
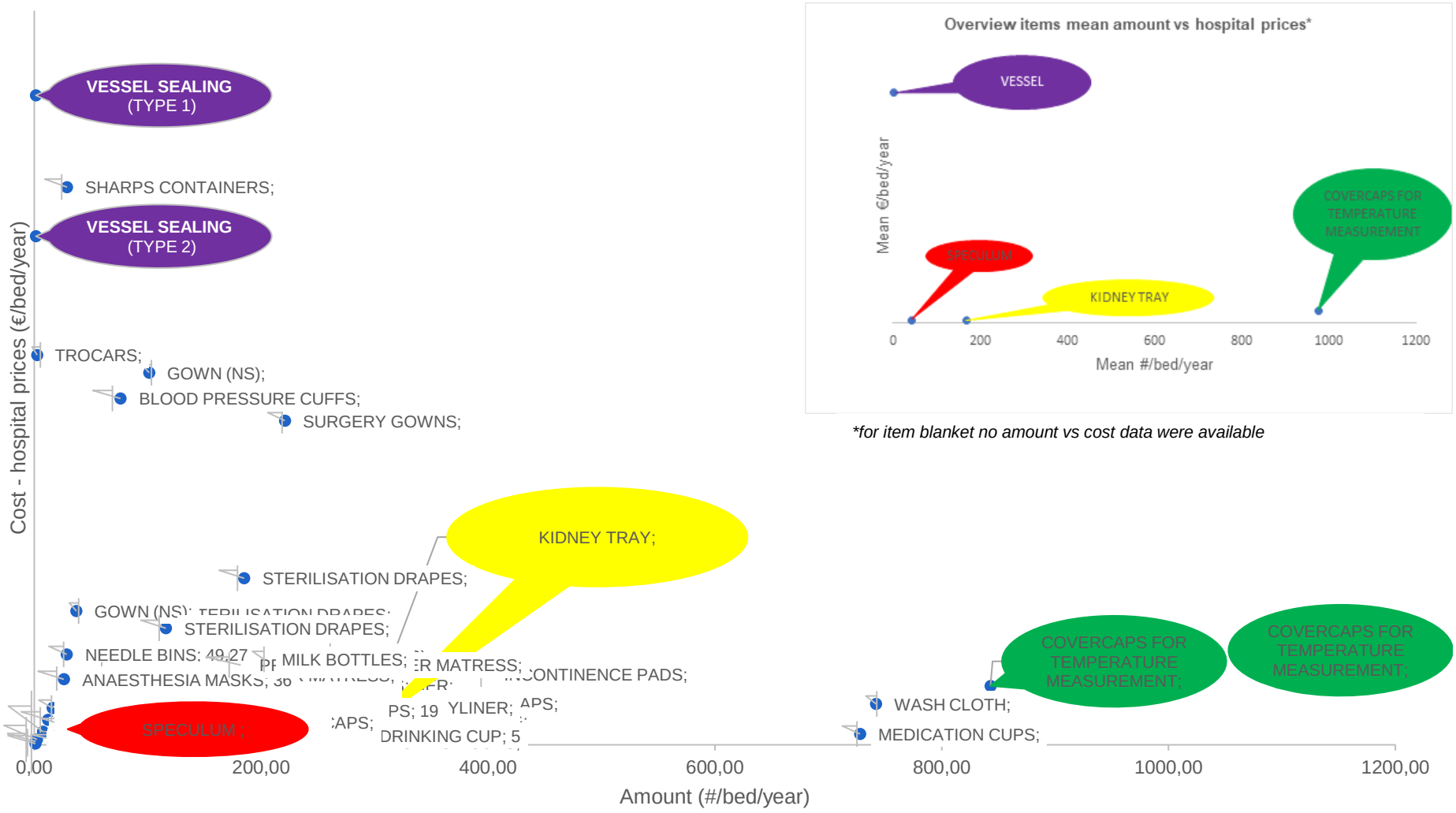


Figure 2: Median consumption rates (Amounts/bed/year)

Cost/amount rates of shortlist items based on hospital prices and catalogue prices were included in Figure 3 (below), and Appendix 9.10, respectively.



*for item blanket no amount vs cost data were available

Figure 3: Cost (hospital prices)/Amount of participating hospitals – rate 2019

4.3.2.3 Selection of items

The last step was selecting five items from the shortlist of 28 items. The selection was based on 1) one item was selected for each reuse process; and 2) the selection criteria listed in Figure 1 (and identical to the criteria used to compose the shortlist from the longlist). The five items were summarised in Table 15. For example kidney trays were included because of the high consumption rate, because possible alternatives would not raise additional safety concerns, and because several types of single-use and reusable trays exist (paper pulp, plastic, metal), where indications on which type of kidney tray is most sustainable can be of added value. For the speculum, the added value lies in preventing an ongoing shift from reusable to single-use, there are no additional safety issues, and limited results from studies are available on previous LCA's, to support conclusions. Thermometer cover caps were chosen because of their surprisingly but systematically high consumption in Belgian hospitals. Vessel sealers had, beside their high cost, also suspected large sustainability impact per device. The patient blanket has been included as example for a high amount of laundry items. A blanket is eminently an item with a very high volume per item, and alternatives do not pose any additional safety problems. The use of single-use blankets is not (yet) standard, therefore prevention of shifting from reusable to single-use may be possible.

Table 15: Overview of the five items with selection criteria

	Category	Consumption	Cost/item	Feasibility	Volume/item	Safety	Sustainability/item	Literature	Stakeholders input
Kidney tray	THERMAL DISINFECTION	x				x			x
Speculum	STERILISATION			x		x		x	
Thermometer cover caps	CHANGE OF ITEM/DEVICE	x							
Vessel sealer	STERILISATION (OR EQUIPMENT)		x				x		x
Patient blanket	LAUNDRY			x	x	x			

Furthermore, each item was selected for its potential to serve as an example for other items that belong to the same category.

5 FIVE SINGLE-USE MEDICAL ITEMS AND ALTERNATIVES

5.1 Goal

In this chapter, the five selected single-use medical items and their reusable alternatives were studied in order to identify the most sustainable and feasible option.

5.2 Methods

Four parameters of each item were studied: sustainability, safety, costs and efficiency (Kwakye et al. 2010; Siu et al. 2017). These criteria are also commonly used when purchasing medical material (Sherman et al. 2018; Klaske 2020).

To evaluate and compare the environmental burdens of medical devices (sustainability), conducting a life cycle assessment (LCA) is a well-known and established method (Schulte et al. 2021; Sørensen et al. 2022). However, conducting an LCA is a complex and time-consuming process. Therefore, it was decided to carry out an LCA of one item, namely a reusable and single-use vaginal speculum. The LCA is discussed in the next chapter. For the other four items, available information according to the life cycle stages of an LCA was collected (Hauschild et al. 2018; International Organization for Standardization 2022), but no full-level LCA was performed.

Relevant information included:

- Environmental sustainability:
    - The items were elaborated based on the frame of an LCA, namely raw materials, manufacturing, distribution, (re-) use, and end of life (disposal/recycling) (Hauschild et al. 2018; International Organization for Standardization 2022). As data on end-of-life were frequently not available in the ecoInvent Database, we focus on raw materials.
    - The carbon footprint or global warming was used, since it was the most used and developed parameter. Data from the ecoinvent Database 3.8 were used to quantify global warming, expressed in kg CO_2/kg raw material.
- Safety:
    - Focus on infection prevention (patient safety) and occupational safety (medical personnel).
- Costs:
    - Focus on purchase cost, reuse cost, and waste or recycling cost.
        - Purchase costs were based on price lists of 3 commercial suppliers (catalogue prices).
        - Reuse cost based on a theoretical estimation including labour cost
        - Waste or recycling cost based on average prices for healthcare institutions.
- Efficiency:
    - Focus on availability, handling, and time consumption to (re)use.

5.3 Results

5.3.1 Kidney tray

5.3.1.1 Description and Specification

Kidney trays (synonym: kidney dish, emesis basin) are often used for holding and transporting small medical devices (syringes, instruments, swabs, dressings, …) and for holding waste (e.g. soiled dressings, blood or other body fluids or other medical waste) arising from medical or nursing procedures. Sterile, as well as non-sterile kidney trays are used, the latter are widely consumed. We focus on both reusable and disposable non-sterile kidney trays. In practice, however, disposable kidney dishes are generally used (outside the operating room).

Kidney trays can be made of different materials (See Table 16).

Table 16: Most commonly used materials for kidney trays

Disposable	Reusable
Paper pulp with varying % recycled paper 	Stainless steel / inox 
Plastic polyethylene (PE) 	Plastic polypropylene (PP) 

5.3.1.2 Sustainability

Very little to no literature can be found on the sustainability of disposable and reusable kidney trays (Gabriel et al. 2018). Gabriel et al. (2018) studied four scenario's: Scenario 1: conventional kidney tray in high-density polyethylene (HDPE), Scenario 2: combination of selected bio-ethanol based (made from sugarcane) ethylene alternative with existing supply chain features to generate ecological impact estimates for a kidney tray made from bioplastic, Scenario 3: green supply chain management and improvements (product stewardship) and Scenario 4: combination bioplastic and green supply chain management and improvements (Gabriel et al. 2018). The results showed that scenario 2 switching to a bioplastic product has the lowest environmental impacts. Unexpectedly though, the product stewardship option had a more negative impact on the natural environment than the conventional HDPE option (See Table 17). The authors suggest there may be greater environmental gains to be obtained by focusing on one's core business (changing raw materials/manufacturing), than by extending influence across the supply chain (more sustainable supply chain options, e.g. transport) (Gabriel et al. 2018). Concerns regarding (bio)plastics were addressed in Appendix 9.11.

McGain et al. (2010) compared a single-use polyurethane with a reusable nylon drug tray, which is not identical to a kidney tray, however sufficiently similar to be included in this overview. The reusable drug tray was cleaned and thermally disinfected in a common washing machine (See Table 17). The single-use tray produced 15% more CO_2 and consumed three times the amount of water. Consequently, the authors concluded from their LCA that the environmental and financial benefits of a hospital switching to reusable drug trays are important. Producing the tray had a huge environmental impact for single-use trays, while for reusable trays, the thermal disinfection had the largest impact (McGain et al. 2010).

Table 17: Summary LCA's on trays

Reference	Objective LCA	Functional unit	Results
Gabriel et al (2018, Australia)	To assess how the new business model might affect the overall life cycle impacts of a reusable kidney dish *4 scenarios were compared: (1) HDPE tray, (2) bioplastic basin, (3) HDPE tray + green supply chain management and improvements, (4) bioplastic tray + green supply chain management and improvements*	Use of one plastic kidney dish (100g)	Global warming: no absolute figures are given, only graphs
McGain (2010, Australia)	To model the financial and environmental costs of reusable and single-use drug trays.	Use of one plastic anaesthetic drug tray *(RU: assuming 300 uses)*	Global warming SU: 126g CO_2eq vs.RU: 110g CO_2eq - SU: polyurethane tray: 111g CO_2eq , polyethylene wrap: 8g CO_2eq paper wrap: 3g CO_2eq , trucking: 3g CO_2eq , shipping: 1g CO_2eq - RU: nylon tray: 2 g CO_2eq , tray washing 99g CO_2eq „ tray drying 9g CO_2eq Water use SU: 3.1l vs RU: 10.3l

SU: single-use; RU: reusable; HDPE: high density polyethylene

Raw materials

The composition of the different types of kidney trays was extracted from the technical datasheets. In Table 18, the carbon footprint of each type of raw material is presented. The data sheets of the kidney trays do not always state the exact composition of the kidney tray e.g. what percentage of recycled paper the kidney dish consists of or what type of polyethylene. Properties and concerns about raw materials and its impact on sustainability are discussed in Appendix 9.11.

Table 18: CO_2 emissions of the raw materials of different types of kidney trays

	Raw material	CO_2 emission *(kg CO_2 eq/ kg raw material) **	Weight/kidney tray *(g)*	CO_2 emission/kidney tray *(kg CO_2 eq/ kidney dish)*
Single-use	Paper pulp ≥ 50% recycled paper	0,52	17 - 19	0,009 - 0.01
	Polyethylene (PE)** High density (HDPE) Low density (LDPE)	 2,29 2,45	9	 0,021 0,022
Reusable	Inox / stainless steel	4,73	130 - 250	0,62 - 1,18 -> per use 0,0006 – 0.001***
	Polypropylene (PP)	2,27	92	0,21 ->per use 0,0002***

Ecoinvent 3.8; **on the data sheet of the kidney tray type PE was not mentioned; * based on 1000 uses*

Based on 1000 uses, a reusable kidney tray in stainless steel or polypropylene generates obviously the lowest carbon footprint according to the CO_2 emissions of the raw materials.

Manufacturing

The production of kidney trays includes energy consumption during the manufacturing process (e.g. for plastic kidney trays: polymerisation, extrusion and injection moulding process), package manufacturing, the use of hazardous substances/chemicals e.g.,…(Gabriel et al. 2018).
Based on the Eionet Report regarding plastics, converting polypropylene and polyethylene in product causes a generally GHG emission of respectively, 0.94 kgCO_2eq/kg polypropylene and 1.13 kgCO_2eq/kg polyethylene (both HDPE or LDPE) (ETC/WMGE 2021).

Transport
The environmental impact of transport depends on fuel type (electricity, fuel, biofuel,…), the mode of transport (road, rail, shipping,...), vehicle type (size of truck,…) and the distance (Rondaij and Spreen 2020). The environmental impact is mainly due to the use of fossil fuels. This is not further explored because of the lack of data.

Use/Reuse
To reuse a kidney tray, it must be disinfected (See Safety – Infection prevention). According to the data sheet, a reusable plastic kidney tray is guaranteed to be autoclavable for 1000 cycles. Since sterilisation is not required in our application, they can last longer. Stainless steel materials are known to last a lifetime.

The environmental impact of thermal disinfection mainly includes the energy consumption and water consumption of the thermal washing machine. Rizan et al (2022b) calculated, that the carbon footprint of the subprocess of disinfecting a surgical instrument in a washer/disinfector was 0,016 $kgCO_2eq$ per instrument (Rizan et al. 2022b).

When the kidney tray is disinfected with a disinfection wipe, the environmental impact of the life cycle of a disinfection wipe needs to be taken into account. Based on the LCA study of Sanchez et al. (2020), the carbon footprint of manufacturing a disinfection wipe consisting of 1g of cotton substrate with active ingredient n-alkyl dimethyl ethylbenzyl ammonium chloride and isopropyl alcohol, was calculated to be 0.16 $kgCO_2eq$ per wipe, and the disposal (incineration) impact was calculated to be at 0.039 $kgCO_2eq$ per wipe. This results in a total emission of 0.20 $kgCO_2eq$ emission per wipe (Sanchez et al. 2020). This is a relatively high impact.

End of life / Waste
Depending on the soiling of the single-use kidney tray, it is sorted differently. If the kidney tray is filled with blood or body fluids, it must be sorted as Hazardous Medical Wase (HMW); if not, it can be sorted as Non-Hazardous Medical Waste (NHMW) (OVAM 2021) (See Figure 4).
Another possible option for specific paper pulp kidney trays is the use of a macerator, which disposes of human waste along with pulp based single-use containers such as bedpans, urinals and bowls. Cutter blades break the waste down into a fine slurry. This slurry is then deposited into the existing sewerage system. Depending on the type of macerator, there is a maximum load capacity of about 3 to 6 pulp products. The energy and water consumption of the macerator has to be taken into account.

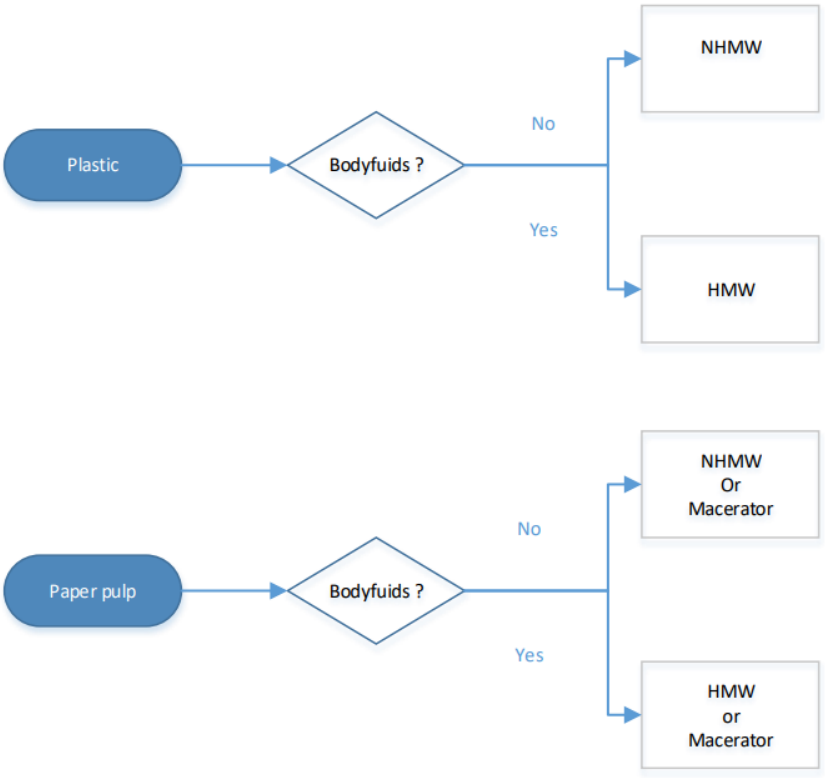


Figure 4: Waste sorting of single-use kidney dish

End-of-life reusable plastic kidney tray will also be discarded with the medical waste. The end-of life stainless steel kidney tray can be recycled. When incinerated, bottom ashes can be reused (Indaver 2022).

In summary, reusable kidney trays are more environmentally friendly than single-use kidney trays. However, the method of disinfection has also a considerable environmental impact.

5.3.1.3 Safety

Infection prevention

Single-use

The use of a new single-use kidney tray contains no risk of transmission of microorganisms.

Reusable

To reuse a plastic or inox kidney tray, disinfection is required. According to the Spaulding classification, a kidney tray is ranked as a non-critical item meaning that it comes at most in contact with intact skin but not with mucous membranes, hence, the sterility of items is 'not critical' (Rutala et al. 2008). Depending on the possibility of contact with blood or other body fluids: low-level disinfection is minimally advised. If (visibly) soiled with blood or body fluids, the kidney tray must be cleaned before disinfection, preferably consisting of thermal disinfection by an automatic washer (See Figure 5). To ensure the correct operation of the automatic washer, it is necessary to validate and monitor the automated disinfection process in accordance with the guidelines provided by the Belgian Superior Health Council (Hoge Gezondheidsraad 2023).

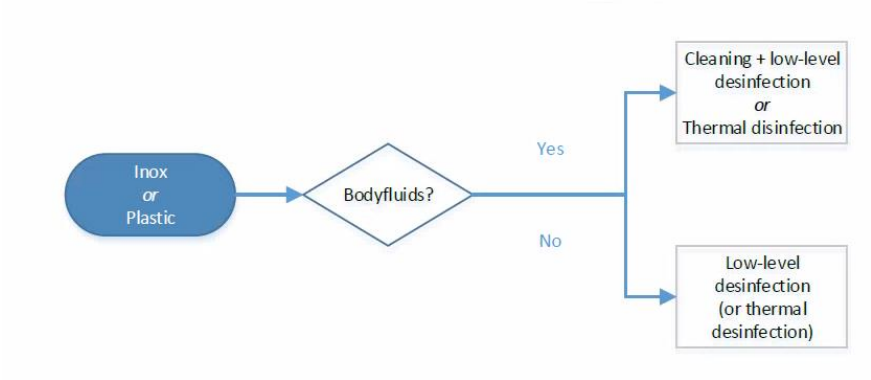


Figure 5: Disinfection options of a reusable kidney dish

Since a kidney tray is a non-critical item, the risk of transmission of micro-organism after disinfection of a reusable tray, is comparable of the risk using a single-use kidney tray.
Patient safety is ensured with both options.

Occupational safety

Commonly, handling a kidney tray involves no risk to the healthcare professional. When blood or body fluids are involved, there is biological risk. Further, disinfection of the kidney tray may involve a minor chemical risk (See Table 19).

Biological risk

When the kidney tray is filled with blood or body fluids, there is an occupational risk and must be handled as if it is infectious. Therefore, gloves are advised (European Commission. Directorate-General for Employment, Social Affairs and Inclusion 2011; Hoge Gezondheidsraad 2014). Attention should be paid when the kidney tray filled with body fluids is discarded as accidental splashing is possible. Personal protective equipment such as eye protection is advised. There is no difference between single-use or reusable trays.

Chemical risk

There is a possible chemical risk when using disinfectants. To reduce this risk, the use of thermal procedures is preferable to chemical disinfection and automated procedures are preferable to manual disinfection. In case of manual disinfection, gloves are indicated (European Commission. Directorate-General for Employment, Social Affairs and Inclusion 2011).

Table 19: Occupational risks associated with the use of single-use or reusable kidney tray.

	Single-use	Reusable
No blood or body fluids	No risk	No risk
Transport and handling kidney tray filled with blood or body fluids	Risk	Risk
Pouring out body fluids	Risk	Risk
Possible overturning	Risk	No risk
Patient with known infection/MDRO	Risk	Risk
Manual disinfection	NA	Risk
Thermal disinfection	NA	No risk

In summary, the patient safety and occupational safety of using a single-use or a reusable kidney tray is comparable.

5.3.1.4 Cost

The total cost of a single-use kidney tray includes the purchase and waste cost. The total cost of a reusable kidney tray includes purchase cost/total uses, and disinfection cost (Overview see Table 20).

Purchase cost

The range of purchase cost per type of kidney dish is presented in Table 20.

Table 20: Purchase cost (including VAT) per type of kidney tray

Single-use		Reusable		
	Per piece		**Per piece**	**Per use ***
Paper pulp	€0.12 - €0.26	**Inox / stainless steel**	€7.49 - €11.15	€0.0075 – €0.0112
Plastic	€0.17 - €0.20	**Plastic**	€2.55 - €10.25	€0.0026 – €0.0103

based on 1000 uses (data sheet reusable plastic kidney tray)

Reuse cost

The reuse cost may comprise manual or thermal disinfection (See Infection prevention above).

Manual disinfection cost

The cost estimation includes the cost of the disinfection product and labour cost (See Table 21):

- Disinfection wipes: ± €0.06 – 0.16 per wipe
- Disinfection spray (750ml) + cloth:
  - Spray: ± €10 (estimated 3ml / spray) -> €0.08 (based on 2 sprays)
  - Cloth: ± €0.013 - 0.2 (disposable – reusable cloth)
- Labour cost:
  - Calculated for a logistic assistant and a nurse based on data from the KCE study Manual for cost-based pricing of hospital interventions (Swartenbroekx et al. 2012). As these data were from 2012, results have been indexed by a factor of 1.3076 (wage index March 2012= 1.5769, wage index June 2022 1.8845) resulting in a cost per hour of €37.50 - €47.46
  - Labour time: 30 seconds

Thermal disinfection cost

The cost of thermal disinfection was calculated on the basis of a simulation costing from the Central Sterilisation Department of het Ghent University Hospital. The cost was estimated at € 0.40 including direct labour cost, energy, capital goods and building infrastructure, and auxiliary materials.

Waste cost

Depending on how waste has to be sorted, the cost varies. If the kidney tray is filled with blood or body fluids, it must be sorted as HMW; if not, than it is sorted as NHMW (OVAM 2021).

Based on an average cost of waste treatment, the cost for

- NHMW is €202 per ton
- HMW is €780 per ton

Another possible option for specific paper kidney tray is the use of a macerator, which disposes of human waste along with pulp based single-use containers such as bedpans, urinals and bowls. Cutter blades break the waste down into a fine slurry. This slurry is then deposited into the existing sewerage system. Costs associated with using the macerator are mainly electricity and water.

Based on a consumption of 1000 kidney trays, the total cost of reusables is higher than the single-use tray, due to disinfection and labour cost. McGain et al. (2010) modelled the financial costs of a reusable and single-use plastic anaesthetic drug trays based on an LCA. Their results indicated that the total cost of one single-use tray (Australian $0.47) was twice as much as a reusable one including thermal disinfection (Australian $0.23).

The total waste cost calculation per piece is stated in Table 21.

Table 21: Overview of the costs related to the use of a single-use or reusable kidney tray

	Single-use				Reusable			
	Paper pulp		Plastic		Inox		Plastic	
Purchase cost / piece	€0.12 - 0.26		€0.17 - 0.20		€ 0.0075 – 0.0112		€ 0.0026 – 0.0103	
Type of disinfection					Manual	Thermal	Manual	Thermal
Disinfection cost / piece					€0.06-0.16	€0.40***	€0.06-0.16	€0.40***
Labour cost *					€0.31-0.40		€0.31-0.40	
Type of waste	NHMW	HMW	NHMW	HMW				
Waste cost / piece	€0,0034 - 0,0038	€0,0133 - 0,0148	€0,0018	€0,0064				
Waste cost bag or barrel/piece**	€ 0.0015	€0.07-0.09	€0.0015	€0.07-0.09				
TOTAL	€0.13 - 0.27	€0.20-0.37	€0.17-0.20	€0.28-0.30	€0.38 - 0.57	€0.41	€0.37-0.57	€0.40-0.41

** based on a labour time om 30 seconds of a logistic assistant and a nurse , **based on 100 kidney trays per bag or barrel*
**** Estimation Central Sterilisation Department of het Ghent University Hospital*

In summary, the overall cost of using a reusable kidney tray is generally higher than that of a single-use kidney tray, mainly due to the cost associated with disinfecting the kidney tray.

5.3.1.5 Efficiency

Availability

There should be sufficient stock on the ward. The single-use kidney tray requires multiple steps for ordering and delivery which are largely administrative: place order, arrival order, items move to storage warehouse, ward places order, order delivered to ward (Conrardy et al. 2010). In contrast, using reusable kidney trays demands no supply purchase and inventory process. Either way, sufficient stock space is needed.

Additionally, there should also be sufficient disinfectant material either disinfectant or an automated washing machine. A consideration regarding thermal disinfection is that a standard nursing unit is not equipped with an automated washing machine. The most practical and logistically feasible is to have a washing machine on the ward. It is imperative not to charge central sterilisation with supplementary thermal disinfection of material.

Handling

Handling of a reusable or a disposable kidney dish is fairly identical (See Table 22). The main difference is the handling after use as already discussed above for single-use (See Sustainability – End of Life) and reusable (see Safety – Infection prevention). This has implication towards time consumption (See below).

A risk associated with using a disposable paper pulp kidney tray is the potential for leakage if moisture remains in the paper pulp kidney dish for an extended period of time (>4 hours).

In general, it is obvious that single-use kidney trays are less robust in comparison to their reusable alternatives.

Time consumption

Using reusable kidney trays demands addition labour time of the healthcare professional to decontaminate manually, this is less the case with thermal disinfection. Considering the consumption of kidney trays is high, this will require an extra time investment of approximately 30 seconds per kidney tray.

Table 22: Overview on efficiency of using a reusable and single-use kidney tray

	Single-use	Reusable
Availability	Sufficient stock: supply ordering	Sufficient stock Need for disinfection equipment
Handling	Disposed**:** - Plastic: NHMW or HMW - Paper pulp: NHMW or HMW *or* in macerator	Disinfection: - Manual - chemical - Automated thermal
Time-consumption	Time disposal <	Time disinfection Manual disinfection is more time consuming for healthcare professionals than thermal disinfection

In summary, the efficiency of a single-use kidney tray is advantageous compared to a reusable kidney tray, primarily due to the time-consuming process of disinfection.

5.3.1.6 Conclusion on kidney trays

Based on the available data, it seems that reusable kidney trays are more environmentally friendly. However, the method of disinfection has also an environmental impact as well as a large impact on cost. The safety is comparable, whereas the efficiency might be in favour of the single-use kidney tray based on the time consumption.

5.3.2 Blanket

5.3.2.1 Description and specification

The Textile Institute defines medical textiles as textile structures designed and produced for use in any of a variety of medical applications, including implantable applications (implantable medical textiles) (The Textile Institute 2023). Medical textiles can be woven, knitted, braided, or non-woven structures, depending on the application and can include both natural and synthetic fibres. Synthetic fibres are predominant in medical textiles – including 100% synthetic fibres such as polyester and polypropylene – whilst cotton is the most popular natural fibre. The type of fibre depends on the specific end-use properties (Health Care Without Harm Europe 2021b; Martínez-Barbosa and Moreno-Corral 2022). In disposable textiles, often several layers of different nonwoven fibres are thermally bonded, e.g. SMS (Spunbond/Meltblown/Spunbond) or SMMS (Spunbond/ Meltblown/Meltblown/Spunbond).

Medical textiles are divided into several categories. Blankets (bedding) are included in the group of healthcare and hygiene products (Health Care Without Harm Europe 2021b; Martínez-Barbosa and Moreno-Corral 2022).
Disposable blankets are generally made from a combination of polypropylene and polyester and reusable blankets from polyester and/or cotton (See Table 23).

Table 23: Most commonly used materials for blankets

Disposable	Reusable
Polypropylene + Polyester 	Cotton + Polyester 
	Cotton 

5.3.2.2 Sustainability

LCA's that studied the environmental impact of single-use and reusable blankets were not found. However, there are several LCA's on other medical textiles such as surgical gowns and isolation gowns (See Chapter 2). These studies found that reusable textiles gave significant environmental benefits compared to single-use textiles (Vozzola et al. 2018a, b, 2020).

Raw materials
The composition of the different types of blankets was extracted from the technical datasheets. In Table 24, the carbon footprint of each type of raw material is presented. Properties and concerns about medical textiles and its impact on sustainability are discussed in Appendix 9.11.

Table 24: CO2 emissions of raw materials of different types of blankets

	Raw material	CO_2 emission *(kg CO_2 eq/ kg raw material)*	Weight/ blanket *(g)*	CO_2 emission/blanket *(kg CO_2 eq /blanket)*	CO_2 emission/use *(kg CO_2 eq/use)*
Single-use	Polypropylene (50%) Polyester (50%)	2,27 4,01	300 g	0,34 + 0,60 = 0,94	0,94
	Polypropylene (25%) Polyester (75%)	2,27 4,01	332 g	0,19 + 1,00 = 1,19	1,19
Reusable	Cotton (50%) Polyester (50%)	4,37 4,01	1950 g	4,26 + 3,91= 8,17	0,09**
	Cotton (100%)	4,37	1568 g	6,85	0,08**

** EconInvent 3.8, ** Based on 90 reuses (data from laundry)*

Per use, the carbon footprint of the raw materials of a reusable blanket is about one tenth of that of a single-use blanket.

Manufacturing

The production of blankets (and its packaging) includes

- Energy consumption (fabric and blanket manufacturing)
- Use of hazardous substances/chemicals e.g. dyes, bleach, flame retardants, …

Based on LCA's on other medical textiles such as surgical or isolation gowns (Vozzola et al. 2018b, 2020), manufacturing reusable blankets requires an increased energy consumption due to the weight difference and the increased energy requirement of woven textile processes. However, the number of times the blanket can be reused must be taken into account.

Transport

The environmental impact of transport depends on fuel type (electricity, fuel, biofuel,…), the mode of transport (road, rail, shipping,...), vehicle type (size of truck,…) and the distance (Rondaij and Spreen 2020). The environmental impact of transport is not further explored because of the lack of data.

Use / Reuse

The major difference in the life cycle of reusable and disposable blankets is that reusable blankets are laundered after each patient use. The laundry process consists generally of a prewash, main wash, rinse, spin or pressing, drying and packaging. This process must be sufficiently disinfecting so that all pathogenic microorganisms responsible for healthcare-associated infections are eradicated (Hoge Gezondheidsraad 2018) (See Safety – Infection prevention).

The Belgian Superior Health Council defined physical criteria for reusable linen. Namely, the mechanical wear is compatible with an average lifetime of the textile of at least 100 washes. A maximum of no more than 15% of the textile is lost at the end of use (Hoge Gezondheidsraad 2018).
According to Martinez-Barbosa and Mereno-Corral (2022), reusable garments generally can be used for 50 or more washing and drying cycles (Martínez-Barbosa and Moreno-Corral 2022). The number of laundering/drying cycles is sometimes suggested by the manufacturer, e.g. for the cotton (50%) and polyester blanket (50%) it is 90 times. Some fibres are more durable than others: polyester or a polyester/cotton mix can survive more laundry cycles than 100% cotton (Watson and Fisher-Bogason 2017).

The laundry process of reusable blankets has the largest environmental impact of its life cycle (Kofoworola et al. 2020) due to following processes:

- Energy consumption (electricity, gas, …) / GHG emissions
  - The weight of the blanket differentiate the overall energy consumption.
  - Type of energy
- Water consumption
- Chemical consumption (laundry products: e.g. phosphate-free surfactants, enzymes, oxidants, optical brighteners, solvents and disinfectants): emissions to water.

- Washing may release microplastics when using synthetic fibres into wastewater (Health Care Without Harm Europe 2021b).
- Transport (external laundry)

Waste

A single-use blanket and its plastic packaging will normally be disposed of as NHMW and is incinerated (OVAM 2021). The size of the blanket determines the volume of waste.

Since single-use blankets consist of different types of material (PP, polyester), recycling is not possible.

In summary, the environmental impact of single-use textiles will be the highest during the production and disposal phase, while for reusable the impacts will be towards the (re)use phase (= laundry). As with reusable gowns, the environmental savings reached from producing fewer blankets compensate the additional burden of the laundry process.

5.3.2.3 Safety

Infection prevention

Single-use

The use of a new single-use blanket contains no risk of transmission of microorganisms.

Reusable

Blankets are replaced and washed after every patient discharge and, in case of long-term admission, e.g. weekly. All textiles visibly soiled with body fluids or blood are replaced immediately. Good practice for proper linen handling, such as the frequency of replacement has been described before (Hoge Gezondheidsraad 2018).

The laundry is preferably done by the use of thermal decontamination. An A_0 value, which is a physical parameter denoting the inactivation of microorganisms (Röhm-Rodowald et al. 2013), of at least 600 is required . If the value is not met, chemical disinfection during the washing process is necessary in order to achieve this requirement (Hoge Gezondheidsraad 2018).

The Belgian Superior Health Council advises the laundry management to function according to the European RABC standard NBN EN 14065 which describes how the laundry can guarantee the microbiological quality and safety of the linen. The total number of microorganisms on the ready-to-use textile must be less than 12 CFU (colony forming unit) per 25 cm^2 (AFNOR standard - France; NBN EN 14065) (Hoge Gezondheidsraad 2018).

Occupational safety

Commonly, handling a blanket involves no or minimal risk to the healthcare professional. Though, when blood or body fluids are involved, there is biological risk. These risks are identical when using reusable as well as disposable blankets.

Biological risk

When a blanket is soiled with blood or body fluids, there is a well-known occupational risk and must be handled accordingly. Therefore, gloves are advised (European Commission. Directorate-General for Employment, Social Affairs and Inclusion 2011; Hoge Gezondheidsraad 2014).

Chemical risk

Professionals working in a laundry must be careful with laundry disinfectants which often have corrosive or irritant properties, and in addition they may act to sensitise skin or respiratory tracts (European Commission. Directorate-General for Employment, Social Affairs and Inclusion 2011). When in contact with these disinfectants protective personal equipment is advised (gloves, respiratory mask, goggles).

In summary, the patient safety and occupational safety of a single-use and a reusable blanket are similar.

5.3.2.4 Cost

Purchase cost

Depending on size, composition and supplier, the purchase cost of disposable blankets may vary (See Table 25).

Reuse cost

Because of the strict regulations and conditions for a laundry, most hospitals outsource their laundry process for (bed) linen. In practice, a lease is often agreed with a rental price per item for the hospital (See Table 25).

Table 25: Purchase/rental cost (including VAT) per type of blanket (per piece/use)

Single-use		Reusable	
	Per piece		**Per use**
Polypropylene + polyester	€2.50 - €7	**Cotton + polyester**	€ 2.30 - €3.50

If a hospital itself has a laundry the reuse cost includes energy, water use, cost of the employees, and associated costs. Then, the purchase cost of a blanket needs to be divided by the number of uses during the lifetime of a blanket.

Waste cost

A single-use blanket will normally be disposed of as NHMW. Since blankets are very bulky, they take up a lot of space in the waste bag. The waste cost is presented in Table 26.

Table 26: Overview total cost (including VAT)

	Single-use	Reusable
Purchase cost / piece	€2.50 - €7	
Laundry cost / piece		€ 2.30 - € 3.50
Waste cost / piece	€0.06	
Cost bag / piece	€ 0.08*	
TOTAL	€2.64- €7.14	€2.30 – 3.50

**based on 2 blankets per waste bag*

Reusable blankets are packaged in plastic (e.g. per 5, 10 or 20), while single-use blankets are packaged in plastic per blanket and in cardboard (e.g. per 20, 50 or 100 blankets). As this depends on the laundry (reusable blankets) or company (single-use blankets) no uniform data were available. In general, the packaging waste will be more for single-use compared to reusable blankets. The cost to discard the packaging materials is not taken into consideration.

The total cost to the hospital is more expensive for a single-use blanket than for a reusable one.

5.3.2.5 Efficiency

Availability

Both types of blankets require an ordering and delivery procedure from either a laundry or medical equipment supplier. In both cases, sufficient stock space is needed. Note that reusable blankets take up more space than disposable blankets, considering their volume and packaging method (See Table 27).

Handling

The ease of use of blankets is similar. When comparing reusable versus single-use medical garments, reusable healthcare garments come out on top because reusable medical textiles meet the same safety standards and are more comfortable than their disposable counterparts (Martínez-Barbosa and Moreno-Corral 2022).

The handling of the blankets is quite identical. After use, a reusable blanket is thrown into the linen bag, while a single-use is discarded with the medical waste (NHMW). Both are picked up by logistic staff.

Time consumption

If the laundry process is outsourced, there will be similar time consumption for both options. Namely, a reusable blanket is thrown into the linen bag and then picked up by the logistics service, while a single-use is discarded with the medical waste (NHMW).

If the hospital has its own in-house laundry, a large time investment has to be taken into account. Then, all steps of the laundry process are done by the hospital itself: sorting, prewash, main wash, rinse, spin or pressing, drying and packaging.

Table 27: Overview on practical matters of using a reusable and single-use blanket

	Single-use	Reusable
Availability	Sufficient stock: supply ordering	
Handling	Disposed as waste	Disposed in linen bag - and washed in (external) laundry
Time consumption	Time disposal waste bag = *or* <	Time disposal linen bag Hospital in-house laundry: large time investment

In summary, the efficiency of a single-use or a reusable blanket is comparable. If a hospital has its in-house laundry, then the time investment required for the laundry process must be taken into account.

5.3.2.6 Conclusion on blankets

In summary, sustainability and cost favour the use of reusable blankets. Safety and efficiency are similar, unless the hospital has its own laundry. If the hospital has its own laundry, the efficiency is less favourable.

5.3.3 Vessel sealing device

5.3.3.1 Description and Specification

Laparoscopic surgery, as a minimally invasive treatment, has experienced rapid growth. Accurate haemostasis, the process of preventing and stopping bleeding, is of utmost importance in laparoscopy, as bleeding can quickly compromise the working environment conditions. The sealing of blood vessels is effected by application of, for example, controlled radiofrequency energy while the vessel is compressed, and the vessel is cut via movement of a knife under a consistent shear. The most frequently employed vessel sealing devices are bipolar devices (consisting of an active electrode and a return electrode into a single electrosurgical instrument with two small poles) or ultrasonic devices. Bipolar vessel sealing devices typically utilise electric current (occasional a battery), while ultrasonic devices employ high-frequency vibrations (Hasanov et al. 2018; Kawaguchi et al. 2020).

Examples of a single-use vessel sealing devices

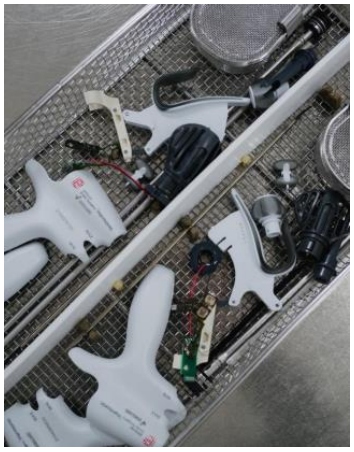
The surgical devices are complex and diverse. Various sealing devices are available with differences in parameters such as shaft length, shaft rotation, seal plat length, cut length, seal plate width, etc. A reusable device comes often with disposable blades.

Two studies compared a new reusable vessel sealing device with a conventional standard single-use device. The studies were not LCA's, but rather focused on efficacy and costs. In an older study, Klar et al (2011) conducted a prospective animal study to compare the efficacy of sealing time, failure rate, and burst pressure between a new reusable vessel sealing device and a conventional standard disposable vessel sealing device (Klar et al. 2011). Kawaguchi et al. (2020) compared in a retrospective study a single-use and a reusable vessel sealing device in modified total neck dissections at a Japanese hospital, with focus on haemostasis, surgical time and medical expenses. No LCA's comparing the environmental sustainability of single-use and reusable vessel sealing devices were available.

5.3.3.2 Sustainability

Raw materials

Vessel sealing devices are complex and primarily composed of a combination of metals (e.g. titanium, stainless steel) and plastics (e.g. poly(phenyl sulfone, poly(tetra fluoro-ethylene (PTFE), polycarbonate, polyamide) as depicted in the figure below (Yung et al. 2010). Some single-use devices have single-use transducer cables, while other cables are sterilisable. Due to the lack of information provided in data sheets and companies' reluctance to disclose the exact composition of these devices, it was not possible to provide a comprehensive overview of all the raw materials included and their associated CO_2 emissions .



Example of various parts of
a vessel sealer/cutter (Vanguard 2023)

From studies conducted on analogue medical devices, such as surgical staplers and clip appliers, it is highly probable that reusable vessel sealers devices are more sustainable (Meissner et al. 2021; Rizan and Bhutta 2022) (See Chapter 2).

Transport

The environmental impact of transportation is influenced by factors such as the fuel type used (electricity, fuel, biofuel, etc.), the mode of transport (road, rail, shipping, etc.), the type of vehicle type (size of truck, etc.) and the distance travelled (Rondaij and Spreen 2020). The primary contributor to the environmental impact is the use of fossil fuels.
Exploration of the environmental impact of transportation is limited due to a lack of available data.

Use/reuse

A reusable vessel sealer can generally be reused 50 times, as warranted by the manufacturer (Kawaguchi et al. 2020). The device requires a sterilisation process including cleaning, thermal washing/disinfection, and sterilisation (See Safety – Infection prevention).

Another option is to remanufacture the single-use vessel sealer. Medical remanufacturing can restore a used single-use medical device to its original functional and safety standards, with a matching warranty (Vanguard 2023). This process involves disassembly and assembly steps, cleaning, decontamination, testing and sterilisation (Schulte et al. 2021; Rizan et al. 2022a). After remanufacturing, the vessel sealer can be reused for a limited number of cycles.
In Europe, remanufactured medical devices must comply with CE certification and meet the requirements of the Medical Device Directive 93/42/EEC (Schulte et al. 2021).

Remanufacturing electrophysiology catheters is a well-established process that ensures equal quality compared to newly produced catheters. An LCA study revealed that using remanufactured catheters reduced the global warming impact by 50.4% compared to single-use catheters (Schulte et al. 2021). Similarly, in their LCA Meister et al (2023) calculated a reduction of 60% (Meister et al. 2023).

Remanufacturing requires cleaning, disinfection and sterilisation before reusing (ethylene oxide sterilisation for remanufactured and steam sterilisation for reusable vessel sealers). No data were available in the literature on the ecological impact of this sterilisation process for reusing vessel sealers.

Remanufacturing of these medical devices takes place outside Belgium. It is allowed to transport used vessel sealers to the company provided the devices are correctly packed and labelled according to the conditions mentioned in the European Agreement concerning the International carriage of Dangerous Goods by Road (ADR) (United Nations Economic Commission for Europe 2022).

Waste

Single-use vascular sealing devices are disposed as hazardous medical waste, requiring high-temperature incineration.

Both single-use and remanufactured vessel sealers involve significant packaging, including hard plastic protection and a cardboard box. Unger and Landis (2016) concluded that the high levels of polyethylene in the single-use vessel sealing device and its packaging contribute significant to environmental impacts (Unger and Landis 2016).

In summary, using reusable or remanufactured vessel sealers is more beneficial for the environment than using single-use vessel sealers.

5.3.3.3 Safety

Infection prevention

Since a vessel sealing devices comes into contact with sterile body tissues or the vascular system, it is considered a critical item according to the Spaulding classification and needs to be sterile (Rutala et al. 2008).

Single-use

The use of a single-use sealing device carries no risk of microorganisms transmission as the device is sterilised by the manufacturer, often using ethylene oxide.

Reusable

To reuse a vessel sealer, the device requires a sterilisation process. In the central sterilisation department, the reusable vessel sealing device undergoes cleaning including an ultrasonic bath, thermal disinfection in the washing machine, and steam sterilisation. However, the complex structure and multiple parts of the vessels sealer make cleaning challenging. Additional auxiliary tools, such as single-use cleaning brushes, may be necessary. Moreover, the cleaning process is performed manually because the use of a washing machine may not provide sufficient contact between the water, disinfecting products, and the device as demonstrated by Chivukal (2021) (Chivukula et al. 2021).

As a rule, the reprocessing of reusable and the remanufacturing of devices occurs under highly controlled strict standard conditions in the central sterilisation departments or in the medical remanufacturers compagnies. Consequently, if the reprocessing process is caried out properly, there is no risk of micro-organism transmission.

Occupational safety

Biological risk

As the vessel sealing device comes into contact with blood during the surgical procedure, there is a potential occupational risk associate with its handling. This risk applies for the different types of vessel sealers.

This risk persist for a longer duration with reusable devices, as they need to be transported to and manipulated in the central sterilisation department. Transportation process itself involves no risk, as the device needs to be collected in a closed transportation box. For the manipulation in the central sterilisation department, the professionals need to wear PPE (protection gown, gloves, goggles, mask) when manual disassemble and clean the device to protect them from splash accidents (European Commission. Directorate-General for Employment, Social Affairs and Inclusion 2011).

Chemical risk

There is a possible chemical risk when using disinfectants. Instrument disinfection may lead to inadmissible indoor air concentrations if manual disinfection is applied, and also with ultrasonic baths cleaning. Therefore, the use personal protective equipment, such as respiratory mask, is indicated (European Commission. Directorate-General for Employment, Social Affairs and Inclusion 2011).

In summary, if the cleaning and sterilisation process is performed properly. the patient safety of using single-use, reusable or remanufactured vessels sealers is comparable. Regarding occupational safety, personal protective equipment is required for the sterilisation process.

5.3.3.4 Cost

Klar et al. (2011) found that the cost for a single-use vessel-sealing device was $500, while the cost for a reusable instrument was $130. Another study on small vessel sealing devices compared a reusable, costing $240 per operation, to a single-use costing $1000 (Kawaguchi et al. 2020). However, both studies did not include the cost of cleaning and sterilisation of the reusable vessel sealing device, but did include the cost of single-use blades in the reusable device.
Hasanov et al. (2018) calculated a cost of approximately €420 for a single-use and €182 for a reusable vessel sealer, including the cost of disposable blades (€98 per blade) and the cost of cleaning and sterilisation (€10 per procedure).
Yung et al (2010) compared the costs of a reusable ultrasonic shear (including purchase price of 4 shears, number of uses, manual cleaning, sterilisation costs) to a single-use ultrasonic shear (including purchase price of 85 shear and reprocessing cost transducer cable). Based on their data (using a shear for 85 cases), the cost for one use of the reusable ultrasonic shear was $280, while the cost for the single-use was $384.

Purchase cost

The cost data are presented in Table 28.

Remanufactured medical devices are estimated to be up to 50% cheaper than new single-use ones. Additionally, the hospital receives compensation for each collected functioning vessel sealer that can be remanufactured (Vanguard 2023).

Reuse cost

The cost of reuse includes sterilisation expenses (See Table 28), which can vary depending on the study and may encompass labour costs (disassembly, cleaning, reassembly) as well as energy costs. In certain studies, additional costs associated with reuse, such as repair and maintaining expenses, are also taken into account.

Waste cost

Single-use vascular sealing devices are discarded as HMW. Based on an average cost for HMW (€ 780 per ton), the waste cost related to one device (+/- 300 gr) is €0.21 (waste barrel not included). The waste cost per piece is stated in Table 28. It should be noted that a single-use vessel sealing device involves considerable packaging: cardboard box and hard plastic protection (Unger and Landis 2016). The cost to discard the latter is not taken into consideration.

Table 28: Overview total cost

	Single-use	Reusable	*Remanufactured*
Purchase cost	€500 - €700	€120-170 €** *(including disposable blades)*	€250-350
Waste cost (HMW)/piece	€0.21		- € 5-€10+
Cost waste barrel/piece*	€0.7-€0.9		
Total sterilisation cost		€10-€30 ***	
TOTAL	€501-701	€130–200**	€240-345

** Based on 10 vessel sealers per barrel*
***Reusable vessel sealers (€3700 - €4900 per device and €33 - €100 per disposable blade) can be used (minimum) 50 times (Hasanov, 2018; Klar, 2011) -> +/- €120 - €170 per use*
**** Based on Hasanov, 2018, Rizan et al. 2022 and calculation Ghent University Hospital*
+ The hospital receives an amount of money per functioning devices (estimation €5-10)

It can be concluded that reusing a vessel sealer generally results in cost savings compared to using a single-use vessel sealer. However, it is important to ensure that when comparing two devices, that they are of the same type and have the same functions.

5.3.3.5 Efficiency

Availability

Both types of vessel sealing devices require an ordering and delivery procedure from either the central sterilisation department or medical equipment supplier. However, the single-use and remanufactured device require a few more steps than the reusable device such as placing order to supplier, arrival order, items move to the storage operating room (Conrardy et al. 2010). Either way, sufficient stock space is needed. A sufficient number of reusable instruments, transducers (or loaded batteries) are needed so that the required ready-to-use vessel sealers are available (Conrardy et al. 2010).

Handling

After use, the reusable vessel sealing devices is collected in a washable container and transported to the central sterilisation department, while a single-use device is discarded as HMW. Single-use devices that will be remanufactured are also collected separately and undergo a separate logistic process.

Time consumption

A single-use vessel sealer is discarded as HMW, while a reusable is collected into a container and then picked up by the logistics service. Using a reusable vessel sealing device requires thorough washing, disinfection, packaging and sterilisation which implies additional labour time of the hospital (Kawaguchi et al. 2020). This demands an extra time investment from the central sterilisation department.
A vessel sealer used for remanufacturing should to be collected and labelled separately and is send to the company.

Table 29: Overview on practical matters of using a reusable and single-use vessel sealing device

	Single-use	Reusable	Remanufactured
Availability	Sufficient stock: supply ordering - More administration - More space needed	Sufficient stock: supply ordering - More space needed	Sufficient stock: supply ordering - More administration - More space needed
Handling	Disposed as hazardous medical waste	Collected in transport container	Collected and labelled in separate transport container
Time consumption	Time disposal waste bag <	Time sterilisation process	Time to collect, label and send

In summary, the most efficient alternative is the single-use vessel sealer due to its disposal after use, eliminating the need for disinfection.

5.3.3.6 Conclusion

Using reusable vessel sealers or remanufactured is more beneficial for the environment. Patient safety is comparable if cleaning and sterilisation is adequately completed. Using reusable and remanufactured vessel sealers is cost saving. The efficiency is in favour of the single-use sealer because of the time investment for sterilisation and the separate collecting process for remanufactured devices.

5.3.4 Cover caps for thermometers

5.3.4.1 Description and Specification

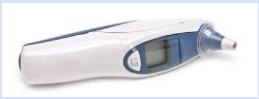
The use of cover caps is standard when **non-invasive** tympanic (ear) thermometers are used. These cover caps were found to account for a large proportion of single-use material consumption in Belgian hospitals (See Chapter 4). Although some of the cover caps are made from rigid plastic and could allow multiple use in the same patient, no reusable cover cap alternatives are available on the market for use between different patients.

Therefore, searching for more sustainable alternatives for single-use cover caps in tympanic thermometers needs to include the comparison with other thermometers available on the market. For this item we will focus on the additional material needed to use several types of thermometers in different patients.

In addition to tympanic thermometers, axillary thermometers, temporal thermometers, and frontal non-contact thermometers are available (Cutuli et al. 2018). In this section, we will focus on non-invasive temperature measurement and the additional materials needed to use them in different patients (See Table 30).

Example of a cover cap

Table 30: Overview of types of thermometers for non-invasive measurement

Ear/tympanic	Axillary thermometer	Temporal scanner	Frontal non-contact
 			
Remote ear thermometers, also called tympanic thermometers, use an infrared ray to measure the temperature inside the ear canal	Temperature measurement in the armpit, or rectal. The latter is the most used method for temperature measurement in infants and children.	Remote forehead thermometers use an infrared scanner to measure the temperature of the temporal artery in the forehead.	Remote thermometer based on infrared energy radiated from the forehead as well as objects, to measure body temperature and surface temperature.

5.3.4.2 Sustainability

No LCA's on the environmental impact of the use of cover caps in the measurement of body temperature, nor a comparison of the environmental impact of different thermometers were available. We will focus on the use of extra materials needed for using the different systems (see overview below - Table 31), rather than on the different types of thermometers itself.

Table 31: Materials needed to (re)use thermometers

	Ear/tympanic 	Axillary thermometer 	Temporal scanner 	Frontal non-contact 
Materials needed for reuse	Cover cap for every use. *(Patient- specific use of cover cap may be possible for some types of cover caps)*	Disinfection (wipe) between two patients *(Plastic cover is available, but rarely used)* *(Patient – specific use is possible)*	Disinfection (wipe) after use	No additional materials are needed for general use

The raw materials of the supplementary items needed when using the various thermometers with different patients are shown in Table 31 above.

Raw materials

Table 32: CO2 emissions of raw materials of different types materials needed to (re)use thermometers

	Raw material	CO_2 emission *(kg CO_2 eq/ kg raw material) **	Weight/cover cap or wipe *(g)*	CO_2 emission/use *(kg CO_2 eq/ kg raw material) **
Cover cap	 Type 1: low density polyethylene (LDPE)	2,45	0.40g	0.001
	 Type 2: polyethylene (PE)	2,29	1.42g	0.003
Wipe	Cotton	4,37	1.00g **	0.16**
	n-alkyl dimethyl ethylbenzyl ammonium chloride Isopropanol Isopropanol	Not available	0.02 g** 2.3 g**	

** EconInvent 3.8; ** Based on (Sanchez et al. 2020)*
LDPE: Low density polyethylene; PE: Polyethylene

From Table 32, the use of a wipe gives a carbon footprint more than 53 times the carbon footprint of the raw materials needed for a cover cap. When using a non-contact thermometer no additional materials are needed.

Manufacturing

The production of cover caps and wipes should include the manufacturing of the caps and wipes, as well as the manufacturing packaging. Energy consumption during manufacturing, and use of hazardous substances/chemicals e.g. disinfectant, flame retardants,…

Transport

The environmental impact of transport depends on fuel type (electricity, fuel, biofuel,…), the mode of transport (road, rail, shipping,...), vehicle type (size of truck,…) and the distance (Rondaij and Spreen 2020). The environmental impact is mainly due to the use of fossil fuels. This is not further explored because of the lack of data.

Use / Reuse

See item raw materials where the reuse of the items was included.

When a disinfection wipe is used to disinfect the thermometer between two patients, the environmental impact of the life cycle of a disinfection wipe needs to be taken into account. Based on the LCA study of Sanchez et

al. (2020), the carbon footprint of manufacturing a disinfection wipe consisting of 1g of cotton substrate with active ingredient n-alkyl dimethyl ethylbenzyl ammonium chloride and isopropyl alcohol, was calculated to be 0.16 $kgCO_2eq$ per wipe, and the disposal (incineration) impact was calculated to be at 0.039 $kgCO_2eq$ per wipe. This results in a total emission of 0.20 $kgCO_2eq$ emission per wipe (Sanchez et al. 2020).

Waste

A cover cap and wipe can both be disposed of as NHMW.

Although not the focus of this item (the use of cover caps), an additional concern when using thermometers is that they all contain batteries. The batteries need to be removed and the thermometers need to be disposed as electronic device. Manufacturers need to pay attention to the design of the thermometers so batteries can easily be removed before disposal.

In summary, the most sustainable option is when additional materials or items can be avoided to reuse a thermometer for different patients.

5.3.4.3 Safety

Infection prevention

To reuse a thermometer for different patients, low level disinfection can be needed, depending on the type of thermometer. According to the Spaulding classification, a thermometer is ranked as a non-critical item, meaning that it comes into contact with intact skin. Normally, it is not soiled with body fluids. Potential infection prevention risks and handling is summarised in the overview below (See Table 33).

Table 33: Overview infection prevention risks and handling

	Ear/tympanic 	Axillary thermometer 	Temporal scanner 	Frontal non-contact 
Contact	Contact with intact skin Can be soiled by earwax	Contact with intact skin When used in the groin area: contact with body fluids such as sweat, urine and faeces is possible	Disinfection wipe after use Can be soiled by sweat	No contact with body fluids, nor intact skin.
Handling & Disinfection needed	Use over cover cap Only regular disinfection needed in accordance with hospital guidelines (every shift/daily/weekly)	Disinfect between patients (regardless of use of sleeve) *Sleeves available (PE film, PE laminated paper)**	Disinfect between patients	Only regular disinfection needed in accordance with hospital guidelines (every shift/daily/weekly)

**not included in analysis*

Occupational safety

Biological risk

For healthcare professionals, no additional risks were associated with the use of thermometers, cover caps or wipes. When contact with body fluids (urine, faeces) is possible for example when axillary thermometers were used in the groin area, gloves are indicated (Hoge Gezondheidsraad 2014).

Chemical risk

As stated in the other items, there is a possible chemical risk when using disinfectants, such as wipes.

In summary, thermometers that do not come into contact with the patient pose the least risk concerning infection prevention. There are no significant occupation safety issues.

5.3.4.4 Cost

The total cost consists of the purchase cost of the thermometer, divided by the number of uses, and summed up with the reuse cost. The latter consisting of the purchase cost of additional materials and the labour cost needed for reuse.

Purchase cost

Depending on size, composition and supplier, the purchase cost of thermometers may vary (See Table 35). The cost per use will depend on the lifetime of the device, which depends on how long it functions and how quickly it is lost. The latter, is a common issue for axillary thermometers.

Reuse cost

The reuse cost consists of use of cover caps or disinfection needed between use. In the interests of comparability, we assumed disinfection after every use, if needed by the type of thermometer or a new cover cap after every use. Periodic disinfection, aside from disinfection between patients, was not included.

Table 34: Purchase and use cost (including VAT) per type of thermometer

	Ear/tympanic 	Axillary thermometer 	Temporal scanner 	Frontal non-contact 
Purchase cost of thermometer	€217.4 – €313.4**	€5.37 - €10.64	€251 - €437**	€61.4 – €112.5**
Material needed to reuse	Cover cap €0.17 - €0.23	Wipe €0.06 – €0.16	Wipe €0.06 – €0.16	-
Cost per use	€ 0.176 – € 0.239	€ 0,061 – € 0.162	€ 0.067 - € 0.17	€ 0.002 – € 0.003
Labour time (seconds)	10	30	30	-
Labour cost [$]	€ 0.13	€ 0.40	€ 0.40	
Total purchase and use cost	€ 0.31 – € 0.37	€ 0,46 – € 0.56	€0,47 – € 0.57	€ 0.002 – € 0.003

**Based on 7120 uses/1 year (1 years of guarantee * 365 days * 2 measurements per day * 10 patients) **Based on 35600 uses/5 year (5 years of guarantee * 365 days * 2 measurements per day * 10 patients)*
$ As data were from 2012, results have been indexed by a factor of 1.3076 (wage index March 2012= 1.5769, wage index June 2022 1.8845) or €47.46 /h

Waste cost

A cover cap and wipe can be disposed of as NHMW. Despite new waste directives, caps will not be able to be recycled because medical devices that came into contact with the patient, are not allowed in PMD.

Table 35: Waste cost (including VAT) related to materials needed for reuse

	Cover cap		Wipe
Type of waste	NHMW	PMD	NHMW
Weight per piece	0.40-1.42g	0.40-1.42g	1g*
Cost waste weight per piece	0.00008-0.0003	0.00008-0.0003	0.0002
Cost per bag (100L)	€ 0.15	€ 0.3	€ 0.15
Cost bag per piece	<0.00001	<0.00001	0.000075
Total waste cost	0.00008-0.0003	0.00008-0.0003	0.00028

* *Based on* (Sanchez et al. 2020); ** 2000 wipes per bag

The overall cost per use was lowest for non-contact thermometers, the overall cost per use was highest for thermometers using cover caps, due to the high cost of the caps which was almost four times higher than the use of wipes (Table 35). Waste cost per piece/per proved negligible (<0.001) due to the low weight and volume of cover caps and wipes.

In summary, from a financial perspective the most interesting option is when additional materials or items can be avoided to reuse a thermometer for different patients.

5.3.4.5 Efficiency

Availability

Cover caps and wipes require an ordering and delivery procedure from either the medical equipment supplier or the pharmacy department, respectively. Stock space needed for cover caps is less than for disinfection wipes.

Handling and comfort of use

Axillary and temporal measurements require disinfection after every use (every patient), therefore wipes or other disinfection materials need to be available and discarded. Tympanic measurement requires the discard of a used cover cap and availability of a new one. The use of non-contact thermometers require no materials for reuse.

The handling of the thermometers is quite identical, only no touch thermometers require no contact with the patient (less disturbing for patient when e.g. sleeping).

Time consumption

Options where disinfection is needed, are the most time consuming followed by the use of cover caps. Thermometers where no additional actions are needed are the least time consuming, but differences are limited.

In summary, the most efficient alternative is when additional materials or items can be avoided to reuse a thermometer for different patients.

5.3.4.6 Conclusion on cover caps

The use of cover caps for tympanic temperature measurement was found to be less costly and more sustainable than when disinfection (one wipe/use) was needed between patients (axillary and temporal scanner). Temperature measurement requiring no disinfection or additional equipment to be used in different patients, such as non-contact thermometers, proved to be the cheapest, most sustainable, safest and most efficient alternative.

5.3.5 Vaginal speculum

The parameters safety, costs and efficiency of a vaginal speculum were described hereafter to be consistent with the other items. The item sustainability was studied through a life cycle analysis and presented in a separate chapter (Chapter 6).

5.3.5.1 Description and Specification

A vaginal speculum is a semi-critical medical instrument for insertion into the vagina, used to perform a gynaecological examination, for the removal of smears, and further introduction of instruments into the uterus. Reusable and disposable specula are frequently used in healthcare. Hospitals as well as outpatient clinics and general practitioners are performing pelvic examinations.

Example of a reusable vaginal speculum

Example of a single-use speculum

5.3.5.2 Sustainability

An LCA was performed to evaluate the environmental impact of the use of reusable compared to single-use vaginal specula during a pelvic examination. This is reported in detail in Chapter 6: Life Cycle Analysis of a vaginal speculum.

5.3.5.3 Safety

Infection prevention

Single-use

The use of a new single-use speculum contains no risk of transmission of microorganisms.
The single-use specula used by the Belgian hospitals that participated in our hospital survey (See Chapter 4) were sterilised with ethylene oxide by the manufacturer. Sterilisation by ethylene oxide is an alternative for steam sterilisation if materials are not resistant to high temperature. In addition, there are specula on the market that meet cleanroom criteria, which is sufficient for contact with mucous membranes. Those specula are also commonly used in hospitals in Belgium and The Netherlands.

Reusable

To reuse a stainless steel vaginal speculum, cleaning and subsequent high level disinfection is required. According to the Spaulding classification, a vaginal speculum is ranked as a semi-critical item since it comes in contact with mucous membranes (Rutala et al. 2008). Furthermore it is contaminated with body fluids after use. Therefore vaginal specula undergo a thermal disinfection, and are subsequently sterilised. Although high-level disinfection is theoretically sufficient, sterilisation is mostly done in daily practice.

Occupational safety

Vaginal specula are soiled with blood and/or body fluids after use. Therefore, they pose a biological risk. Further, disinfection and sterilisation of a speculum may involve a minor chemical risk for central sterilisation department staff.

Biological risk

A used speculum must be handled as if it is infectious. Therefore, wearing gloves is advised during use until they are discarded as waste or collected for transport to the central sterilisation department (European Commission. Directorate-General for Employment, Social Affairs and Inclusion 2011; Hoge Gezondheidsraad 2014).

Chemical risk
There is a possible chemical risk when using disinfectants. To reduce the chemical risk, the use of thermal procedures is preferable to chemical disinfection and automated procedures are preferable to manual disinfection. In case of manual disinfection, gloves are indicated (European Commission. Directorate-General for Employment, Social Affairs and Inclusion 2011).
There is a possible chemical risk when using disinfectants (see item kidney tray), but procedures in the central sterilisation unit are already in place to avoid a chemical risk.

In summary, no relevant differences between both alternatives concerning safety (patient and occupational) were present.

5.3.5.4 Cost

Purchase cost
Depending on size, composition and supplier, the purchase cost of disposable and reusable specula may vary (See Table 36).
The cost per use of reusable specula will depend on the lifetime of the device. This will be further discussed in the LCA (see Chapter 6). Items in stainless steel are, in principle, almost impossible to break down, but for reasons of uniformity with the LCA (See Chapter 6) a lifetime of 500 uses is taken into account to calculate cost per use.

Reuse cost
The reuse cost consists of the cost to clean, thermal disinfect, package, and sterilise the speculum.

Table 36: Purchase and reuse cost (including VAT) per type of speculum (per piece/use)

	Single-use	Reusable
Purchase cost per piece	€0.74 - €1.33	€ 15.00 - € 49.69
Purchase cost per use	€0.74 - €1.33	€ 0.03 - €0.10
Packaging (double)	-	€ 0.10 - € 0.28
Labour cost of reuse	-	€ 0.78*
Total cost	€ 0.74 - €1.33	€ 0.91 - € 1.16

**based on measurements staff central sterilisation department Ghent University Hospital*

Waste cost
A single-use speculum can be disposed of as NHMW. Reusable specula could be recycled, but in practice it is disposed of as HMW.

Table 37:Waste cost (including VAT) per type of speculum

	Single-use	Reusable
Type of waste	NHMW	HMW
Weight per piece	34.4-39.9 g	179.0 g
Waste cost per piece	€ 0.007 – € 0.008	€ 0.14
Waste cost per use		€ 0.00028
Cost per container(100L)	-	€ 7 - € 9
Cost per piece/use		€ 0.00007 - € 0.00009*
Cost per bag (100L)	€ 0.15	€ 0.15
Weight of paper packaging/piece	6.08 g	10 g
Cost of paper packaging/piece	-	-
Weight of plastic	0.23 g	8 g
Cost of plastic	< € 0.0001	€ 0.001
TOTAL waste cost per use	€ 0.007 – € 0.008	€ 0.00135 - € 0.00137

**Based on 200/container or bag and a lifespan of 500 uses for a speculum*

The waste cost is higher for single-use compared to reusable, due to the long lifespan of these reusable materials (Table 37).

Table 38: Total cost (including VAT) per type of speculum per use

	Single-use	Reusable
Purchase & reuse	€ 0.74 - €1.33	€ 0.91 - € 1.16
Waste	€ 0.007 – € 0.008	€ 0.0014
TOTAL	€ 0.75 – € 1.34	€ 0.91 – € 1.16

In summary, the cost of a single-use and reusable speculum are similar, and can be more or less costly compared to reusable depending on how competitively priced the single-use specula are (Table 38).

5.3.5.5 Efficiency

Availability

Both types of vaginal specula require an ordering and delivery procedure from either the central sterilisation department or medical equipment supplier. Either way, sufficient stock space is needed. Note that reusable specula take up more space than single-use specula, due to their packaging.

Handling and comfort of use

The handling is quite identical, with small differences . Reusable specula are more robust to use and no parts will break off, furthermore they are available in more different types and shapes. On the other hand, single-use specula are more comfortable for the patient (less cold), often transparent which facilitates observation, and the different types are easily recognisable (different colours).
After use, a reusable speculum is collected in a washable container and transported to the central sterilisation department, while a single-use speculum is discarded as NHMW, or by some practitioners as HMW. Both are picked up by logistic staff.

Time consumption

In both options, there is an equal time consumption in use. A reusable speculum is collected into a container and then picked up by the logistics service, while a single-use is discarded with the medical waste (NHMW/NHMW). Time consumption of hospital personnel to clean, disinfect, package and sterilize reusable specula is included in the cost part of this item.

5.3.5.6 Conclusion for vaginal specula

In summary, cost and safety of single-use versus reusable specula were comparable, whereas efficiency may be in favour of single-use devices due to the time investment for sterilisation.

6 LIFE CYCLE ANALYSIS (LCA) OF VAGINAL SPECULUM

6.1 Background literature

A vaginal speculum is a semi-critical medical instrument for insertion into the vagina, used to perform a gynaecological examination, for the removal of smears, and further introduction of instruments into the uterus. Reusable and disposable specula are frequently used in healthcare. Hospitals as well as outpatient clinics and general practitioners are performing pelvic examinations.

Example of single-use speculum

Example of reusable speculum

The environmental impact of single-use and reusable vaginal specula was compared in three studies (Donahue et al. 2020; Rodriguez Morris and Hicks 2022; Snijder and Broeren 2022), of which only two were published in a peer reviewed journal (Donahue et al. 2020; Rodriguez Morris and Hicks 2022) (See Table 39 and Appendices 9.1 & 9.2).

In the study of Donahou et al. (2020) three types of specula were compared; two reusable stainless steel, and one acrylic single-use speculum. The reusable specula had a robust favourable carbon footprint compared to the single-use acrylic specula. Compared to single-use acrylic specula, the reusable speculum has a lower carbon footprint after 2 or 3 completed examinations. The material production and manufacturing phase contributed for more than 90% to the carbon footprint of the acrylic speculum, whereas the use and reprocessing phase contributed between 65-74% to the carbon footprints of the two stainless steel specula (Donahue et al. 2020). Similarly, the findings of Snijder and Broeren (2022) comparing stainless steel specula with two types of single-use specula, one of fossil plastic and one of biobased plastic, estimated that after 500 uses the environmental impact of reusable specula was about 50% lower, compared to a single-use speculum from fossil plastic. The estimated impact of reusable specula was also slightly better than that of biobased plastic (Snijder and Broeren 2022).
Finally, the study of Rodriguez Morris and Hicks (2022) compared a reusable stainless steel speculum and an acrylic single-use speculum. The authors concluded that no speculum outperforms the other consistently across all impact categories. The reusable speculum outperformed the single-use alternative in five impact categories (global warming, acidification, respiratory effects, smog formation, and fossil fuel depletion), but not for ozone depletion. The authors referred to the use of personal protective equipment (PPE), and more specifically the use of gloves, during the disinfection process of reusable specula. Furthermore, the impact of hard coal sourced electricity was dominant in almost all impact categories (Rodriguez Morris and Hicks 2022).

Table 39: Summary LCA's on vaginal speculum

Reference	Objective LCA	Functional unit	Results
Donahue et al. (2020, US)	Environmental impact of three vaginal specula: one SU acrylic and two RU stainless steel specula	20 gynaecologic examinations by either type of speculum	Global warming RU stainless steel 304 (lifespan 20 ex.): 5.72 kg CO_2eq RU stainless steel 316 (lifespan 20 ex.): 6.51 kg CO_2eq SU acrylic:17.54 kg CO_2eq
Rodriguez Morris and Hicks (2022, US)	Environmental impact of SU acrylic and RU stainless steel specula	5000 pelvic exams, equivalent for one year of clinic operation	Global warming RU stainless steel (lifespan 5 years): 326 kg CO_2eq SU acrylic: 2220 kg CO_2eq Ozone depletion: RU stainless steel (lifespan 5 years): 0.00033 kg CFC-11e SU acrylic: 0.000042 kg CFC-11e
Snijder and Broeren (2022, The Netherlands)	Environmental impact of SU fossil plastic, SU biobased plastic and RU stainless steel specula	One gynaecologic examination using a vaginal speculum	Global warming RU stainless steel (lifespan 500 uses): 0.13 kg CO_2eq SU fossil plastic: 0.30 kg CO_2eq SU biobased plastic: 0.14 kg CO_2eq

RU: reusable, SU: single-use

In summary of these studies, the majority of the results indicate a benefit for reusable specula. The findings were not fully conclusive, as the use of nitril gloves and energy mix significantly impacted specific impact categories in one study.

Supplementing the selection process described in Chapter 4, we conducted this LCA on vaginal specula because of 1) the limitations of the available studies and because 2) data applicable to the Belgian context were lacking.

The two published studies on vaginal specula were conducted outside of Europe (Donahue et al. 2020; Rodriguez Morris and Hicks 2022). In the UK or other European countries the power mix is principally sourced from renewables, whereas in the US natural gas is the most important source, and in Australia the power mix is mostly based on coal (McGain et al. 2017). Therefore it would be interesting to identify the impact of renewable energy on the reuse process of medical equipment, such as vaginal specula. The Ghent University Hospital uses a power mix based on 100% renewable energy and consumes steam created as a waste-product by a nearby waste disposal plant.

Currently, environmental implications are seldomly included in the procurement of medical materials and devices, but the attention is growing. Manufactures are also becoming more aware of their role and the ecological impact of the production and use of their products. In this process the use of bioplastics is put forward by manufactures as a more ecological alternative. Single-use specula made from biobased plastics have a smaller carbon footprint compared to single-use made from fossil based plastic (Snijder and Broeren 2022). At first glance, this could be the preferred option for single-use specula, but Snijder & Boeren (2022) performed a scoping LCA, only including the midpoint impact category global warming. A comprehensive overview ecological impact categories is currently lacking.

6.2 Goal

The goal of the study was to evaluate the potential environmental impact of the use of reusable compared to single-use vaginal specula based on rational, scientifically solid grounds using the method of life cycle analysis (LCA).

6.3 Methods

The LCA followed the ISO 14040/14044 guidelines (International Organization for Standardization), and was modelled using SimaPro 9.4.0.2. Primary data was used whenever possible. Secondary data was retrieved from the ecoinvent database (version 3.8).

6.3.1 Functional unit

The functional unit was one pelvic examination by either a sterile stainless steel reusable, or a single-use speculum of three different types: one containing fossil plastics acrylonitrile butadiene styrene (SU ABS), one containing biobased plastic polylactic acid (SU PLA), and one consisting of polystyrene blades and polyethylene bolt and sterilised with ethylene oxide (EO SU). The reusable speculum was an uneven-bladed stainless steel speculum (90x80x30 mm) manufactured in Germany and most commonly used in the Ghent University Hospital. Reusable specula were assumed to be used a minimal of 500 times based on Snijder and Broeren (2022) and expert opinion (head of the central sterilisation department and materials manager OR of the Ghent University Hospital). An additional decontamination and sterilisation (steam sterilisation) cycle of the reusable speculum was required before the first use and included in the modelling (See Appendix 9.12).

The single-use specula were all three medium size (26 mm) specula. The SU ABS and SU PLA specula were both manufactured in The Netherlands and did not undergo a sterilisation process. The EO SU speculum was manufactured in Poland and sterilised using ethylene oxide. A single-use speculum was not commonly used to perform pelvic examinations in the Ghent University Hospital. Therefore, the use of a medium sized single-use speculum was based on figures from the survey of consumption of single-use materials of Belgian hospitals (See Chapter 4).

6.3.2 System boundary

A cradle-to-grave approach was used, including the production of the specula and packaging materials (consisting of raw materials and manufacturing), as well as distribution, (pre-) use phase, and end-of-life of specula and packaging materials.

The systems studied can be separated into foreground and background subsystems and are detailed in Figure 6 and Figure 7 for reusable and single-use specula, respectively. The foreground subsystem consists of all processes, assessments, and flows for which primary data were collected. The background subsystem includes the other processes that are linked through mass or energy exchanges with the foreground processes. The production of electricity is an example of a background process. For the background system secondary data from databases and literature were used.

For the (re-)use phase, energy, water, and materials used for decontamination and sterilisation of the reusable specula were included (See Appendix 9.12). Waste treatment of specula, all packaging materials, and waste water used throughout one life cycle were included, as well as emissions to air, soil and water for all processes retrieved from the life cycle inventory database. Capital goods and building infrastructure for the decontamination and sterilisation (foreground system) were excluded, as well as infrastructure from secondary data (background system) retrieved from the ecoinvent database to be consistent with the primary data collected. PPE used by personnel during cleaning and disinfection of the specula were not included, as this is used while working in the dirty zone of the central sterilisation department, where the specula are manipulated together with other instruments. Details of the system boundaries were outlined in Figure 6 for reusable and Figure 7 for single-use specula. The use of specula in outpatient clinics related to the university hospital, was excluded.

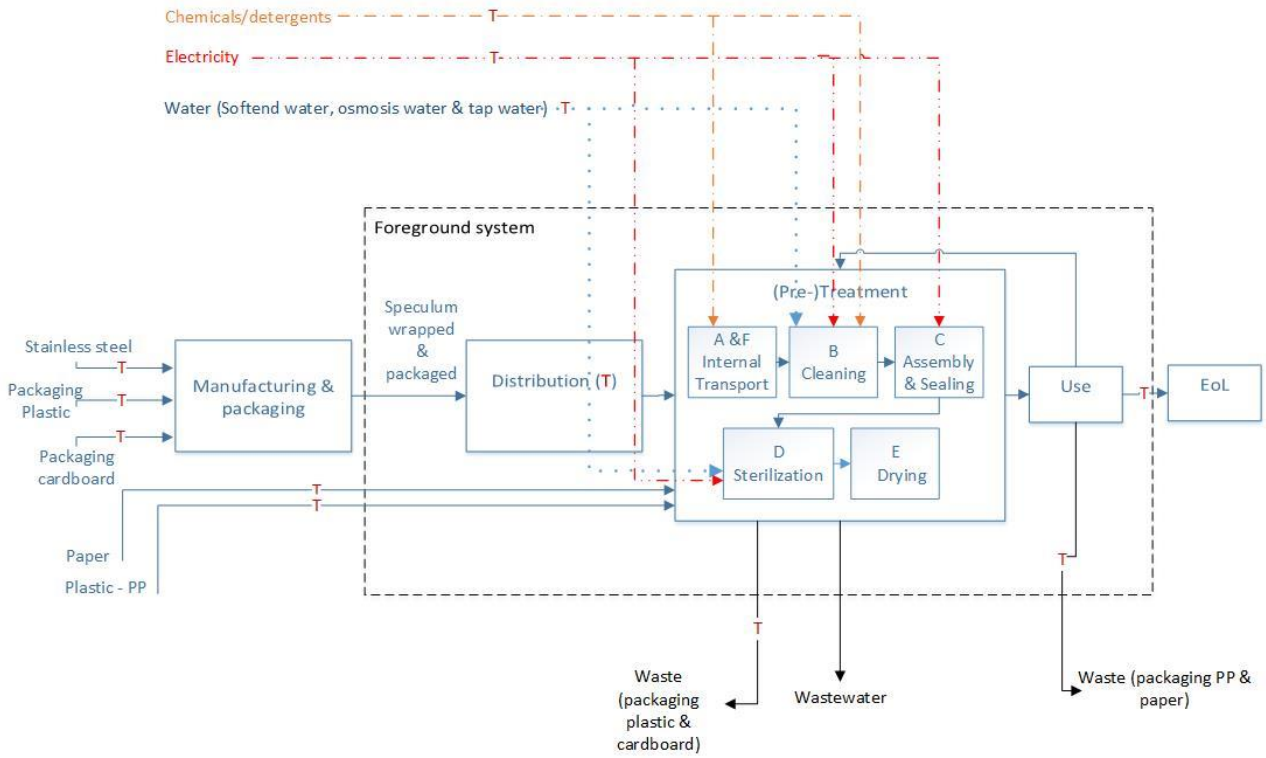


Figure 6: System boundary reusable specula

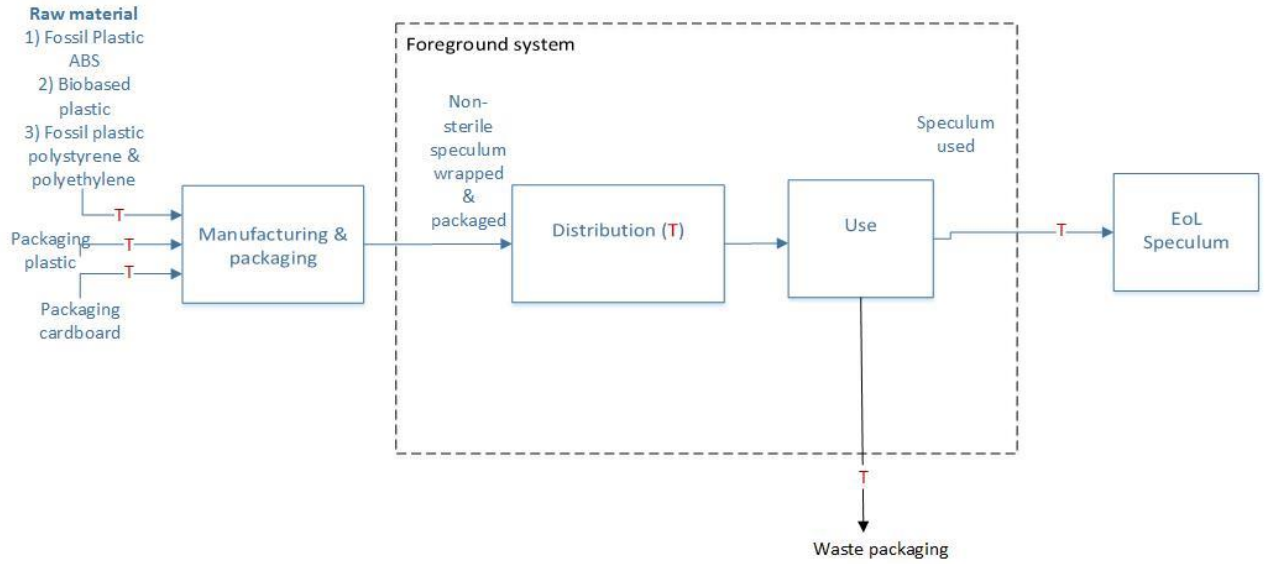


Figure 7: System boundary single-use specula

6.3.3 Life cycle inventory

Parameters for raw materials and manufacture of vaginal specula and packaging were included in Table 40. Manufacturer information was used to determine the composition, or expert knowledge where such information was not available. Each component and packaging material was weighed using the same balance scale. Associated primary and secondary packaging were included in the model, up to the packing unit supplied to the hospital. One-time packaging of the reusable specula present at the time of purchase was assumed to be identical as packaging of single-use specula. The inventory was developed through matching

the materials (from specula and packaging) with closest materials included within the ecoinvent database version 3.8. A summary of the used datasets from the ecoinvent database was included in Appendix 9.13. An overview of the assumptions used was included in Appendix 9.14.

Table 40: Speculum and packaging composition data

Product	Material	Weight, g	Weight, g/piece
Reusable speculum (RU)	Speculum Stainless Steel (18/8) (uneven-bladed 90x80x30 mm)	179g	179.0g
Sterilisation bag reusable speculum	Laminate plastic	4g (x2 - double packed)	8.0g
Sterilisation bag reusable speculum	Paper	5g (x2 - double packed)	10.0g
Secondary packaging for distribution from manufacturer to hospital	Plastic (LDPE & LLDPE)	4g/10pieces	0.4g
Cardboard packaging for distribution from manufacturer to hospital (small box)	Cardboard (small box)	200g/10pieces	20.0g
Disposable speculum 1 (SU ABS)	Speculum from fossil plastic (= ABS or Acrylonitrile butadiene styrene) Medium size (26 mm)	34.4g	34.4g
Disposable speculum 2 (SU PLA)	Speculum from biobased plastic (= PLA made from sugarcane) Medium size (26 mm)	39.9g	39.9g
Packaging for distribution from manufacturer to hospital	Plastic (LDPE & LLDPE)	45g/200 pieces	0.2g
Carton packaging for distribution from manufacturer to hospital (secondary packaging)	Cardboard (large box)	1215g/200 pieces	6.1g
Disposable speculum 3 (EO SU)	Speculum from fossil plastic (=polystyrene blades and polyethylene bolt) Sterilised with ethylene oxide (EO) Medium size (26 mm)	31g	31 g (29g blades and 2g bolt)
Plastic packaging per speculum	Plastic LDPE & LLDPE	4g	4g
Packaging for distribution from manufacturer to hospital	Plastic (LDPE & LLDPE)	45g/200 pieces	0.2g
Carton packaging for distribution from manufacturer to hospital (secondary packaging)	Cardboard (large box)	1215g/200 pieces	6.1g

RU: reusable; SU: single-use; LDPE: Low density polyethylene; LLDPE: Linear low-density polyethylene; ABS: Acrylonitrile butadiene styrene; PLA: Polylactic acid; EO: ethylene oxide

Distribution was included in foreground and background subsystems, represented as "**T**", and detailed in Figure 6 and Figure 7. Distribution was modelled using estimates of travel distances of the wrapped speculum between the manufacturer and Ghent University Hospital by Google maps, and assuming average size of trucks if land transport was used. Details of modelled transport necessary for the use of reusable and single-use specula were summarised in Appendix 9.13 and Appendix 9.15.

Reusable specula can be separately packaged in a sterilisation bag consisting of paper on one side and plastic laminate on the other side, or integrated into a reusable instrument set together with other instruments wrapped in polypropylene sterilisation sheets (blue wrap). The plastic laminate of the sterilisation bag is composed of five layers: one layer of PET, 3 layers of PP and one layer of glue. The composition of these packaging bags, although technically possible, makes it currently not feasible to recycle the plastic sides. Since single-use specula are individually packaged, the comparison was made with individually packaged reusable specula. Sterilised specula are double packed, so for each reusable speculum the packing material of two sterilisation bags was used.

A detailed overview of the different steps of the reuse phase of reusable specula was included in Appendix 9.12. Sterilisation was conducted in an in-house sterilisation department using steam sterilisation, which is most common in Belgian hospitals. Input and output data were collected through direct observation, own measurement, and data from the manufacturers of machines and materials used in Ghent University Hospital. Where not available, data were based on expert opinion (from staff of the central sterilisation department or biomedical department).
Steam derived from waste-heat of a nearby waste incinerator was used as steam for the cart wash and the heating of osmose water to clean steam. This waste heat was modelled as a burden-free input. The energy mix used in the Ghent University Hospital is 100% renewable energy mix (mainly from wind) from a Belgian energy provider. Waste (specula and laminate plastics from sterilisation bags) was assumed to be incinerated, aside from the (initial) packaging materials (cardboard, paper and plastics – double packaged) which were recycled. It is assumed that the reusable speculum will be disposed of, after 500 uses as HMW,

and that the majority (92%) of the metal is recovered from the resulting bottom ash (Rigamonti et al. 2010; Indaver 2022). An overview of the assumptions used was included in Appendix 9.14. Reusable specula were double packaged in laminate bags consisting of paper and laminate plastic. The paper side was recycled, the plastic laminate side was disposed of as NHMW and sent to waste incinerators after use. Benefits from incineration (recovered energy) and recycling (recycled materials substituting virgin materials) were taken into account as avoided impacts.

6.3.4 Outcome measures

The primary outcome was global warming impact, with total GHG expressed as carbon dioxide equivalents ($kgCO_2eq$). Global warming was selected because of the high awareness about this challenge in today's society and the urgency to mitigate our global warming impact. Seventeen additional midpoint impact indicators were calculated using ReCiPe 2016 Midpoint (H) V1.07 / World (2010) H. Of those seventeen midpoints, four were selected due to their relevance for this item. Fossil resource scarcity was selected to reflect the difference between the use of fossil-based and bio-based materials. Mineral resource scarcity was chosen because the reusable specula are made of steel. Due to water and steam consumption in the reprocessing phase of reusable specula, water consumption was selected as the fourth midpoint impact category. Only the midpoint global warming is discussed in the text, for the four most relevant midpoints described above, graphs were included in Appendices 9.17. For all midpoints, the estimates were included in Appendix 9.16.

The secondary outcome was the environmental impact evaluated by the associated damage to human health (measured in disability-adjusted life years [DALYs]), ecosystems (loss of local species) and resource scarcity (financial cost involved in future mineral and fossil resource extraction). Estimates of damages and graphs for all endpoints were included in Appendix 9.16 and Appendix 9.17, respectively. Those endpoint estimates were obtained through ReCiPe 2016 Endpoint (H) V1.07 / World (2010) H/A (Huijbregts et al. 2017).

6.3.5 Scenario analyses

To evaluate the generalisability of the findings, following alternative scenarios were modelled, changing just one parameter in the scenario:

- Scenario 1 modelled the energy mix used for the disinfection and sterilisation process of a reusable vaginal speculum using the average Belgian energy mix provided by the ecoinvent database.
- Scenario 2 modelled the steam used for the disinfection and sterilisation process of a reusable vaginal speculum and cart wash using steam generated by Ghent University Hospital itself (using an ecoinvent dataset for industrially produced steam mainly based on the incineration of natural gas)
- Scenario 3 modelled the impact of the number of reuses
    - Scenario 3A: increasing the number of reuses of reusable specula to 1000 times. The manufacturer stated that no defined limit can be set for the maximum number of reprocessing cycles that can be performed. Based on expert opinion a use of 1000 times seems easily achievable.
    - Scenario 3B: decreasing the number of reuses of reusable specula to 50 times, as specula can be available on infrequently used places or in infrequently instrument sets.
- Scenario 4 modelled the impact of using one sterilisation bag instead of two for reusable specula
- Scenario 5 modelled the impact of the waste treatment process of the packaging materials. In this scenario all waste was incinerated (using ecoinvent datasets for waste incineration). Scenario 5 is still a common practice in many Belgian hospitals.

6.4 Results

6.4.1 Life cycle assessment

An overview of all midpoint and endpoint estimates for the reusable (RU) and three single-use (SU) specula were presented in Appendix 9.16. Global warming (kgCO2eq) was provided in Figure 8 for the four types of specula, and details were given in Table 41 (for global warming) and Appendix 9.17 (for other midpoints). Life cycle GHG emissions from reusables were largely due to packaging production (used during treatment on-site) and end-of-life treatment of that packaging, and the on-site reprocessing (treatment) of the specula, whereas life cycle GHG emissions from single-use alternatives were mainly due to raw material production and manufacturing, incineration of the speculum at the end of life, and packaging (first purchase) production.

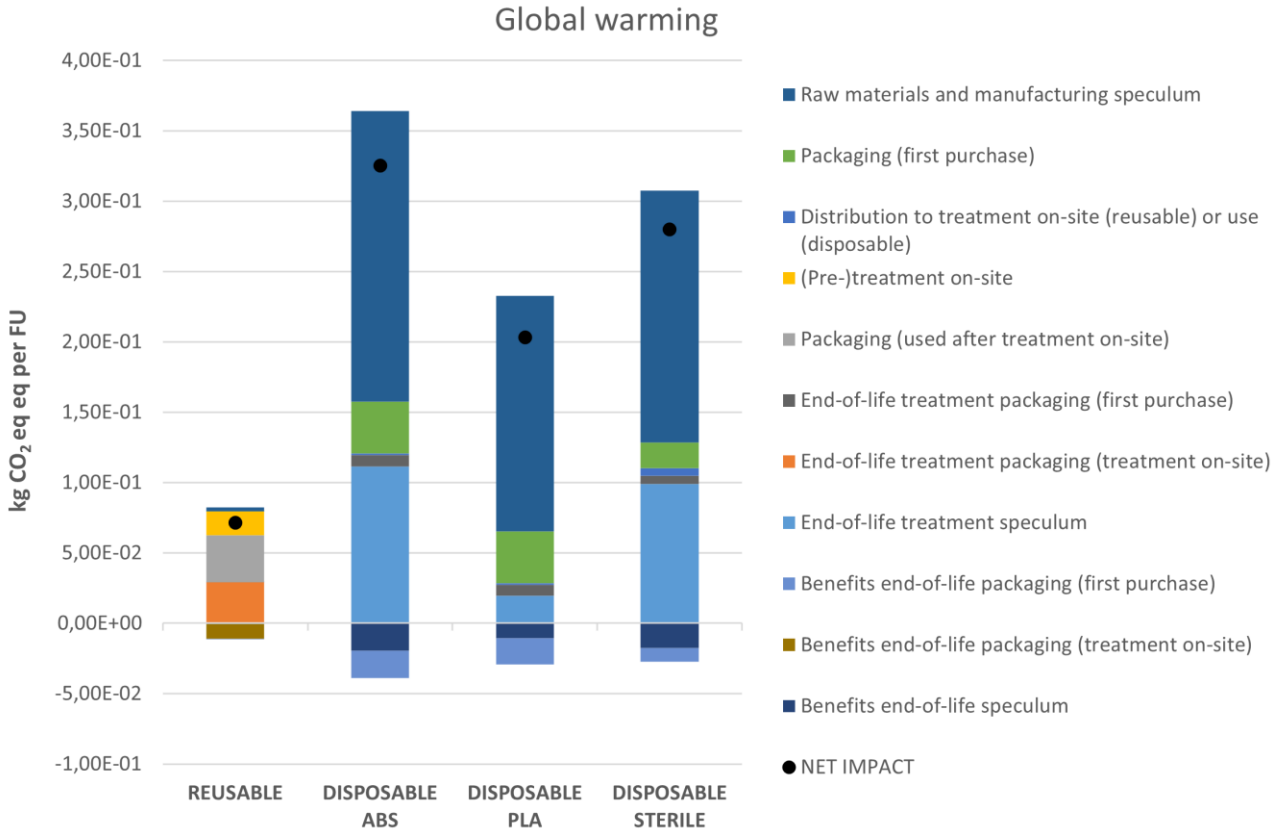


Figure 8: Life cycle greenhouse gas emissions (kgCO_2eq) of one use of a speculum for the four types of specula

The most favourable option, from global warming perspective, is the use of a sterile stainless steel RU speculum producing 78% less GHG emissions than a single-use speculum from fossil plastic (SU ABS), 65% less emissions than a single-use biobased plastic speculum (SU PLA), and 74% less emissions than an ethylene oxide sterilised single-use speculum consisting of two types of fossil plastic (EO SU).

None of the specula scored best across all **midpoint** estimates. For water consumption SU specula made from biobased plastics were the least favourable, for fossil resource scarcity a SU ABS speculum was the least good, whereas for mineral resource scarcity RU specula were worst. Across all three **endpoint** estimates, the use of RU specula was most favourable (See Appendix 9.16 and 9.17).

6.4.1.1 Reusable specula (RU)

For global warming, the packaging used during treatment on site proved to have the greatest impact (76% of the total burdens of GHG emissions) for RU specula, including packaging for sterilisation and end-of-life treatment of the packaging after use. In addition, the treatment phase (cleaning, disinfection and sterilisation) has the second largest impact (21% of the total burdens of GHG emissions for RU specula) (See Table 41 for overview of the GHG emissions per phase). The limited impact of the treatment phase is related to the use of renewable energy and the use of steam from a nearby waste incinerator. The impact of raw materials and manufacturing of the reusable speculum was highest for the midpoint mineral resource scarcity (61%). For the endpoint estimates, the impact of raw materials and manufacturing was lower or negligible (Appendix 9.17).

6.4.1.2 Single-use specula from fossil plastic (SU ABS)

Throughout the four midpoint impact categories and three endpoint damage categories, raw materials and manufacturing proved to have the greatest impact, or 57% of the total burdens of GHG emissions for SU ABS specula. In addition, handling waste from end-of-life specula has the second largest impact (31% of the total burdens of GHG emissions on SU ABS specula) (See Table 41). SU ABS specula were only the least favourable of the four types of specula for the endpoint resource scarcity. An overview of the secondary outcome measures was included in Appendix 9.16 and 9.17.

6.4.1.3 Single-use specula from biobased plastic (SU PLA)

Throughout the four midpoint impact categories and three endpoint damage categories, raw materials and manufacturing proved to have the greatest impact, or 72% of the total burdens of GHG emissions for SU PLA specula. In addition, packaging production and end-of-life treatment had the second largest impact (16% of the total burdens of GHG emissions on SU PLA specula) (See Table 41). For the endpoints ecosystem quality and human health, SU PLA specula were the least favourable of the four types of specula. An overview of the secondary outcome measures was included in Appendix 9.16 and 9.17.

6.4.1.4 Ethylene oxide sterilised single-use specula composed of two types of fossil plastic (EO SU)

Throughout the four midpoint impact categories and three endpoint damage categories, raw materials and manufacturing proved to have the greatest impact, or 58% of the total burdens of GHG emissions of EO SU specula. In addition, handling waste from end-of-life specula has the second largest impact (32% of the total burdens of GHG emissions on EO SU specula) (See Table 41). An overview of the secondary outcome measures was included in Appendix 9.16 and 9.17.

Table 41: Overview of the global warming impact (kg CO_2eq) per phase for the four types of specula

	Reusable specula	SU ABS specula	SU PLA specula	SU sterile specula
NET IMPACT	7,13E-02	3,25E-01	2,03E-01	2,80E-01
BENEFITS	-1,10E-02	-3,88E-02	-2,94E-02	-2,74E-02
Benefits end-of-life speculum	-5,30E-04	-1,97E-02	-1,06E-02	-1,76E02
Benefits end-of-life packaging (treatment on-site)	-1,04E-02			
Benefits end-of-life packaging (first purchase)	-2,73E-05	-1,91E-02	-1,88E-02	-9,73E-03
BURDENS	8,23E-02	3,64E-01	2,33E-01	3,07E-01
End-of-life treatment speculum	1,33E-06	1,11E-01	1,95E-02	9,88E-02
End-of-life treatment packaging (treatment on-site)	2,94E-02			
End-of-life treatment packaging (first purchase)	3,66E-05	8.12E-03	7,67E-03	5,94E-03
Packaging (used after treatment on-site)	3,33E-02			
(Pre-)treatment on-site	1,70E-02			
Distribution to treatment on-site	5.16E-08	1.25E-03	1,39E-03	5,29E-03
Packaging (first purchase)	4,94E-05	3,67E-02	3,67E-02	1,85E-02
Raw materials and manufacturing speculum	2,53E-03	2,07E-01	1,68E-01	1,79E-01

SU ABS: single-use fossil based plastic; SU PLA: Single-use biobased plastic; SU sterile specula: Ethylene oxide sterilised single-use specula from fossil based plastics
Figures are expressed according to LCA-standards; E-01= x 0.1;E-02= x 0.01; E-03= x 0.001; E-04= x 0.0001; …

6.4.2 Scenario analysis

6.4.2.1 Scenario 1: energy mix

The Ghent University Hospital uses an energy mix based on 100% renewable energy sources, which may not be the case for other Belgian hospitals. Therefore, scenario 1 modelled the energy mix used for the disinfection and sterilisation process of a reusable vaginal speculum using the average Belgian energy mix. The most favourable option, from global warming perspective, remained the use of a reusable speculum producing 61% less GHG emissions than a SU ABS, 37% less emissions than a SU PLA speculum, and 54% less than an EO SU speculum (See Appendix 9.18). The treatment process (cleaning, disinfection and sterilisation) gained impact compared to the baseline scenario, and became responsible for most of the emissions when using reusable specula.

6.4.2.2 Scenario 2: steam

Steam derived from waste-heat of a nearby waste incinerator is used in Ghent University Hospital as steam for the cart wash and the heating of osmosis water to clean steam. In scenario 2 the steam used for these applications was modelled using average steam production (which is based on an ecoinvent dataset for average steam production in the chemical industry, mainly produced from natural gas incineration). In that scenario SU PLA specula became the most favourable option from global warming perspective, directly

followed by the reusable with 11% more emissions, EO SU specula with 28% more emissions, and SU ABS with 38% more emissions compared to SU PLA specula. On the other hand, reusable specula remained the best option for two of the three endpoint estimates (human health and ecosystem quality) (See Appendix 9.18).

6.4.2.3 Scenario 3: Number of uses

Lifespan of a reusable speculum was based on an assumption of 500 uses (Snijder and Broeren 2022), therefore the impact of the number of reuses was included in the scenario analysis. In scenario 3A the number of reuses was increased to 1000, and decreased to 50 reuses in scenario 3B. The results are included in Appendix 9.18. Although the relative impact of raw materials and manufacturing was highest in scenario 3B (for 50 uses), compared to the baseline scenario and scenario 3A, no substantial differences were found between the three scenarios. RU specula remained the most favourable concerning global warming and throughout the three endpoint estimates (See Appendix 9.18).
From five reuses, a RU speculum became more sustainable than a SU ABS, from eight reuses it became more sustainable than a SU PLA speculum, and from six reuses it became more sustainable than a EO SU speculum from a global warming perspective.

6.4.2.4 Scenario 4: Packaging

Reusable specula were double packaged, for each speculum two sterilisation bags were used. When this could be reduced to one sterilisation bag, as proposed in scenario 4, the results became even more favourable for reusable specula (See Appendix 9.18). The most favourable option, from global warming perspective, remained the use of a RU speculum producing 86% less GHG emissions than a SU ABS, 78% less emissions than a SU PLA speculum, and 84% less than an EO SU speculum (See Appendix 9.18).

6.4.2.5 Scenario 5: Waste treatment

When all the packaging materials were not recycled but sent to incineration with energy recovery, a common practice in many Belgian hospitals, RU specula remain the most favourable option. The net global warming impact (including burdens and benefits), however, was more favourable in this scenario (packaging sent to incineration) than the baseline scenario (recycling packaging). This is due to a higher net global warming impact for recycling of paper and cardboard compared to their incineration with energy recovery (Gradus et al. 2017). On the contrary, the recycling of the (fossil-based) plastic packaging was better from a global warming perspective compared to their incineration with energy recovery. This can be explained by the fact that CO_2 emissions from biogenic origin (biomass), which is the case for paper and cardboard, are not counted by the global warming impact assessment method because CO_2 was taken up when the biomass (trees to produce paper) was growing. Whether recycling of paper and cardboard is better than their incineration also depends on the electricity dataset used to model the benefits from recovered energy. The more carbon-intensive the avoided electricity, the more favourable the incineration with energy recovery (Arena et al. 2004). However, it should be noted that our study only considered one recycling cycle, while paper can be recycled up to 7 times and so ensures that CO_2 stays longer stored. A review of the European Environment Agency on LCA studies of paper and cardboard waste management concluded that for most environmental impact categories recycling of paper and cardboard is better than incineration with energy recovery, where there is a strong influence of the assumptions used in the LCA (such as the carbon-intensity of the avoided energy) (European Environment Agency 2005).

6.4.2.6 Best case scenario

The best case of all the above scenarios on reusable specula included the combination of an energy mix based on 100% renewable energy sources, the use of steam derived from waste-heat, 1000 reuses, and minimal packaging. These assumptions combined with the assumption of recycling of all packaging materials because of current circularity targets within Europe is presented in Appendix 9.18.

6.5 Conclusion on LCA of vaginal speculum

In summary, the use of reusable vaginal specula was environmentally the most favourable alternative compared to three types of single-use specula. The best case scenario includes the use of reusable specula combined with using an electricity mix based on 100% renewable energy sources, the use of steam derived from waste-heat, 1000 reuses, and minimal (single) packaging.

7 DISCUSSION

7.1 Main findings

The initiative for this project has been taken by the Directorate-General for the Environment of the Federal Public Service Health, Food Chain Safety and Environment. The underlying question is how to manage medical waste in hospitals, in particular investigate whether it is possible to replace single-use medical devices by reusable items. If this replacement would be successful, it could result in a significant reduction of the amount of solid medical waste, and a reduction of the extraction of raw materials.

The background for this project is double. There is at first, the urge to comply with the sustainable development goals in particular with SDG 12: ensure responsible consumption and production patterns, including waste reduction. The commitment for every country joining the declaration was pronounced after its publication in 2015 (United Nations 2015). Second and not less important is the recent highly unwanted pressure on the medical health system due to the COVID-19 pandemic and more precisely, about the uncontrollable high pile of waste from hospitals. It became very clear that the management of the waste – and in particular the medical waste – had to be reconsidered. The WHO is even calling for reforms surrounding the disposal of medical waste (WHO 2018, 2022). It is clear that the question of the WHO to completely revise the management of medical waste went far beyond the exceptional situation during the pandemic but referred to the whole of considerations related to medical waste.

Concerns about the environment and the role of healthcare organisations are already present in many hospitals and e.g. within the Ghent University Hospital, several concrete actions in order to fulfil the obligations linked to SDG 12 to reduce the amount of waste and establishing within the organization a culture of sustainability are ongoing: selective collection of different waste streams whenever possible followed by recycling (paper, plastics…), raising awareness for environmental issues, etc.

All this was the fertile ground for the project to start. Together with 12 collaborating hospitals, the Ghent University Hospital took the challenge to investigate the option to reduce the amount of waste through considering the dichotomy of single-use and reuse medical equipment and the Governmental project was the possibility to study this point.

Old common sense dictates that the best way for reducing the amount of medical waste is producing less waste. However, medical waste production is inevitable in the actual Western World healthcare environment and the amount of waste is to a large extend proportionate to the perfectionated high level of medical care. One of the important aspects of reducing the amount of waste is to reduce the single-use medical material which is, by definition, thrown away after one action in the context of diagnosis, treatment or regular care of patients. Actual healthcare has a preference for single-use material for a number of reasons: safety of the patients certified by the producer of the material, easiness of use, on time delivery, logistic simplicity on the positive side. However, on the negative side are the effects on the environment since the amount of waste increases significantly and the costs are frequently high. Hence, any decision on the possibilities for replacing SUD's by reusable material need to be evidence-based.

The project evolved in four subsequent steps.

Step 1: inventory of the medical material used in hospitals. The collaboration with 12 hospitals was obtained and based on that information, a "long list" of 78 devices was constructed. These devices were used in most of the collaborating hospitals;

> *Seemingly simple, this turned out to be a very difficult exercise due to the differences in names and descriptions proper to multiple companies delivering the material. The collaborating hospitals, although very willing to share data, frequently did not had the time to deliver their information according to a preformed layout. It required a lot of efforts and time and frequent re-consultation of the partners to get this information correct.*

Step 2: reduce the number of items in this long list into a "short list" of 28 devices. This selection process was based on a number of criteria including the possibility to gather enough information that would eventually lead to a conclusion. At the same time, the selection was also guided by the advice of experienced employees

within the hospitals. Among these experts are nurses in general healthcare function, nurses working in the operation theatre, responsible employees in the sterilisation department, etc.

> *The authors of this document are well aware of the fact that the feasibility of this selection process can be discussed. It is clear that personal experience of employees within a hospital is variable and the selection presented in this project could be biased. However, in favour of our choices, the co-workers were thoroughly informed on the background of the study and the consulting employees were aware of the importance of their contribution. They participated in a number of meetings on the subject, choices were discussed among the employees and there was agreement on the importance of these choices. In spite of the drawbacks, we are confident that most of these selected items in the short list are valuable within the scope of the project, and any result could lead to valid conclusions.*

Step 3: regrouping items of the short list into five representative categories according to the criteria: sterilisation or high level disinfection of small medical devices, sterilisation of operating room equipment, thermal disinfection or low level disinfection, laundry process and change of item or device. One item for each type was selected from the short list as a representative.

> *In view of the ultimate goal, i.e. how to take decisions whether to use single-use or reusable devices, a further narrowing of the number of items was needed. Therefore, a second selection was carried out based on some characteristics of the items within hospital care. This resulted in a list of five categories of devices and each item from the short list was attributed to one of the five categories. In contrast to the selection process described in step 2, this second selection is less subject to discussion. Indeed, we retain the items of the short list and the regrouping into the categories is logic and rational. The final result is a list of 5 medical devices.*

Step 4: select one out of the five items to perform a detailed study, i.e. one life cycle analysis and four items for analysis on safety, cost, efficiency, and different aspects related to environmental sustainability based on literature data and document study, meeting with relevant stakeholders, and working visits.

> *The least disputable conclusions on the feasibility of choosing single-use or reusable devices should be based on a life cycle analysis. However, in view of the time and efforts needed to execute an LCA, one item was selected for the LCA while for the four other items, conclusions based on literature data and a limited number of observations are presented. It is clear that the latter are not LCA's according to the definition but, based on carefully studied literature data, we are confident that the conclusions are valid and contribute to the general conclusion.*

As the purpose of this study was to identify for five single-use medical devices the most sustainable and/or circular alternatives, we discuss these items from the point of view of the circularity principles. The results are summarized in Table 42 and Table 43.

Kidney trays

> *Based on the available data, reusable kidney trays are apparently more environmentally friendly. However, the method of disinfection has an environmental impact as well as a large impact on cost. The safety is comparable, whereas the efficiency might be in favour of the single-use kidney tray based on the time consumption. Since date are lacking, no more firm conclusions are possible. This should be further explored, for instance, through an LCA and LCC comparing single-use and reusable kidney trays, including the various disposal and disinfection methods.*

Blankets

> *Based on this study, sustainability and cost are in favour of reusable blankets. Safety and efficiency are similar, unless the hospital has its own laundry. Generally, extending the life cycle of textile products mitigates their environmental impact. As hospitals consume huge amounts of disposable textiles, such as surgical or isolation gowns, surgical caps, surgical drapes, warm-up jackets, was cloths, napkins,… there is a great potential for reducing environmental impact (Health Care Without Harm Europe 2021b). Hospitals or laundries could use sustainable procurement criteria including e.g.: fibre source (percentage recycled source), GHG footprints, hazardous substances, ecolabel certifications related to textiles, design for reuse or recycling (Watson and Fisher-Bogason 2017; Kofoworola et al. 2020; Health Care Without Harm Europe 2021b).*

Thermometer

The use of single-use cover caps for tympanic temperature measurement was found to be less costly and more sustainable than when disinfection with a wipe was needed between patients. Temperature measurement by a non-contact thermometer requiring no disinfection or additional equipment (cover caps) to be used in different patients proved to be the cheapest, most sustainable, and most efficient alternative. Avoiding waste is the basis of Lansink's ladder (Lansink 2018). The simple principle of preventing the use of or using fewer materials was clearly illustrated in this item in favour of non-contact thermometers.

Vessel sealer

Using reusable vessel sealers or remanufactured ones is more beneficial for the environment. Patient safety is comparable if cleaning and sterilisation is adequate. Using reusable and remanufactured vessel sealers is cost saving. The efficiency is in favour of the single-use sealer because of the time investment for sterilisation and the separate collecting process for remanufactured devices .
To remanufacture single-use vessel sealers in accordance with legislation, it is required that the reprocessor re-validates the vessel sealer as a new product. This is a time-consuming process for the remanufacturer to bring the product to the market with the required stringent regulatory certifications, and also required to ensure the safety of the patient.

Vaginal speculum:

Based on the LCA, using reusable vaginal specula was environmental most favourable alternative compared to single-use specula. Cost and safety were comparable, whereas efficiency may be in favour of single-use devices due to the time investment for sterilisation.

To investigate the environmental sustainability of reusable and single-use specula, a cradle-to-grave LCA was performed to compare reusable stainless steel specula (RU) and single-use specula made of fossil-based ABS (SU ABS), bio-based PLA (SU PLA), or ethylene oxide sterilised single-use specula consisting of two types of fossil based plastic (EO SU). Packaging (production and waste managing of double sterilisation bag) and to a lesser extent cleaning, disinfection, and sterilisation account for most of the ecological footprint of reusable specula. One could question whether sterilisation of specula is always necessary (Rodriguez Morris and Hicks 2022; Snijder and Broeren 2022). During surgical procedures, this is evident, in other conditions (ambulant care, outpatient clinics), this is less necessary, and washing at high temperatures may be sufficient, to achieve a high level disinfection as specula come in contact with mucous membranes (Snijder and Broeren 2022). *The use of (double) packaging of reusable specula in sterilisation bags should also be questioned (Rodriguez Morris and Hicks 2022).*

Single-use specula made from biobased plastics have a smaller carbon footprint compared to single-use made from fossil based plastic. At first glance, this could be the preferred option for single-use specula. However, biobased plastics are perceived as more environmentally friendly than conventional fossil plastics, but this is questionable. Bio-based plastics might increase plastic pollution, exaggerate climate change such as ecosystem degradation, deforestation, water scarcity, and harm biodiversity, and create competition with crops intended for human consumption. In the EU policy framework on biobased, biodegradable and compostable plastics (European Commission 2022a), the European Commission states that producers should minimize use of primary biomass and prioritise the use of organic waste and by-products as feedstock. If nevertheless biobased plastics are used, producers should ensure it does not cause harm to biodiversity or the ecosystem, for example by ensuring that they contribute to the circular economy (European Commission 2022a).

Table 42: Comparison of single-use and reusable medical material based on exploratory literature search

Comparing SINGLE-USE vs. REUSABLE based on exploratory literature search				
	Aspect ENVIRONMENT		**Aspect COSTS**	
	SU	**RU**	**SU**	**RU**
Instrument/device				
Laryngoscope	~		-	+
Flexible endoscope	~		~	
Trocar	~ *Depending on sterilisation process*		-	+
Laparoscopic stapler, cutter, scissors, clip applier	-	+	**nd**	
Surgical scissors	-	+	-	+
Reusable solid containers vs single-use blue wrap	-	+	-	+
Sharp container	-	+	**nd**	
Gowns/coverall	-	+	**nd**	
Laryngeal mask airway	-	+	**nd**	

SU: single- use; RU: reusable; nd: no data found; ~: no clear difference is found; +: in favour of; -: not in favour of

Table 43: Comparison of single-use and reusable medical material based on the studied items

Comparing SINGLE vs. REUSABLE based on studied items								
	Aspect ENVIRONMENT		**Aspect COSTS***		**Aspect SAFETY**		**Aspect EFFICIENCY**	
	SU	**RU**	**SU**	**RU**	**SU**	**RU**	**SU**	**RU**
Instrument/device								
Kidney tray	-	+	+	-	=		+	-
	Impact disinfection		*Disinfection/labour*				*Labour/time*	
Blanket	-	+	-	+	=		=	
							Depending laundry external/internal	
Vessel sealer	-	+	-	+	=		+	-
					If adequately cleaned and sterilised			
Cover cap thermometer**	-	+	-	+	=		-	+
	LCA							
Vaginal speculum	-	+	=		=		+	-

*SU: single-use; RU: reusable; LCA: life cycle analysis; *Cost is based on catalogue prices; **In case of the thermometer cover caps: RU stands for the absence of the need of cover caps or wipe for use in multiple patients; and SU includes the use of cover caps for use in multiple patients*

Conclusion:
Taken together, the overall conclusion is that as far as the **environment** is concerned, the reusable equivalents of the devices are favourable, except for laryngoscopes, flexible endoscopes and trocars. The emerging picture as far as **costs and efficiency** is concerned is mixed although in most cases, using the single-use device is more expensive. The conclusions are less evidence/literature based because in most cases data on the impact of costs for labour and/or time for e.g. re-sterilisation of reusable items are lacking or are unknown. In terms of **safety**, there is equivalence between the 5 studied single-use and reusable devices.
The authors are aware of the limitation being the shortness of data, which prevents unequivocal conclusions. However, we are convinced that the main findings are mentioned, allowing the most balanced conclusions possible.

7.2 Limitations

In this study, we encountered challenges in analysing and comparing the medical items due to context specificity, data incompleteness, underrepresentation of actual costs and reliance on assumed information.

Firstly, the literature overview was exploratory, rather than conducting a systematic review. The authors chose to elaborate on items of which at least two LCA's were available in the literature and to focus on sustainability. As a consequence, other themes such as efficiency, cost, safety were not (fully) addressed, and only a limited number of single-use devices were included in the literature overview. Furthermore, the result of an LCA was always connected to a specific location and working method. Therefore, not all results from the literature review concerning the level of sustainability can blindly be copied to the Belgian healthcare system. However, this overview did offer valuable insights into the various medical devices that have been the subject of sustainability research, and their results.

Secondly, some limitations on amount and cost of medical materials need to be addressed. Because of the COVID-19 pandemic, purchase data of 2019 were requested since it was assumed that the hospital activities during the pandemic were not representative for normal hospital activities. However, it is likely that a further shift has occurred from reusable to single-use in recent years which might have led to an underrepresentation of real consumption and costs of medical items. Interviews with stakeholders mentioned, for example, single-use blood pressure cuffs and single-use bedpans which were not fully captured by this survey. The use of isolation gowns and masks was not prominent in 2019, yet exploded during the pandemic, and will possibly remain high in the coming years.
Furthermore, data from 2019 were used for hospital prices, and 2023 data for catalogue (list) prices. The 2019 prices were not indexed in the study. However, given the limitations of data collection of the hospital survey, the prices collected were used for illustrative purposes only.
The purchase cost was based on the publicly available catalogue prices since the hospitals were reluctant to share their individual prices. Consequently, the purchase costs overestimates the price paid by hospitals which biased the cost results in chapter 5. In this study, the costs of single-use and cost of reusable items often seemed comparable or in favour of reusables. However, it should be noted that hospitals (often) negotiate better prices than the catalogue prices. Due to the limited response regarding the cost part of the hospital survey, this aspect could not sufficiently be addressed.

Thirdly, considering that the sustainability of the items included in chapter 5 was not examined by an LCA (and only emissions of the raw materials could be included), the conclusions on environmental sustainability should therefore be interpreted with caution. As conducting an LCA is a complex and time-consuming process, it was not feasible to perform it for the other items within the scope of this project.

Fourthly, an assumption was made for the lifespan of the items and devices included. For example, concerning the reusable specula, the manufacturer did not specify an instrument lifetime on its technical data sheet or instrument information. Reusable specula were more sustainable compared to their single-use alternatives, in literature even after two, three or seven uses (Rodriguez Morris and Hicks 2022, Snijder and Broeren 2022), a correct lifespan of reusable specula may therefore be less crucial for the interpretation of the results.

A life cycle analysis is context specific. For example, the source of energy (coal, oil fuel, solar power, nuclear) influences the carbon footprint. For this reason scenario analyses were performed to enhance generalisability.

Finally, the goal of this exploratory research was to identify medical items with a high consumption or cost in Belgian hospitals, and to provide insights in possible environmental more sustainable alternatives, including also safety issues, cost, and efficiency of use. This resulted in the description of five items as provided above, and the recommendations below. To elaborate on concrete proposals to existing legislations at the different levels (federal and regional), as well as the definition of competences needed to implement certain recommendations are beyond the scope of the study and the area of expertise of the researchers and (nonetheless widely) consulted stakeholders. Nevertheless, the research conducted does allow following cautious recommendations to be made and listed (See 7.3 and Table 44).

7.3 Recommendations

From the hospital survey, the findings related to the items studied (including the LCA) and the stakeholders consultations, the following recommendations emerged. The recommendations are listed in order of priority based on circular strategies. Therefore, we employ the waste management hierarchy, originally introduced by Lansink's ladder in 1979. The original waste management hierarchy consisted of five steps from prevention, preparing for re-use, recycling, recover to disposal (Lansink 2018).

In the boxes, we identified practice requirements and proposed corresponding recommendation to stimulate sustainability. Table 44 summarises a gap analysis and recommendations to improve environmental sustainability in the use of medical items.

1. PURCHASE OF MEDICAL DEVICES AND ITEMS

- Need for information on sustainability of medical devices and items in the procurement process
- Need for integrating reusable options in the procurement process

IT IS RECOMMENDED TO:

Integrate following elements in the procurement process:

- Let sustainability criteria weigh on purchase decisions
- Involve a sustainability coordinator/team

Implement the principles of the digital product passport (EU) for medical devices, but also broader for all medical items or materials used in healthcare

Include also the reusable option a procurement file

- Adapt (public) procurement legislation accordingly
- Adapt public tender EU legislation accordingly

Encourage the use of reusable materials and/or discourage single-use materials

- Prioritise on single-use medical items with high volume, weight, environmental impact per item, cost
- Make cost of reusable more attractive than of single-use
- Financing (pilot) projects on studying reusing medical items and disinfection methods

Encourage hospitals or hospital networks to have a sustainability coordinator and green teams who promote environmentally sustainable healthcare and advocate for changes at various levels. This could be implemented comparable to the Hospital Outbreak Support Teams (HOST) pilot projects

Provide training of sustainability coordinator in healthcare

Several reasons, such as low purchase cost, ease of use, patient safety, time savings, past disease outbreaks, and recently, the COVID-19 pandemic, have driven hospital's procurement decisions to shift to single-use materials, resulting in a higher ecological footprint of global healthcare, and more specifically hospitals . This shift towards using single-use materials instead of reusables is still ongoing in healthcare. The COVID-19 pandemic has further intensified and accelerated this process, despite temporary market

shortages for all types of single-use materials and devices (Rizan et al. 2021). This situation has led to the implementation of creative solutions, the exploration of (reusable) alternatives within hospitals, and methods to safely reuse available materials. Although these challenges have demonstrated that reusable alternatives were possible and feasible, and that materials could often be used for longer periods than initially indicated by manufacturers, many of these solutions were temporary contingencies rather than well-designed and thoroughly tested sustainable alternatives. The legislative framework and significant personnel shortages were strong drivers in the choices to abandon most, if not all, of these contingency solutions as soon as the usual materials were available again. Environmental implications were seldomly considered in these purchase discussions.

The purchase department has a crucial role in optimising circular strategies in the hospital and can stimulate an environmental awareness. However, there is no legal requirement to include sustainability criteria or a sustainability coordinator in the procurement process (award criteria). Currently, there is no requirement for procurement of medical devices to ask information on raw materials, production process, packaging, transport, recycling/remanufacturing, sustainability efforts of compagnies. Hospitals are in no way encouraged to use reusables; and there are no incentives to promote the preference to reusable medical items, except reduction of the costs for hospitals.
Moreover, there is no mandatory requirement for hospitals to designate a sustainability coordinator. Hence, it is essential to appoint a sustainability coordinator, ensure their adequate training, and involve them in the procurement process to effectively address sustainability concerns. This coordinator can be part of a green team in the hospital, some Belgian hospitals have established dedicated green teams to enhance sustainability efforts. In several countries, these teams are already well-developed (f.i. the Netherlands: https://milieuplatformzorg.nl, Canada: https://greenhealthcare.ca/,UK: https://sustainablehealthcare.org.uk).

A limited number of hospitals have a sustainability coordinator, but a specific training for sustainability coordinators (in healthcare) is lacking. Furthermore, sustainability is not, and if so, only to a very limited extent, included in healthcare training programmes (Visser et al. 2022). However, having knowledge of sustainability, the impact of materials, and the lifecycle impact of medical devices, etc. is crucial in making environmentally friendly choices, also in terms of purchasing materials. Moreover, a lack of knowledge can potentially result in greenwashing (European Commission 2022b). From the LCA in this study, a biobased plastic polylactic acid (PLA) specula was evaluated which at first looks good, but the LCA proves the opposite.

For hospitals, other institutions, and researchers it is crucial to have access to detailed information on the materials used in medical devices (specific composition and type of chemicals used, weight, transportation method, mining location of raw materials, and manufacturing process) as well as the processes involved (water and energy use, detergent composition and usage), in some cases also costs. Moreover, the availability of this information is necessary to study the sustainability of medical devices, including LCA's and LCC's.
Each hospital could decide which specific single-use items they wish to prioritise, considering factors such as purchase volume and cost, similar to the approach adopted in this study. Additionally, environmental impact per item and weight of the device could be taken into account as may indicate high consumption of raw material; and it is essential to take safety issues into consideration.

Consequently, it is advisable to consider the following possible criteria in a procurement process:

a) Comparability of reusable devices with single-use items
b) Detailed information on the raw materials used: exact composition and weight. Further considerations:
    - E.g. where mined
    - E.g. paper: recycled paper (instead of virgin paper), ecolabel certification, chlorine free paper
    - E.g. textiles: type of fibre (e.g. recycled fibres instead of cotton), free of hazardous chemicals
    - Avoid disposable stainless steel, and other high-grade materials for single-use purposes
c) Transparency regarding the production process (location, type of process(es), use of chemicals)
d) Detailed information on packaging (exact composition and weight)
e) Consideration of transportation factors (type and distance)
f) Guidelines for recycling, remanufacturing and waste treatment (including advice and possibilities)
g) For medical devices with batteries: manufacturers need to add an instruction sheet including information whether the batteries are rechargeable or removable, if they can either be reused or recycled, so waste containing batteries can be avoided
h) Evaluation of the sustainability efforts made by the company

European law mandates that all listed companies (except listed micro-enterprises) must provide information on what they see as environmental risks and opportunities and on the impact of their activities on the environment. This must also be done for their social impact. European companies (including hospitals) meeting the criteria will be required for the Corporate Sustainability Reporting Directive (CSRD) according to scope 3 for their reporting in 2026 (on 2025) (Europese Commissie 2022). This will oblige suppliers to report and reduce their environmental impacts.
However, more legislation is needed to boost companies to include sustainability criteria as part of a (public) tender. The principle of the European commission's digital product passport proposal (Ecodesign for Sustainable Products Regulation) could potentially help, as well as for the medical device as for its packaging (European Commission 2022b).

Ideally, based on the aforementioned information, it would be advantageous for medical devices to be assigned an environmental sustainability rating or code. This would assist hospitals in making informed and sustainable choices. However, we acknowledge that due to the complexity of this matter, implementing such a system is not straightforward.

2. SUSTAINABILITY OF ADDITIONAL MEDICAL ITEMS AND DEVICES

- Need for more sustainability information on other high volume and high cost single-use items
- Attention to correct and rational use of single-use medical items that cannot be replaced by more sustainable options (e.g. gloves)

IT IS RECOMMENDED TO

- Stimulate further research on
  * Sustainability of the other frequently used items of the shortlist
  * Sustainability of disinfection processes
  * Comparison between single-use surgical instruments with reusable instruments utilising in-house sterilisation or external sterilisation company by conducting an LCA in combination with an LCC
- Further support the campaigns on hand hygiene with special attention to correct glove use, including the perspective of environmental sustainability
- Sensibilisation campaigns on environmental sustainability themes in health care

When literature was juxtaposed with the results of the hospital survey, it became apparent that for many of the items with high consumption in Belgian hospitals, there has been little to no research yet on more circular alternatives. This study only investigated five items out of the 28 medical items with high consumption or with a high cost in Belgian hospitals. However, each of the selected items was intended to serve as an example for a whole group or category of items. We hope this report succeeds in this endeavour. Nevertheless there are certainly more items where further investigation would be of added value. Therefore, further research into the sustainability of the remaining items is recommended. Evidence-based information from studies that are well and thoroughly conducted can help healthcare professionals (ranging from people on the floor such as physicians, cleaning staff, nurses and paramedics over hospital hygiene teams, purchase and financial departments to hospital management) to enable changes in phasing out single-use materials in favour of more sustainable options.

There is often lack of or limited evidence-based information available on the environmental sustainability of commonly used single-use and reusable items and existing research does not always provides a clear understanding. For example, we identified a potentially significant impact related to the cleaning and disinfection process, especially in the case of kidney trays. Further research is needed, including an assessment of the environmental impact of single-use disinfection wipes versus disinfection sprays with reusable or disposable wipes, as well as thermal disinfection. In order to make well-founded statements about the sustainability of medical devices, conducting an LCA specific to the device in question is necessary. Additionally, conducting an LCA that specially compares disinfection methods is crucial in the context of reusing medical devices and making informed decisions on the application of reusable materials.

A number of hospitals in Belgium work with single-use surgical instruments (scissors, tweezers, …), others with reusables which are cleaned, disinfected and sterilised in an in-house sterilisation department or in an

external sterilisation facility. Practitioners and stakeholders indicate the need for research comparing the environmental impact of these options, as evidence based information is currently lacking.
At the top of all purchase lists of the participating hospitals, gloves (non-sterile, followed by sterile) were identified. This item was not further addressed in this study, as it was not the focus of the study. A reusable alternative is not (currently) available, and recycling is not (yet) an option. In order to address glove use, the main effort should be on behavioural change to discourage use outside the correct indications, and to address overuse. Perhaps, it might be worth considering a reassessment of the indications for glove usage. The correct use of gloves was the focus of the 10th national hand hygiene campaign (2022-2023). However, the focus of the campaign "Use gloves rationally, this is essential" was only on infection prevention. A broader view where cost and sustainability were considered alongside safety would certainly be appropriate. Research into the ecological impact of correct use of gloves and the effect of sensitisation campaigns is recommended.

3. PRACTICAL IMPLEMENTATION OF ENCOURAGING REUSE OF MEDICAL ITEMS AND DEVICES IN NEED OF CLEANING, DISINFECTION AND/OR STERILISATION

a) Need for optimisation of the logistics process of cleaning and disinfection
b) Need for expansion of disinfection and sterilisation capacity

IT IS RECOMMENDED TO

– (Pilot) study the practical issues related to augment the disinfection capacity for reusable devices,
– Cost-benefit study on outsourcing the sterilisation of reusable medical items and devices
– Encourage hospitals to use renewable energy and explore the possibilities of collaborations with other industries for example to use waste steam

Importantly, switching from a single-use to a reusable equivalent is not just a switch of materials, but mostly a switch of logistics, habits, and procedures. Of utter importance is the possibility to clean, disinfect and/or sterilise the reusable medical devices in a proper, safe, cost-effective, efficient and sustainable way.

Currently, most hospitals are not logistically ready to switch from single-use to reusable, especially with the non-critical items. On the contrary, the transition from reusable to single-use is still in full swing. To reuse non-critical medical devices, the washing/cleaning and disinfection capacity needs to be expanded. As mentioned above, the most sustainable way to disinfect has yet to be clarified.
If thermal disinfection is indicated, an automatic washer may be useful. However, not to burden the central sterilisation department with cleaning and disinfecting material (not sterilising), an automatic washer on the nursing ward is needed. Comparable to the bedpan washer on the nursing units, but separately because of hygienic reasons, may be an option. When a washing machine is available on the wards, the logistic process will also be simplified. When the logistics of disinfecting and/or sterilising processes are optimised for one medical device, it is often optimal for most other medical devices.

As indicated in this study, cleaning and disinfection of reusable non-critical material may require more time and manpower. It should be examined for which healthcare professional this task is most suitable. For instance, this could be included in the responsibilities of a logistic assistant or other healthcare support workers.

The semi-critical and critical items can follow the logistic process of the central sterilisation department. However, these additional material flows, separation of clean and dirty materials, need to be elaborated in each hospital according to their infrastructure, bearing in mind that hospitals, for instance an outpatient clinic, often have no suitable location to deposit their dirty items.
Additionally, if more items need to be processed by the central sterilisation department, the capacity needs to be adjusted. Eventually, the central sterilisation department needs to be expanded or the possibility of outsourcing certain materials to external sterilisation companies can be investigated. The opportunities for regional collaborations or cooperation within hospital networks could offer opportunities. For this, a cost-benefit study is needed.

Furthermore, hospitals should be encouraged to use renewable energy and where possible to explore collaborations with surrounding companies to reuse, for example, residual heat/steam. Also, efficient water recycling can be applied, for example by reusing cooling water from steam pipes, etc. (Hoge Gezondheidsraad 2023). The results of the scenario analyses on the LCA on vaginal specula gave insight in

the importance of the use of an energy mix from renewable sources, and the use of steam generated as a by-product of other industry (here waste incineration). In the study of Snijder and Broeren (2022) a cogeneration power plant was used to generate the steam used for sterilisation. The authors found that 40% of the carbon footprint of reusable specula was related to steam generation during sterilisation (Snijder and Broeren 2022). In our study the impact of treatment in the central sterilisation department (cleaning, disinfection and sterilisation) increased by a factor of 10 by adjusting the method of generating steam. Encouraging hospitals to use alternative ways of generating (a part of the) steam and relying on renewable energy sources can reduce the climate impact of reusable devices in need of sterilisation, and thereby the full sterilisation unit.

4. INTRODUCE MORE REUSABLE (MEDICAL) TEXTILES
- Need for more reusable textile alternatives
- Need for expanding the logistic process

IT IS RECOMMENDED TO
- Include the reusable option in the procurement process
- Encourage studies on the development of reusable alternatives in textile
- Encourage financially the use of reusable textile alternatives

Because of the large volume, the blanket was chosen to elaborate on the category laundry. Since the pandemic, medical textiles such as isolations gowns are used in large amounts, and this is likely to continue for the next years. Because of worldwide shortages, there was a switch to reusable alternatives due to necessity. This use was again abandoned once single-use gowns were available. However, based on literature (Vozzola et al. 2020; Bijleveld and Uijttewaal 2022; Vozzola et al. 2018a, b), as well as our findings on the item blanket (Chapter 5), the utilisation of reusable textile materials emerges as the most favourable approach.

When using more reusable textiles, the logistics process should adapt accordingly comparable to the flow process already used in hospitals for bedlinen. If a hospital collaborates with an external laundry service, this laundry service could invest in reusable textiles that would be rented out to the hospital. Conversely, if the hospital has its own laundry, the hospital needs to invest in these textiles.
For some items a high quality alternative is (already) available (eg. bibs), but single-use alternatives are often cheaper to purchase (per piece). Due to hospitals' high financial pressure, efficiency exercises are indicated. Making sustainability a criterium in the purchasing process, on top of the costs, with sufficient impact is indicated. We align with Health Care without Harm's recommendation that, in situations where both reusable and single-use options are available, preference should be given to the reusable alternatives, and the ongoing shift from reusable towards single-use textiles should be stopped (e.g. blankets, sheets, bibs, washing cloths). When reintroducing reusable medical linen products, the procurement criteria for reusable textiles should to be included in the purchase process (Health Care Without Harm Europe 2022).

Further research is required to clarify whether the use of reusable gowns and other linen is more interesting than single-use alternatives. Similar challenges exist for other single-use medical textiles such as surgical caps which have also a high consumption, but have possibilities for reusable alternatives. However, the supply of reusable textiles with the required standards in the market is limited (Hoge Gezondheidsraad 2018). The Belgian government is currently stimulating research on ecodesign in the clothing textile industry aiming at reducing the environmental and health impact of products and materials throughout the product life cycle (Belgium Builds Back Circular). This could be stimulated also for medical textiles. A Flemish project reCURE on medical reusable surgical gowns and surgical drapes is ongoing. That study investigates the acceptability and desirability of these items and also the optimisation in terms of functionality (reCURE | Reuse Lab | Universiteit Antwerpen (uantwerpen.be). This study is a good initiative, but much more research is needed to develop and test alternatives for other items (e.g. for isolation gowns, surgical caps, …). Moreover, funding for this type of studies on sustainability is limited or lacking.

5. USE OF REMANUFACTURED MEDICAL DEVICES
- Need for more use of remanufactured medical devices

IT IS RECOMMENDED TO
- Review legal obligations/regulations necessary for reusing medical material after remanufacturing (within safety standards)
- Increase the opportunities for medical device certification

The regulations around remanufacturing/refurbishment of medical devices are very stringent and hinder companies to invest on this domain (Srivatsav et al. 2017).

The Medical Device Regulation (MDR) EU 2017/745 (05 May 2017) is a European regulation on medical devices which has been in force since 26 May 2021. The aim of this European legislation is to ensure the safe use of medical devices. Reprocessing of single-use devices (article 17) is part of this Medical Devices Regulation. However, the topic "Single-use devices and their reprocessing" is reserved for the Member States to regulate by their national law. Consequently, each Member state can decide to permit the reprocessing of single-use devices. Thus, there are differences between countries.

Belgium has chosen to permit reprocessing provided that compliance with implementing regulation 2020/1207 and, consequently, regulation 2017/745 can be demonstrated to a notified body (Hoge Gezondheidsraad 2023). This is described in section 6 article 12 of the law of 22 December 2020 on medical devices and chapter 3 article 6 of the Royal Decree of 12 May 2021 implementing the law of 22 December on medical devices. One can opt for reprocessing through an external reprocessor that complies with the current regulation and legislation. Alternatively, one can also decide to perform reprocessing within their own healthcare facility, following the guidelines outlined in Article 17 of MDR 2017/745 and implementing regulation 2020/1207.

An external remanufacturer needs to be certified as a manufacturer which implies stringent regulations: CE regulation. For remanufacturers, it is difficult to find a notified body that can certify for Common Specification. Common specifications are detailed practical rules setting out how particular types of devices should comply with certain requirements of Regulation (EU) (2017/746EN) EUR-Lex - 02017R0746-20230320 - NL - EUR-Lex (europa.eu). Similarly, also for hospitals it is difficult to fulfil the requirements for remanufacturing. Moreover, the control, maintenance, repair, and testing of functionality, as stipulated in Article 17 of MDR 2017/745 and implementing regulation 2020/1207, will certainly pose an additional challenge for hospitals.

Clearly, the remanufacturing of medical devices must be done within safety standards and strict regulations are needed to ensure quality and safety.

6. OPTIMISING MEDICAL WASTE SORTING FOR RECYCLING
- Need for sorting waste correctly according to the current regulations: NHMW, HMW, PMD, other waste streams
- Need for participation to additional existing alternatives to avoid waste and promote recycling

IT IS RECOMMENDED TO
- Sensitise hospitals to sort optimally according to the authorised recycling streams e.g. plastic medical packaging with PMD waste, (non-confidential) paper with paper/carton
- Review the waste legislation of hazardous medical waste and non-hazardous medical waste to potentially recycle more
- Encourage research aimed at rethinking the material and amount of material used for essential packaging
- Stimulate manufactures to develop reusable medical devices instead of single-use medical devices to reduce medical waste

Currently, some authorised recycling streams are not (fully) practised in hospitals. For instance, since July 2022, plastic packaging of medical devices may be collected with PMD waste in Flanders (Plastic, Metal and

Drink packaging) (Fostplus 2023). Examples of these medical plastic packaging are the packaging of disinfectant wipes, vial of hand alcohol, packaging of linen and packaging of sterilised material. Obviously, packaging that poses a potential risk due to the presence of residues of hazardous active substances and packaging from infectious patients that poses a possible contamination risk do not belong in the PMD bag. By collecting these plastics with PMD, it is diverted from incineration and can be recycled. Sensitise hospitals to sort waste correctly and according the current regulations is needed.

Furthermore, focus on collecting as much (non-confidential) paper and cardboard as possible separately and not depositing it with the NHMW.
Correctly sorting NHMW and HMW remains also an area of concern. If NHMW is sorted as HMW this implies unnecessary consumption of HMW plastic containers or cardboard boxes and unnecessary high temperature incineration.
Hospitals have to adhere to the waste legislation of its region in Belgium (Flanders: VLAREMA - Flemish Regulation on the Sustainable Management of Material Cycles and Waste; Wallonia: Décret relatif aux déchets, Brussels-Capital Region: Ordinance on Waste).

In addition to the already existing waste streams, there are various initiatives and projects aimed at optimising medical waste for recycling. These initiatives are sometimes funded by the region (f.i. Vlaanderen Circulair). Also several waste and recycling companies have committed to implementing waste sorting practices. Examples of already existing initiatives in Belgian hospitals to collect and recycle disposables are:

- Single-use PVC medical devices, such as oxygen and anaesthetic masks, tubing, IV and dialysis bags, are transformed into e.g. vinyl wall covering (VinylPlus Med)
- Polypropylene blue wrap (sterilisation wrap)
- Surgical staplers
- Single-use steel instruments

Considering the aforementioned initiatives, it would be beneficial to review the current medical waste legislation (both for NHMW and HMW), as there is potential for environmental benefits by reducing incineration and increasing the recycling of medical waste. It is obvious, that this must be done within the limits of safety.

The use of reusable materials can be encouraged by making the use of single-use more costly or penalise the amount of waste, as is the case in Geneva (Peters 2022). Where governmental institutions are penalised if less than 70% of all waste is recycled. The Hospital of Geneva also included in its sustainability strategy to *"quantify the use of single-use equipment and identify ways of the most effective reduction or replacement"* (Hôpitaux Universitaires Genève 2022).

An identified problem with disposal of packaging of medical devices is that it often composed of different types of material. For instance, sterilisation bags are made from paper and laminated plastic. It is practically possible to separate these two materials manually when unpacking an dispose them separately as paper and NHMW. The additional problem is the laminated plastic part, which is made of four layers of plastic and one layer of glue, not can be recycled. Although it is currently already technically possible to separate these layers for recycling, this is not yet standard practice in waste management and recycling plants (Ragaert et al. 2017). Consumption of these bags is very high in hospitals. Rethinking the construction and composition of current sterilisation bags to make them more suitable for recycling, is recommended.

Ideally, manufacturers should be made responsible for the disposal of single-use medical devices and consider recycling or reprocessing the device. First of all, this requires notification of the exact material composition of the device and the packaging. Further, in the instruction manual, the necessary actions to safely collect the devices for recycling should be mentioned. For complex materials with a high environmental impact per item, such as single-use laparoscopic devices (vessel sealer, clipper, scissors, trocars, …) manufacturers could be stimulated or made (financially) co-responsible for the disposal of their device and packaging materials. Subsequently, consideration should be given to finding effective ways to incentivise manufacturers to prioritise the development of reusable systems, rather than persisting in investing in single-use alternatives that have significant environmental impacts on both materials and packaging.

Table 44: Overview gap analysis and recommendations to improve the environmental sustainability when using medical items

Recommendations for practice	Gaps	Recommendation for government/policy	Based on
Purchase department Integrating in procurement process: - Sustainability criteria - Sustainability coördinator/team	The procurement process lacks information on: - Reusable alternatives - Raw materials (exact composition and weight) - Production process (location, type of process(es), use of chemicals) - Packaging (exact composition and weight) - Transport (type and distance) - Recycling (which items and how)/remanufacturing (inclusion of advises and possibilities)/ waste treatment (if the above is not possible, see points 2 and 3) - Sustainability efforts of the compagnies No incentives to give preference to reusable medical items No/limited evidence based information on environmental sustainability of (frequently used) single-use/reusable items. No obligation to include sustainability criteria and a sustainability coordinator in procurement process (award criteria) No specific training sustainability coordinator (health care) Risk of greenwashing	Implement the principles of the digital product passport (EU) for medical devices, but also broader for all medical items or materials used in health care. - Public procurement legislation - Public tender: EU legislation - In a procurement file: include/compare also the reusable option Encourage use of reusable materials - By making cost of reusable more attractive - Financing pilot projects - Encouraging waste avoidance Introduce sustainability coordinator/team in hospitals. Provide professional training for sustainability coordinator	- LCA - Items - Stakeholder involvement - Hospital survey - Stakeholder involvement - Stakeholder involvement - Stakeholder involvement

	Hospitals (need to) rely on firms' subjective information and/or LCA's		
Sustainability information of other medical items /devices: - Need for more sustainability information on other high volume and high cost single-use items.	- Lacking information on sustainability of frequently used medical devices - No (or limited) financing for research on sustainability. - Need for correct and rational use of single-use medical items that cannot be replaced by more sustainable options (e.g. gloves)	- Stimulate further research on sustainability of other items of the long list - Ensure funding for high-quality research on sustainability (on alternatives for single-use materials) - Further support the campaigns on hand hygiene with special attention to correct glove use.	- Hospital survey - Literature - Stakeholder involvement
Practical implementation of encouraging reuse of medical items and devices in need of cleaning, disinfection and sterilisation.	- Need for optimisation of the logistics process of cleaning and disinfection - Need for expansion of disinfection and sterilisation capacity	Pilot study - On the practical issues related to augment the capacity of disinfection of reusable devices - To compare environmental impact of several cleaning and disinfection methods Encourage hospitals to use of renewable energy and the possibilities of collaborations with other industries (e.g. use of waste-steam)	- Hospital survey - Literature - Stakeholder involvement
Introduce more reusable textiles	- Reusable textiles are not often used in hospitals - Limited reusable alternatives on the market - Need for expansion of the logistic process - Reusables are not always financially attractive - Need for inclusion of reusables in the procurement process	- Encourage development of (safe) reusable alternatives in textile by studies - Financially encouraging the use of reusable textile alternatives - Include reusable option in procurement process	- Hospital survey - Literature - Stakeholder involvement
Use of remanufactured devices e.g. vessel sealers, … (extend the life cycle)	- Limited supply of remanufactured medical devices. - Strict MDR regulation impedes reprocessing and remanufacturing of medical devices.	- Adapt Medical Device Regulation (MDR) EU 2017/745 (05 May 2017) within safety standards - Increase opportunities for medical devices certification	- Hospital survey - Stakeholder involvement

Optimising medical waste sorting for recycling	- Some recycling possibilities are not fully practiced in hospitals (e.g. plastic packaging) - More possibilities for recycling in hospitals, currently individual and voluntary initiatives e.g. single-use PVC, polypropylene blue wrap, surgical staplers, single-use steel instruments,… These items are normally collected as hazardous or non-hazardous medical waste. - No information on the exact material composition of medical devices and packaging which is needed correctly collect the devices. - Some materials cannot be recycled.	- Sensitise hospitals to sort optimally according to the authorised recycling streams e.g. plastic medical packaging with PMD waste, (non-confidential) paper with paper/carton. - Review the waste legislation of hazardous medical waste and non-hazardous medical waste to potentially recycle more. - Introduce principles of digital product passport for product and packaging (see before). - Encourage research aimed at rethinking the material used for essential packaging.	- Literature - Stakeholder involvement

CONCLUSIONS

The results of this project demonstrate clearly that decisions on whether to use single-use or reusable medical items within a hospital cannot be taken light heartedly. Remarkable was the evidence gap noted by the lack of existing studies on environmental impact (LCA's) on many of the items on the longlist compiled from the procurement data of the twelve participating hospitals. The exploratory literature review includes items for which at least two LCA's were available.

For the five selected devices, the study evaluated their sustainability and circularity alternatives. Reusable kidney trays appeared to be more environmentally friendly, but disinfection methods and costs played a significant role. Reusable blankets were found to be more sustainable and cost-effective, for hospitals using an external laundry. Single-use cover caps for thermometers were less costly and more sustainable than when disinfection wipes were needed between patients, but non-contact thermometers turned out to be most favourable when looking at sustainability, cost and efficiency. Reusable or remanufactured vessel sealers were environmentally beneficial with comparable safety if cleaning, disinfection and sterilisation can be done properly, but single-use sealers were more efficient due to sterilisation time.

For the comparison of the environmental impact of single-use and reusable vaginal specula, an LCA was conducted. Reusable vaginal specula were the most environmentally favourable option, with major impact of the packaging materials for reusable specula and raw materials and manufacturing for single-use specula. The use a renewable energy, waste-steam and double sterilisation bags importantly impacted the results of reusable specula.

Considering that we have to prevent waste and that raw materials are not inexhaustible, circularity is key. For medical devices our data suggest that we will have to move towards reusing or, if that is not possible, recycling, remanufacturing, … This shift will have major consequences for manufacturer, but also for healthcare organisation and workers. Maybe one of the major obstacles in elaborating this shift is to adapt entrenched habits. Our results deliver an instrument to convince people to change. Further high-quality research, such as properly conducted life cycle assessments as well as implementation research, is recommended to make conclusive decisions, support healthcare organisations in their procurement discissions, and overcome practical obstacles.

Overall, the project provides valuable insights into the potential for replacing single-use medical devices with reusable alternatives. The findings contribute to the broader efforts of hospitals to reduce waste, promote sustainability, and align with the circular economy principles.

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9 APPENDICES

9.1 APPENDIX 1: Evidence table LCA's Methodology

Laryngoscopes

Refence (year, country)	Method LCA	Functional unit	System boundaries	Raw materials	Manufacturing (Packaging)	Distribution	Use phase/reuse	EoL/Recycling	Inventory databases
McGain et al. (2017, Australia)	ISO 14040 standards Consequential Using Monte Carlo analysis	Not specified	Not specified	Yes	Yes	Yes	Yes	Yes	LCI's, Ecoinvent, Swiss Centre for Life Cycle Inventories, Zurich Switzerland
Sherman et al. (2018, US)	ISO 14040-44 standards Attributional LCA & LCC	1 handle and 1 blade for a single patient encounter	Cradle to grave	Yes	Yes	Yes	Yes	Yes	Ecoinvent adjusted for US energy system (US-EI database, Earthshift, Huntington, VT)

LCC: life cycle cost; EoL: end-of-life

Flexible endoscopes

Reference (year, country)	Methodology LCA	Functional unit	System boundary	Raw material	Manufacturing (Packaging)	Distribution	Use/Reuse	EoL/ Reclycing	Inventory database
Badoudjian et al. (2022, France)	ISO 14040-44 standards Attributional	SU: one cystoscope RU: reprocessing a cystoscope one time	Cradle-to-grave	SU: Yes RU: No	SU: Yes RU: No	SU: Yes RU: No	RU: Yes	SU: Yes RU: No	Ecoinvent
Bringier et al.(2023, France)	ISO 14040-44 standards Attributional	2000 uses of a flexible bronchoscope *(200 tracheal intubations per year for 10 years)*	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes	Ecoinvent
Davis et al. (2018, Austrialia)	Not mentioned Attributional	Use of one ureteroscope	Cradle-to-grave	Yes	Yes	No	Yes (RU)	Yes	Not mentioned
Duijndam (2022, The Netherlands)	ISO 14040-44 standards Attributional	450 uses of flexible intubation scopes	Simplified cradle-to-grave	Yes	Yes	Yes	Yes	Yest	Ecoinvent
Hogan et al.(2022, Ireland)	Not mentioned Attributional	Use of one cystoscope	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes	Not mentioned
Kemble et al. (2023, US)	Not mentioned Attributional	One use of cystoscope	Cradle-to-grave	-	Yes	Yes	Yes	Yes	Not mentioned

Le et al. (2022, US)	Not mentioned Exploratory LCA Attributional	One endoscopic retrograde cholangiopancreatography (ERCP) procedure	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes	Ecoinvent
Sørensen and Grüttner (2018, Danmark)	Simplified LCA ISO 14040-44 standards Attributional	Use of one bronchoscope	Focus on use and EoL SU: Cradle-to-grave RU: Reuse-to-grave	SU: Yes RU: No	SU: Yes RU: No	SU: No RU: No	SU: No RU: Yes *(using/washing/ sterilisation drying/storing)*	SU: Yes *(recycling all recyclable material and incineration with energy recovery of scope + PPE Packaging)* RU: Yes *(disposal PPE)*Not mentioned	Not mentioned

SU: single-use, RU: reusable; PPE: personal protective equipment; EoL: end-of-life

Trocars

Refence (year, country)	Method LCA	Functional unit	System boundaries	Raw materials	Manufacturing (Packaging)	Distribution	Use phase/reuse	EoL/Recycling	Inventory databases
Boberg et al. (2022, Sweden)	ISO 14040-44 standards Attributional	500 uses of single-use, reusable, and mixed (SU and RU) trocar systems	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes *(disposal/ recycling)*	Econinvent
Rizan and Bhutta (2022, UK)	ISO 14040-44 standards Attributional	Number of 3 types of instruments required to perform one laparoscopic chole-cystectomy (= 2 small diameter ports, 2 large diameter ports, 1 laparoscopic scissor, and 1 laparoscopic clip applier)	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes *(disposal)*	Ecoinvent Industry data
Unger and Landis (2016, US)	ISO 14040-44 standards Life Cycle Impact Assessment (LCIA)	Seven medical devices: – deep vein thrombosis compression sleeve – pulse oximeter – ligasure	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes	Ecoinvent ELCD (European Reference Life Cycle Database)

	Attributional	– harmonic scalpel – endoscopic trocar – arthroscopic shaver – scissor tip (= the number of medical devices needed to fulfil the reprocessed device supply chain requirements of the hospital)							

SU: single-use; RU: reusable; EoL: end-of-life

Laparoscopic stapler, cutter, scissors and clip applier devices

Refence (year, Country)	Method LCA	Functional unit	System boundaries	Raw materials	Manufacturing (Packaging)	Distribution	Use phase/reuse	EoL/Recycling	Inventory databases
Rizan and Bhutta (2022, UK)	ISO 14040-44 standards Attributional	Number of 3 types of instruments required to perform one laparoscopic cholecystectomy (=2 small diameter ports, 2 large diameter ports, 1 laparoscopic scissor, and 1 laparoscopic clip applier)	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes	EcoInvent Industry data

EoL: end-of-life

Surgical scissors

Refence (year, country)	Method LCA	Functional unit	System boundaries	Raw materials	Manufacturing (Packaging)	Distribution	Use phase/reuse	EoL/Recycling	Inventory databases
Ibbotson et al. (2013, Germany)	ISO 14040 standards Screening LCA Attributional	4 500 use cycles of surgical scissors during 18 years	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes	Ecoinvent Australian data 2007 databases

Rizan et al. (2022, UK)	ISO 14040-44 standards Attributional	One use of a reusable surgical scissor (type 17-cm, straight Mayo reusable; manufactured in Germany and used in the UK)	Cradle-to-grave	Yes	Yes	Yes	Yes *(decontamination & repair if relevant)*	Yes *(waste)*	Ecoinvent European Life Cycle Database

EoL: end-of-life

Medical blue wrap

Refence (year, country)	Method LCA	Functional unit	System boundaries	Raw materials	Manufacturing (Packaging)	Distribution	Use phase/reuse	EoL/Recycling	Inventory databases
Babcock et al. (2016, USA)	Not mentioned Attributional	Sterilization protection for 100 surgical toolsets used 365 times per year over 10 years	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes	Ecoinvent, U.S. LCI database, Emissions & Generation Resource Integrated Database, the1994 Manufacturing Consumption of Energy Survey PlasticsEurope, PE International The European Reference Life Cycle Database.
Friedericy et al. (2021, The Netherlands)	ISO 14040-44 standards Attributional	Sterile packaging of a standard format instrument tray for 5000 sterilization cycles	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes	Ecoinvent

EoL: end-of-life

Sharps containers

Refence (year, Country)	Method LCA	Functional unit	System boundaries	Raw materials	Manufacturing (Packaging)	Distribution	Use phase/reuse	EoL/Recycling	Inventory databases
Grimmond and Reiner (2012, UK)	PAS 2050 Attributional	Provision for 100 occupied hospital beds for one year	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes/No	GaBi (Ganzheitliche Bilanz) DEFRA (Department for Environment; Food and Rural Affairs) Warm (Waste Reduction Model)

Grimmond et al. (2021, UK)	British Standards Institute PAS 2050 Attributional	Total fill line litres (FLL) of sharps containers needed to dispose of sharps for 1-year period in 40 trusts	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes/No	Plastic Europe GaBi database 2018/2019 UK Department for Environment, Food and Rural Affairs well-to-wheel GHG values for vehicles
McPherson et al. (2019, US California)	British Standards Institute PAS 2050 Attributional	Supply of sharps containers, disposable and reusable, for a one-year period	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes/No	WinPepi American Chemistry Council, 2010, USOE, 2010, DEFRA, 2010, NCASI,

EoL: end-of-life

Surgery gown/isolation gown/coverall

Refence (year, Country)	Method LCA	Functional unit	System boundaries	Raw materials	Manufacturing (Packaging)	Distribution	Use phase/reuse	EoL/Recycling	Inventory databases
Bijleveld and Uijttewaal (2022 The Netherlands)	ISO 14040-44 standards	One surgical gown	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes	Ecoinvent
Vozzola et al. (2018a, USA)	ISO 14040-44 standards Attributional	1000 uses of a cleanroom coverall	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes	Environmental Clarity
Vozzola et al. (2018b, USA)	ISO 14040-44 standards Attributional	1000 uses of isolation gown	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes	Environmental Clarity
Vozzola et al. (2020, USA)	ISO 14040-44 standards Attributional	1000 uses of surgical gown	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes	Environmental Clarity

EoL: end-of-life

Laryngeal mask airway

Refence (year, Country)	Method LCA	Functional unit	System boundaries	Raw materials	Manufacturing (Packaging)	Distribution	Use phase/reuse	EoL/Recycling	Inventory databases
Eckelman et al. (2012, USA)	ISO 14040 standards Attributional	40 uses of laryngeal mask airway	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes	Ecoinvent
Liang (2019, Sweden)	ISO 14040-44 standards Attributional	40 uses of laryngeal mask airway	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes	Ecoinvent ELCD (European Reference Life Cycle Data System)

Vaginal speculum

Refence (year, Country)	Method LCA	Functional unit	System boundaries	Raw materials	Manufacturing (Packaging)	Distribution	Use phase/reuse	EoL/Recycling	Inventory databases
Donahue et al. (2020, US)	ISO 14040-44 standards Attributional	5000 pelvic exams with a vaginal speculum	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes	Ecoinvent WARM (Waste Reduction Model)
Rodriguez Morris and Hicks (2022, US)	ISO 14040-44 standards Attributional	20 pelvic exams with a vaginal speculum	Cradle-to-grave	Yes	Yes	No	Yes	Yes	Ecoinvent ELCD (European Reference Life Cycle Data System) USLCI (United States Life Cycle Inventory Database)
Snijers et al. (2022, The Netherlands)	ISO 14040-44 standards Attributional	One pelvic exam with a vaginal speculum	Cradle-to-grave	Yes	Yes	Yes	Yes	Yes	Ecoinvent

EoL: end-of-life

9.2 APPENDIX 2: Evidence table LCA's Results

Laryngoscopes

Reference	Objective	Outcome	Results						Sensitivity analyses	Remarks
			Raw materials	Manufacturing (Packaging)	Distribution	Use phase/reuse	EoL/Recycling	Total		
McGain et al. (2017, Australia)	Environmental impact of different scenarios of replacing RU anaesthetic equipment with SU variants	CO_2 emissions ($kgCO_2eq$) Water use (kilolitres) Cost	Not specified	Not specified	Not specified	Not specified	Not specified	Climate change: Scenario 1 (RU anaesthetic equipment) – Scenario 5 (replacement of RU with SU anaesthetic materials) = 5575 - 6763= - 1 188 kg CO_2eq Water depletion: 82.2 (S1) -69.7 (S5)= 12.5 kilolitres Eutrophication: 0.00-0.07: -0.07 kg P eq Solid Waste: 250-917= -667kg Human Toxicity: 12-491= -479 kg 1.4-DBeq Terrestrial ecotoxicity: 0.011-0.2=0.181 kg 1.4-DBeq Freshwater ecotoxicity: 0.7-88.0= -87.3 kg 1.4-DBeq Marine ecotoxicity:0.7-92.3= -91.6 kg 1.4-DBeq	NA Scenario based consequential LCA	In Australia emissions increased by converting from SU to RU due to power source mix. Scenario's using European and US power mixes lead to reductions in CO_2 emissions for all anaesthetic equipment included in this study.
Sherman et al. (2018, US)	Providing quantitative comparisons of environmental impacts and total cost of ownership among laryngoscope	Primary: GHG (CO_2eq) Secondary: stratospheric ozone depletion, PM2.5 which contribute to respiratory disease; cancer						Handles RU with HLD: 0.06 kg CO_2eq LLD: 0.08 kg (40% more than HLD) CO_2eq per use, STZ (steam sterilization): 0.23 kg CO_2eq (400% more than HLD)	1) 100% recycling scenario demonstrated marginal reductions in GHG emissions over the standard	

	options for one hospital	and noncancer disease through chemical exposure, ground-level ozone, degradation of water quality and ecosystem health by acidification and eutrophication aquatic ecotoxicity and use of non-renewable fossil resources						SU plastic: 1.41 kg CO_2eq metal: 1.60 kg CO_2eq (approximately 25 times more GHG emissions than the reusable handle treated with HLD) Blades RU with HLD: 0.06 kg CO_2eq STZ: 0.22 kg CO_2eq (400% more than HLD) SU plastic: 0.38 kg CO_2eq metal: 0.44 kg CO_2eq (approximately 40-50% more GHG emissions than the reusable treated with STZ)	waste disposal scenario for SU and had no significant impact on RU device emissions and no significant impact on cost 2) calculate break-even scenarios between RU and SU: SU handles become preferable if lifetime falls below 5 for plastic and below 4 uses for plastic. Blades: SU become preferable if lifetime of RU falls below 5 for plastic and below 3 for metal blades	

SU: single-use; RU: reusable; NA: not applicable; HLD: high level desinfection LDL: low level desinfecion; GHG: greenhouse gasses; STZ: steam sterilisation; EoL: end-of-life

Flexible endoscopes

Reference	Objective	Outcomes	Results						Sensitivity analyses	Remarks
			Raw materials	Manufacturing (packaging)	Distribution	Use phase/reuse	EoL/Recycling	Total		
Badoudjian et al. (2022, France)	To provide the first LCA of flexible cystoscopy comparing the LCA of RU flexible cystoscopes and SU cystoscope	Global warming potential ($kgCO_2eq$), Mineral resource scarcity (MJ), Ecotoxicity potential (kg1.4-DBeq), Acidification potential (kg SO_2 eq), Eutrophication potential (kg PO_4eq)						Global warming: SU: 2.06 $kgCO_2eq$ RU: 3.08 $kgCO_2eq$ Mineral resource depletion: SU: 25.03 MJ RU: 49.92 MJ Ecotoxicity SU: 1.07 kg1.4-DBeq RU: 2.20 kg1.4-DBeq Acidification SU: 0.0105 kg SO_2 eq RU: 0.0369 kg SO_2 eq Eutrophication SU: 0.0028 kg PO_4eq RU: 0.0052 kg PO_4eq		The functional unit and system boundaries of the studied products differ.
Bringier et al (2023)	To compare the potential environmental impact of RU and SU flexible bronchoscopes	Global warming potential (GWP) ($kgCO_2eq$) and 11 other environmental categories Abiotic depletion (kg Sbeq), abiotic depletion (fossil fuels) (GJ), ozone depletion	Production and manufacturing: SU: 86.1% RU: 0.2% Packaging: SU: 5.3% RU: 0%,		Transport: SU: 3.1% RU: 0.1%	Use: SU: 0%, RU: 73.3%	Waste: SU: 5.4% RU: 26.3%	Global warming: SU: 7.8 t CO_2eq vs RU: 5.8 t CO_2eq Abiotic depletion SU: 2.4 kg Sbeq) RU: 0.01 kg Sbeq) Abiotic depletion (fossil fuel) SU:93 GJ RU: 91.2 GJ	–	

		(gCFP-11 eq), human toxicity (t1.4DB eq), fresh water aquatic ecotoxicity , marine aquatic ecotoxicity, terrestrial ecotoxicity (kg 1.4DB eq), photochemical oxidation acidification (kg SO_2), eutrophicitation (kg PO_4 eq), water use (m^3) (in the life stages GWP is expressed as % of the total life cycle GWP of SU or RU)					Ozone depletion SU: 3.31 gCFP-11 eq RU: 0.09 gCFP-11 eq Human toxicity SU: 33.5 t1.4DB eq RU: 6.7 Fresh water aquatic ecotoxicity SU: 53.5 kg 1.4DB eq RU: 29.6 kg 1.4DB eq Marine aquatic ecotoxicity: SU: 253 kg 1.4DB eq RU 162 kg 1.4DB eq Terrestrial ecotoxicity SU: 64.6 kg 1.4DB eq RU: 5.99 kg 1.4DB eq Photochemical oxidation SU: 1.76 kg SO_2 SU 0.92 kg SO_2 Eutrophicatio n SU: 80.5 RU: 4.43 Water use: SU: 2.530 m^3 SU: 3.920 m^3		
Davis et al.(2018, Australia)	Compare environmental impact of SU with RU flexible	Estimated carbon emissions (CO_2)/Global warming	SU: 3.83 + 0,3 kgCO_2eq (sterilization RU: 0.06 kgCO_2eq		RU:3,95 kgCO_2eq (washing sterilisation) + <0.005 (repacking) + 0,45 (kgCO_2eq (repair)	SU: 0,3 (kgCO_2eq RU: 0,005 (kgCO_2eq	SU: 4.43 kgCO_2eq RU: 4.47 kgCO_2eq	–	No validated data.

	ureteroscopes	potential ($kgCO_2eq$)							
Duijndam (2022, The Netherlands)	Investigate environmental impact of a SU and a RU flexible intubation scope.	Climate change ($kgCO_2eq$) + 9 midpoint impact categories					Climate change: SU: 1230 $kgCO_2eq$ RU: 1120 $kgCO_2eq$		No absolute figures for the different life cycle phases, only graphs.
Hogan et al (2022, Danmark)	Compare the carbon footprint of SU with RU cystoscopes	Global waste Estimated carbon emissions (CO_2)/Global warming potential ($kgCO_2eq$)	SU: 1.34 kg $C0_2eq$ RU: 0,013kg $C0_2eq$	SU: 0,049 kg $C0_2eq$ RU: -	Sterilisation SU: 0,3 kg CO_2eq RU: 3,5 kg CO_2eq	Incineration: SU: 0,61 kg CO_2eq RU: 0,52 kg CO_2eq Landfill: SU: 0,11 kg CO_2eq RU: 0.22 kg CO_2eq	Global warming potential SU: 2.41 $kgCO_2eq$ RU: 4.23 kgCO2eq (p>0.0001)	-	Short duration No validated data Estimated impact data Incomplete LCA: only carbon footprint, not overall environmental impact.
Kemble et al. (2023, US)	Compare the carbon footprint of SU and RU flexible cystoscopes	Estimated carbon emissions (CO_2)/Global warming potential ($kgCO_2eq$)	SU: 1.37 + 0.22 (packaging) + 0.3 (sterilization) $kgCO_2eq$ RU: 0.002 $kgCO_2eq$	SU: 0.20 $kgCO_2eq$	RU: 0.20 $kgCO_2eq$ (reprocessing) 0.005 $kgCO_2eq$ (repackaging) + 0.3 (PPE) + 0.02 (repair) $kgCO_2eq$	SU: 0.31 $kgCO_2eq$ RU: 0.0001 $kgCO_2eq$	SU: 2.40 $kgCO_2eq$ RU: 0.53 $kgCO_2eq$	New reprocessor was introduced: RU: total impact 1.04 $kgCO_2eq$	Detergents were not included
Le et al (2022, US)	To compare environmental and human health effects of SU, RU and RU with disposable endcap duodenoscopes.	Global warming potential (kg CO_2eq) + 22 midpoints 3 endpoints: Human health (DALYs), ecosystem quality (species.yr), nonrenewable resource use (US $)	SU: 91-96% of total impact GWP		RU: Electricity: 62% of total impact GWP Cleaning and disinfection: 26% of total impact GWP	SU: disposal 3-5% of total impact GWP	SU 1*: 36.3 kg CO_2eq SU 2*: 71.5 kg CO_2eq RU: 1.53 kg CO_2eq RU + disposable endcap: 1.54 kg CO_2eq Human health SU1:1.7e^{-7} DALY SU2: 3.42 e^{-4} DALY RU: 1.31e^{-5} DALY RU+: 1.29e^{-5} DALY	Range of infection rates	Composition of the duodenoscope based on an available data or a ureteroscope Several authors disclosed financial relationships

								Ecosystem quality SU1: 2.58e^{-7} species.yr SU2: 4.67e^{-7} species.yr RU: 6.22 e^{-8} species.yr RU+: 6.12e^{-8} species.yr Resource consumption SU1: 2.24 US$ SU2: 4.28 US$ RU: 8.5e^{-2} US$ RU+: 8.53^{-2} US$		
Sørensen and Grüttner (2018, Danmark)	Compare CO_2-equivalent emissions and resource consumption from a SU to a RU bronchoscope	GHG emissions as CO_2-equivalent (kg CO_2eq) Primary energy consumption (MJ) *Scarce resources consumption (DKK)*	SU: scope RU: PPE	SU: scope RU: PPE		RU: *using/washing/ sterilization/drying/ storing*	Recycling all recyclable materials and incineration with energy recovery of auxiliary materials SU: scope RU: PPE + materials for cleaning	GHG emissions SU: 1.6 kgCO_2eq RU: 2.9 kgCO_2eq Energy consumption SU: 29 MJ RU: 48 MJ *Scarce resources consumption* *SU: 2,1 DKK* *RU: 2,9 DKK*	Different standards cleaning & disinfection Different uses of PPE 1 PPE/ ≥ 2 cleanings Different equipment cleaning & disinfection (energy consumption washing/drying) Different waste treatments (disposals of PPE or SU scopes)	Partial LCA Producer SU scope involved in data collection and funding Estimated impact data, only graphs are showed.

SU: single-use; RU: reusable; DALYs: disability-adjusted life years; GWP: global warming potential; GHG: greenhouse gas; PPE: personal protective equipment; DKK Danish krone

**because of lack of data on the composition of SU, the authors modelled a lower bound SU scenario (scenario 1 = same % of electronics as the RU) and an upper bound scenario (scenario 2 = same mass of electronics as the RU).*

Trocars

Reference	Objective	Outcome	Results						Sensitivity analyses	Remarks
			Raw materials	Manufacturing (Packaging)	Distribution	Use phase/reuse	EoL/Recycling	Total		
Unger and Landis (2016, US)	To model environmental impacts of varying levels of reprocessing at a hospital in Phoenix, Arizona	Global warming, carcinogenic, non-carcinogenic, and respiratory effects	Graph	Graph	Graph	Graph	Graph	Not specified	Varying quantities of ETO consumed by the commercial gas sterilizer	No absolute nor relative figures on outcome measures were included in the manuscript
Boberg et al. (2022, Sweden)	To compare environmental impacts of a single-use, a mixed, and a reusable trocar system for laparoscopic cholecystectomy	Global warming ($kgCO_2eq$) +15 midpoint categories & 4 endpoint categories: resources, climate change, ecosystem quality, and human health	Graph (per endpoint)	Graph (per endpoint)	Graph (per endpoint)	Graph (per endpoint)	Graph (per endpoint)	SU trocars – 182% higher impact on resources – 379% higher impact on climate change – 83% higher impact on ecosystem compared to reusable trocars	Differences between SU and RU trocars were found to be sensitive to lower filling of machines in the sterilization process (for resource use and ecosystem quality), 50% decrease in number of uses, and using a fossil fuel electricity mix (ecosystem quality).	Mixed trocar system: use of SU and RU trocars.
Rizan and Bhutta (2022, UK)	To compare the environmental life cycle cost of hybrid and SU instruments (trocar) for laparoscopic cholecystectomy	Global warming (CO_2eq) + 17 midpoints and 3 endpoint categories: damage to human health (DALY), natural environment (species.yr), resource scarcity (US $)	Graph	Graph	Graph	Graph	Graph	Hybrid 933g CO_2eq /4 trocars Human health $1.67e^{-6}$. DALY Ecosystem $3.67e^{-9}$ species. yr Resources 0.0853 US $ SU 3495g CO_2eq/4 trocars Human health $6.13e^{-6}$ DALY	Five alternative scenarios examining impact of number of uses, separate clip applier, impact of energy mix, changing transportation, type of trocars used: performance of hybrid instruments was better even – with low number of reuses of instruments,	Work was funded by Surgical Innovations Ltd. who manufacture hybrid laparoscopic instruments

								Ecosystem 1.36e^{-9} species.yr Resources 0.344473 US $	– decontamination with separate packaging – decontamination using fossil-fuel-rich energy sources, – changing carbon intensity of instrument transportation	

Laparosopic surgical stapler, cutter scissors, clip appliers

Reference	Objective	Outcomes	Results						Sensitivity analyses	Remarks
			Raw materials	Manufacturing (packaging)	Distribution	Use phase/reuse	EoL/Recycling	Total		
Rizan and Bhutta (2022, UK)	To compare the environmental life cycle cost impact of hybrid and single-use laparoscopic instruments (**scissors** and **clip applier**) used for a laparoscopic cholecystectomy	Global warming (gCO_2eq) + 17 midpoints and 3 endpoint categories: damage to human health (DALY), natural environment (species.yr), resource scarcity (US $) **Scissors**	Global warming SU: 660 gCO_2eq vs Hybrid 232 gCO_2eq (SU parts), 1.27 gCO_2eq (RU parts)		Global warming SU: 324 gCO_2eq	Global warming Decontamination Hybrid: 79 gCO_2eq	Global warming: SU: 154 gCO_2eq	Global warming SU 1138 gCO_2eq Hybrid 378 gCO_2eq Human health SU: 2.90.e^{-6}. DALY Hybrid: 1.28 e^{-6}. DALY Ecosystem SU: 5.22 e^{-9} species.yr Hybrid: 1.84 e^{-9} species.yr Resources SU: US $ 0.1176 Hybrid: US $0.0314	Five alternative scenarios examining impact of number of uses, separate clip applier, impact of energy mix, changing transportation, type of trocars used: performance of hybrid instruments was better even – with low number of reuses of instruments, – decontamination with separate packaging – decontamination using fossil-fuel-rich energy sources, – changing carbon intensity of instrument transportation	Work was funded by Surgical Innovations Ltd. who manufacture hybrid laparoscopic instruments
		Clip applier	Global warming SU: 112 gCO_2eq Hybrid 112 gCO_2eq (SU parts), 4,37 gCO_2eq (RU parts)		Global warming SU: 923 gCO_2eq	Global warming Decontamination Hybrid: 247 gCO_2eq	Global warming: SU: 294 gCO_2eq	Global warming SU 2559 gCO_2eq Hybrid 445gCO_2eq		

							Human health SU: 6.30.e^{-6}. DALY Hybrid: 1.09 e^{-6}. DALY Ecosystem SU: 1.24 e^{-9} species.yr Hybrid: 1.96 e^{-8} species.yr Resources SU: US $ 0.2944 Hybrid: US $ 0.0464		

SU: single-use; RU: reusable; DALYs: disability-adjusted life years

Surgical scissors

Reference	Objective	Outcome	Results						Sensitivity Analyses	Remarks
			Raw materials	Manufacturing (Packaging)	Distribution	Use phase/reuse	EoL/Recycling	Total		
Rizan et al. (2022, UK)	Evaluate the environmental impact & financial cost of repairing surgical scissors for 3 scenarios no repair, onsite (hospital) and offsite	Global warming impact, with GHG expressed as carbon dioxide equivalents (CO_2eq) + 17 midpoint impact categories providing endpoint estimates for damage on human health, natural environment, and resource scarcity	Amounts not specified – Figure with carbon footprint for each category available	Amounts not specified – Figure with carbon footprint for each category available	Amounts not specified – Figure with carbon footprint for each category available	Amounts not specified – Figure with carbon footprint for each category available	Amounts not specified – Figure with carbon footprint for each category available	70.3 g CO_2eq/use Onsite repair: 56.3 g CO_2eq/use Offsite repair: 57 g CO_2eq/scissor use	Scenario analysis to evaluate the impact of assumptions in number of uses, reducing number of repairs, increasing distance to offsite repair centre, alternative electricity sources, and waste handling processes. Whitin all scenarios, highest carbon footprint for non-repaired scissors and lowest for those repaired onsite	
Ibbotson et al. (2013, Germany)	Evaluate the environmental impact & total cost of ownership (customer	18 explicit impact categories in different units, such as kgCO_2eq and kg oileq	Graph Presented in a contribution percentage of the total	Graph	–	Graph	Graph	Graph	LCA results are reliable throughout all assumptions and data uncertainties. TCO results are more dependent on	

	perspective) comparing disposable scissors of stainless steel, disposable scissors of fibre-reinforced plastic and reusable stainless steel		environmental impact results of the stainless steel disposable scissors						the choice of case study parameters, such as price and case-specific costs of sterilization.	

TCO: total cost of ownership

Medical blue wrap

Reference	Objective	Outcomes	Results						Sensitivity analysis	Remarks
			Raw materials	Manufacturing (packaging)	Distribution	Use phase/reuse	EoL/Recycling	Total		
Babcock et al. (2016, US)	To compare SU polypropylene blue wraps and RU aluminium containers	Global warming potential ($kgCO_2eq$) Solid waste (kg)		Graph: SU: 22.2% of total impact RU: 1.6% of total impact		Graph: SU: 77.3% of total impact RU: 97.5% of total impact	Graph: SU: 2.5% of total impact RU: 0.9% of total impact	SU: 823 000 $kgCO_2eq$ RU: 377 000 $kgCO_2eq$	-	
Friedericy et al. (2021, The Netherlands)	To compare the environmental impact of SU and RU sterilisation packaging for surgical instruments To investigate the environmental break-even point of use-cycles ?	Carbon footprint ($kgCO_2eq$) *ReCiPe (points/5000 cycles)* *EcoCosts (€/5000 cycles)*						Carbon footprint: SU incineration: 1869 $kgCO_2eq$ SU recycling: 883 $kgCO_2eq$ RU landfill: 285 $kgCO_2eq$ RU recycling: 270 $kgCO_2eq$ ReCiPe Graph EcoCosts Graph Break-even point (SU incineration	Three scenarios for electricity compared to EU-27 mix - 100% photovoltaic cells EU conditions give a potential reduction in the eco-cost of the RSC system of 28 euro per 5000 cycles - 100% coal-fired power plants: large increase in eco-cost - World average mix: increase in eco-cost	

								vs RU landfill) : Carbon footprint: 98 use-cycles ReCiPe 228 use-cycles Eco-costs 67 use-cycles.		

SU: single-use; RU: reusable; EU: european

Sharp containers

Reference	Objective	Outcome	Results						Sensitivity analyses	Remarks
			Raw materials	Manufacturing (Packaging)	Distribution	Use phase/reuse	EoL/Recycling	Total		
Mc Pherson et al. (2019, US)	Impact GHG emissions during 12 months 1100-bed facility (5 hospitals) of RU and SU sharps container.	GHG emissions (CO_2, CH_4, N_2O) in metric tons of carbon dioxide eq.($MTCO_2eq$)	SU SC: 148.6 RU SC: 3.1		SU SC:69.8 RU SC: 77.6	SU SC: 0 RU SC: 4.9	SU SC: 30.2 RU SC: 0.6	SU SC: 248.6$MTCO_2eq$ RU SC (lifespan of 26.4 years): 86.20 $MTCO_2eq$ (162.4 $MTCO_2eq$ reduction or 65.3%, p<0.001) + elimination of 50.2 tonnes plastic (31.8 landfill + 18.4 incineration), 8.1 tonnes cardboard.	Lifespan RU SC: variations of 41.7 years & 15 years has minimal impact (0.4 & 1.3%) US electricity sources alter processing and manufacturing GHG by 82%	
Grimmond et al. (2021, UK)	Global warming potential (GWP) of hospitals replacing SU by RU sharp containers. 12 months hospital-wide use in 40 trusts	Carbon dioxide equivalents (CO_2eq). Other GHGs are converted to their CO_2eq based on per unit radiative forcing using IPCC 100-year GWP Total annual metric tonnes of CO_2eq of both containment systems; kg CO_2eq/1000 FLL kg CO_2eq/1000 patient activity episodes	SU SC: 2179.4 RU SC: 116.7		SU SC: 554.2 RU SC:422.0	SU SC: 0 RU SC:58.4	SU SC: 1162.8 RU SC:31.9	SU SC: 3896.4 $MTCO_2eq$ RU SC (lifespan of 18 years): 628.9 tonnes CO_2eq reduction of 3267.4 $MTCO_2eq$ or 83.9% + elimination of 900.8 tonnes plastic (landfill + incineration), 132.5 tonnes cardboard.	Items in sensitivity analyses had small effects (<5%) on final GWP. One exception was theoretical RU SC lifespan of 1year which achieved an end-comparison reduction of 57.3% (26.6% less than the base comparison)	

Grimmond and Reiner (2012, US)	Global warming potential (GWP) of replacing SU by RU sharp containers. Study period from 12 months pre and post replacement	GHG emissions (CO_2, CH_4, N_2O) in metric tons of carbon dioxide eq.($MTCO_2eq$)		SU SC: 32.1 RU SC: 4.9	SU 1 RU SC: Not included only Figure	SU & RU SC: Not included only Figure	SU & RU SC: Not included only Figure	SU SC: 139.1$MTCO_2eq$ RU SC (lifespan of 39.6 years): 25.1 $MTCO_2eq$ Replacement by RU SC: reduction of annual GWP by 127 MTCO2eq (-83.5%) and diverted 30.9 tons of plastic and 5.0 tons of cardboard from landfill	Distance between health care facility and manufacturer were reversed: GWP reduced from 83.5 to 64.5% for RU SC, but manufacture remained largest contributor	

SU: single-use, RU: Reusable, SC: sharp container; GHG: greenhouse gas, GWP: global warming potential; MTCO2eq metric tonnes carbon dioxide equivalent

Surgical gown / isolation gown / coverall

Reference	**Objective**	**Outcomes**	**Results**						**Sensitivity analysis**	**Remarks**
			Raw materials	**Manufacturing (packaging)**	**Distribution**	**Use phase/reuse**	**EoL/Recycling**	**Total**		
Bijleveld and Uijttewaal (2022, The Netherlands)	To compare environmental impacts of RU and SU surgical gowns	Carbon footprint ($kgCO_2eq$)	Graph	Graph	Graph	Graph	Graph	Graph	Green energy: reduction of 5-11% Recycling SU gown: reduction, but still higher impact than RU gowns. Lower number of reusing (25 times): limited increase	No absolute figures are given, only graphs.
Vozzola et al. (2018a, US)	To compare the environmental impact of RU and SU cleanroom overalls	Global warming potential ($kgCO_2eq$) Process energy (MJ) Natural resource energy (MJ) Water consumption (kg) Solid waste (kg)	Global warming potential Manufacturing coverall + supply chain (transport) RU:115 $kgCO_2eq$ SU HDPE: 414 $kgCO_2eq$ SU PP: 824 $kgCO_2eq$ Manufacturing packaging RU:22.8 $kgCO_2eq$ SU HDPE: 48.4 $kgCO_2eq$ SU PP: 48.4 $kgCO_2eq$ Natural resource energy Manufacturing coverall + supply chain (transport) RU:1790 MJ SU HDPE: 6130 MJ			Global warming potential Laundry RU:336 $kgCO_2eq$ SU HDPE: 143 $kgCO_2eq$ SU PP: 204 $kgCO_2eq$ Sterilization RU:1.08 $kgCO_2eq$ SU HDPE: 0.461 $kgCO_2eq$ SU PP: 0657 $kgCO_2eq$ Use Transport	Global warming potential RU: 0 SU HDPE: 6.19 SU PP: 8.35 Natural resource energy RU: 0 SU HDPE: 86.1 SU PP: 123	Global warming potential RU:517 SU HDPE: 712 SU PP: 1220 Process energy RU: 4560 MJ SU HDPE: 6930 MJ SU PP: 11100 MJ		Input form the American Reusable Textile Association

			SU PP: 12900 MJ Manufacturing packaging RU:355 MJ SU HDPE: 792 MJ SU PP: 792 MJ			RU:42.1 $kgCO_2eq$ SU HDPE: 99.9 $kgCO_2eq$ SU PP: 132 $kgCO_2eq$ Natural resource energy Laundry RU: 5560 MJ SU HDPE: 2370 MJ SU PP: 3380 MJ Use Transport RU:661 MJ SU HDPE: 1530 MJ SU PP: 2030 MJ Sterilization RU:5560 MJ SU HDPE: 2370 MJ SU PP: 3380 MJ		Natural resource energy RU: 8380 MJ SU HDPE: 10900 MJ SU PP: 19200 Blue water RU: 80.7 kg SU HDPE: 304 kg SU PP: 345 kg Solid waste RU: 10.2 kg SU HDPE: 171 kg SU PP: 238 kg		
Vozzola et al. (2018b, US)	To compare 4 environmental impacts of RU and SU isolation gowns	Global warming potential ($kgCO_2eq$) Natural resource energy (MJ) Water use (kg) Solid waste consumption (kg)		GWP SU manufacture & delivery: 300 $kgCO_2eq$ (gown) + 6.95 $kgCO_2eq$ (packaging) RU manufacture & delivery: 68.6 $kgCO_2eq$ (gown) + 1.03 $kgCO_2eq$ (packaging) NRE SU manufacture & delivery: 4996 (gown) + 120 MJ (packaging) RU manufacture &		GWP RU Laundry: 146 $kgCO_2eq$ + 0.411 $kgCO_2eq$ (water) + 2.08 $kgCO_2eq$ (restore waste water) NRE RU Laundry: 2.538 MJ + 7.31 MJ (water) + 14.4 MJ (restore waste water) Blue water RU Laundry: 8.71 kg	GWP SU Landfill: 1.99 $kgCO_2eq$ (gowns + packaging) + 0.794 $kgCO_2eq$ (biological waste) RU Landfill: 0.139 $kgCO_2eq$ (gowns + packaging) + 0.0132 $kgCO_2eq$ (biological waste) NRE SU Landfill: 34.9 MJ (gowns + packaging) +	GWP SU: 310 $kgCO_2eq$ RU: 218 $kgCO_2eq$ NRE SU: 5150 MJ RU: 3712 MJ Blue water SU: 74.6 kg RU: 43.8 kg Solid waste SU: 63.4 kg RU 0.413-4.42kg (depending on 100% or 0% recycling)	Different weight of SU RU gowns Laundry process	

				delivery: 1133 MJ (gown) + 16.7 MJ (packaging) Blue water SU manufacture & delivery: 74,6 kg (gown) RU manufacture & delivery: 35.1 kg (gown)			-0.682 MJ (biological waste) RU Landfill: 2.538 MJ (gowns + packaging) + -0.0114 MJ (biological waste) Solid waste SU Landfill: 63.2 kg (gowns + packaging) + 0.194 kg (biological waste) RU Landfill: 0.413-4.41 kg (gowns + packaging) + 0-0.00323 kg (biological waste)			
Vozzola et al. (2020, US)	To evaluate environmental impacts of reusable and disposable surgical gowns	Global warming potential (GWP) ($kgCO_2eq$) Natural resource energy (MJ) Water use (kg) Solid waste consumption (kg)		GWP SU manufacture & supply chain: 1.495 $kgCO_2eq$ (gown) + 121 $kgCO_2eq$ (packaging) + 6.26 $kgCO_2eq$ (sterilization) RU manufacture & delivery: 143 $kgCO_2eq$ (gown) + 76.7 $kgCO_2eq$ (packaging) NRE SU manufacture & supply chain: 23.958 MJ (gown) + 2.040 MJ (packaging)		GWP RU Laundry: 278 + 19.8 $kgCO_2eq$ (sterilisation) NRE RU Laundry: 4821+ 343 $kgCO_2eq$ (sterilisation) + Blue water RU Laundry: 57 + 1.39 kg (sterilization) Use phase transport GWP SU: 3.47 $kgCO_2eq$ RU: 38.7 $kgCO_2eq$	GWP SU: 10.9 $kgCO_2eq$ RU: 1.40 $kgCO_2eq$ NRE SU: 149 MJ RU: 23.9 MJ Solid waste SU: 0.505 kg RU: 0-0.00842 kg	GWP SU: 1636 $kgCO_2eq$ RU: 557 $kgCO_2eq$ NRE SU: 26289 MJ RU: 9396 MJ Blue water SU: 1097 kg RU: 185kg Solid waste SU: 265 kg RU 35.5-43.4 kg (depending on 100% or 0% recycling)	Different weight of SU RU gowns Laundry process Transport	Study funded by American Reusable Textile Association Life Cycle Assessment Committee

				+ 89 MJ (sterilization) RU manufacture & delivery: 2.366 MJ (gown) + 1.246 MJ (packaging) Blue water SU manufacture & delivery: 1058 kg (gown) + 36.6 kg (packaging) + 2.38 kg (sterilization) RU manufacture & delivery: 69.7 kg (gown) + 56.7 kg (packaging) Solid waste manufacture & delivery: 224 kg (gown) + 40.3 kg (packaging) RU manufacture & delivery: 0-7.9 kg (gown) + 35.5 kg(packaging)		NRE RU: 53.5 MJ SU:596 MJ				

SU: single-use; RU : reusable, GWP: global warming potential, NRE: Natural resource energy; PP: single-use polypropylene, SU HDPE: high density polyethylene;

Laryngeal mask airway

Reference	**Objective**	**Outcomes**	**Results**						**Sensitivity analyses**	**Remarks**
			Raw materials	**Manufacturing (packaging)**	**Distribution**	**Use phase/reuse**	**EoL/Recycling**	**Total**		
Eckelman et al. (2012, USA)	To compare the environmental impact of SU and RU	Global warming (kg CO_2eq)	SU production+ polymerisation PVC: 23% of the GHG emissions and 60% of human health impacts; polycarbonate		SU truck transport: 15% of the GHG emissions	RU natural gas production + combustion to produce steam for the	SU waste: 11% of the GHG emissions and 15% of human health impacts	GHG emissions SU: 11.3 kgCO_2eq	RU: -fully loaded autoclave (10 pieces): 5.6 kgCO_2eq	Only global warming impacts are reported, other impact

	laryngeal mask airway	Other environmental concerns Human health related impacts	production: 14% of the GHG emissions; thermoforming 13% of the GHG emissions		autoclave: 77% of the GHG emissions		RU: 7.4 $kgCO_2eq$	- individual autoclave: 37 $kgCO_2eq$ - autoclave efficiency +10%: 6.8 $kgCO_2eq$ - 10 reuses: 11.4 $kgCO_2eq$ SU: - transport by air: 20.5 $kgCO_2eq$	categories are reported in a comparative analysis
Liang (2019, Sweden)	To compare the environmental impact of SU and RU laryngeal mask airways	Global warming ($kgCO_2eq$) + 17 midpoint categories & 3 endpoint indicators: human health, ecosystem quality, and resources	Graph	Graph	Graph	Graph	No figures are given. Comparative analysis of the single-use and reusable LMA for 3 endpoints (human health, ecosystems and resources): reusable LMA has less than 40% impact burdens compared with the disposable LMA.	- Source electricity - Ingredients detergents - Reuse cycles	No absolute figures are given

SU: single-use; RU : reusable, LMA: laryngeal mask airway; GHG: greenhouse gas

Vaginal speculum

Reference	**Objective**	**Outcomes**	**Results**						**Sensitivity analyses**	**Remarks**
			Raw materials	**Manufacturing (packaging)**	**Distribution**	**Use phase/reuse**	**EoL/Recycling**	**Total**		
Donahue et al. (2020, US)	Environmental impact of 3 vaginal specula: one SU acrylic and two RU stainless steel specula	Global warming emissions (kg CO_2eq)	RU stainless steel 304: 24.9% RU stainless steel 316: 34.4% SU acrylic: 90.6%		RU stainless steel 304: 0.46% RU stainless steel 316: 0.4% SU acrylic: 6.5%	RU stainless steel 304: 74.1% RU stainless steel 316: 65.2% SU acrylic: NA	RU stainless steel 304: - RU stainless steel 316: - SU acrylic: 2.9%	RU stainless steel 304 (lifespan 20 ex.): 5.72 kg CO_2eq RU stainless steel 316 (lifespan 20 ex.):6.51 kg CO_2eq SU acrylic:17.54 kg CO_2eq	Impact changes in autoclave loading was significant when shifting to individually sterilizing specula (not as great between half-full and completely loaded autoclave) Difference between the most carbon intensive grid and	

									least carbon intensive grid resulted only in a 33-36% reduction in total CO_2eq emissions	
Rodriguez Morris and Hicks (2022, US)	Environmental impact of SU acrylic and RU stainless steel specula	Global warming potential Acidification potential Human health: carcinogens Ecotoxicity potential Eutrophication potential Fossil fuel depletion potential Human health: non-carcinogens Ozone depletion potential Respiratory effects Photochemical oxidant creation potential	Numbers not reported Graph	Numbers not reported Graph	Numbers not reported Graph	Numbers not reported Graph	Numbers not reported Graph	Global warming potential RU stainless steel (lifespan 5 years): 326 kg CO_2eq SU acrylic: 2220 kg CO_2eq Ozon depletion RU stainless steel (lifespan 5 years): 0.00033 kgCFC-11e SU acrylic: 0.000042 kgCFC-11e	For stainless steel, the steel production is overall the most sensitive impact. The use of nitril gloves are a dominant input, and makes RU speculums have more total impacts in the ozone depletion category when compared to SU acrylic speculum. For electricity inputs is the most sensitive the electricity coming from hard coal. Also significant as electricity from hard coal is dominant in use phase of RU stainless steel specula.	Impacts from transportation, cardboard packaging, labour and overhead were not included
Snijers et al. (2022, The Netherlands)	Environmental impact of SU of fossil plastic (ABS), SU biobased plastic (PLA) and RU stainless steel specula	Global warming emissions (kg CO_2eq)	Numbers not reported Graph	Numbers not reported Graph	Numbers not reported Graph	RU: 99% (500 uses) SU: NA	Numbers not reported Graph	RU: 0.13 kg CO_2eq SU ABS: 0.30 kg CO_2eq SU PLA: 0.14 kg CO_2eq	Scenario analysis using a more sustainable electricity mix: reduction between 10 and 15% for reusable, but also a reduction for single-use (if produced in the Netherlands)	Scoping LCA (only including global warming)

SU: single-use; RU: reusable; NA: not applicable; ABS: Acrylonitrile butadiene styrene*; PLA: single-use biobased plastic*

9.3 APPENDIX 3: Inviting letter in French

service public fédéral
SANTE PUBLIQUE,
SECURITE DE LA CHAINE ALIMENTAIRE
ET ENVIRONNEMENT

Direction générale Environnement
Division Politique de produits et Substances chimiques

VOTRE LETTRE DU
VOS RÉF.
NOS RÉF. DPPC/BH/299459
DATE 02/08/2022
ANNEXE(S)
CONTACT BERENICE.HUET@HEALTH.FGOV.BE

A l'attention des directeurs d'hôpitaux

OBJET DEMANDE DE PARTAGE D'INFORMATION RELATIVE A L'APPROVISIONNEMENT EN DISPOSITIFS MEDICAUX A USAGE UNIQUE

Chers directeurs d'hôpitaux,

Ces dernières années, la Belgique et la Commission européenne ont fixé des objectifs ambitieux concernant le développement d'un système des soins de santé durable et circulaire. Ceci comprend également une politique réfléchie en matière de dispositifs à usage unique.

En tant que SPF Santé publique, Sécurité de la Chaîne alimentaire et Environnement, nous souhaitons identifier le potentiel des actions envisageables. À cette fin, un groupe de recherche de l'UZ Gent/UGent mène actuellement une étude exploratoire. Nous espérons à cet égard pouvoir compter aussi sur votre contribution et coopération.

Dans une première phase d'exploration, nous souhaitons identifier les dispositifs médicaux[1] fréquemment utilisés ayant un impact élevé sur l'environnement et les coûts. En outre, nous allons chercher ensemble des alternatives plus durables et/ou circulaires, où nous cartographierons l'empreinte écologique, les aspects liés à la sécurité, l'impact sur le fonctionnement et les économies de coûts.

Pour bien démarrer cet exercice, nous sollicitons votre coopération. Nous souhaitons tout d'abord avoir un aperçu des dispositifs *à usage unique* qui constituent la plus grande partie de la montagne de déchets et/ou qui entraînent les coûts les plus élevés au sein des hôpitaux belges. Nous souhaitons à cet égard identifier la consommation des dispositifs très spécifiques à une spécialisation et par ex. les poches de perfusion, les gants jetables, textiles hospitaliers, etc.

Concrètement, nous élaborons pour l'année 2019 (dernière année pré-corona) un aperçu des dispositifs médicaux achetés, avec les données suivantes qui s'y rapportent :

- Nom du dispositif médical acheté
- Producteur

[1] Un dispositif médical est un produit de santé qui accomplit son action médicale par un moyen physique ou mécanique. Un dispositif médical est donc tout instrument, appareil, équipement, logiciel, implant, réactif, matière ou autre article, utilisé seul ou en association, destiné à être utilisé chez l'être humain à des fins médicales spécifiques

service public fédéral
SANTE PUBLIQUE,
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ET ENVIRONNEMENT

- Nombre d'unités de conditionnement commandées
- Prix d'achat par unité de conditionnement (hors TVA)
- Nombre d'articles par unité de conditionnement
- + certains paramètres optionnels, si disponibles : poids/volume, destination, composition et type (réutilisable ou à usage unique).

Ces données ne sont pas toujours faciles à obtenir, mais le groupe de recherche coordinateur souhaite examiner avec vous ce qu'il est possible d'envisager pour extraire les informations utiles des données disponibles.

Pour garantir la confidentialité des données, les chercheurs ont élaboré un protocole de transfert des données et vous êtes invité à transmettre les données à l'adresse mail suivante : singleuse@uzgent.be. Un modèle Excel simple est également à votre disposition pour vous aider dans cet exercice d'inventaire.

Pourriez-vous nous faire part de votre intérêt et/ou engagement à coopérer le plus rapidement possible au collaborateur de projet David van der Ha (david.vanderha@uzgent.be) ?

Vous serez ensuite contacté afin de discuter des étapes à suivre, de fournir des explications et transmettre des documents. Nous espérons achever cette première phase d'ici la fin de l'été, après quoi les hôpitaux participants recevront un feed-back.

Pour toute question ou information complémentaire, vous pouvez toujours vous adresser au Pr Dr Norbert Fraeyman (norbert.fraeyman@uzgent.be) ou au collaborateur de projet David van der Ha (david.vanderha@uzgent.be).

Enfin, nous souhaitons mettre progressivement en place un réseau d'apprentissage dans le contexte belge. Si vous avez déjà pris des initiatives durables en matière de réduction des déchets, si vous souhaitez travailler sur ce sujet et/ou si vous connaissez un collaborateur ou collègue qui souhaiterait participer à la réflexion, veuillez en informer aussi l'équipe de recherche via david.vanderha@uzgent.be?

Nous vous remercions d'avance pour votre coopération et nous espérons lancer avec vous un projet qui aura un impact significatif.

Cordialement,

p.o.

Anne-France Rihoux
Chef de service – DGEM Division Politique de Produits et Substances chimiques

Galilee Laan 5/2 • 1210 Brussel • www.health.fgov.be

federale overheidsdienst
**VOLKSGEZONDHEID,
VEILIGHEID VAN DE VOEDSELKETEN
EN LEEFMILIEU**

Directoraat-generaal Leefmilieu
Afdeling Productbeleid en Chemische Stoffen

UW BRIEF VAN
UW REF.
ONZE REF. DPPC/BH/299459
DATUM 02/08/2022
BIJLAGE(N)
CONTACT BERENICE.HUET@HEALTH.FGOV.BE

Ter attentie van de ziekenhuisdirecteuren

BETREFT VERZOEK OM INFORMATIE TE DELEN OVER DE LEVERING VAN MEDISCHE HULPMIDDELEN VOOR EENMALIG GEBRUIK

Geachte ziekenhuisdirecteuren,

De Belgische overheid en Europese Commissie hebben de voorbije jaren uitdagende doelstellingen vastgelegd wat betreft het uitbouwen van een duurzame en circulaire gezondheidszorg. Dit behelst ook een doordacht beleid rond *single use* materialen.

Als FOD Volksgezondheid, Veiligheid van de Voedselketen en Leefmilieu wensen we het potentieel van mogelijke acties te identificeren. Daartoe voert een onderzoeksgroep van UZ Gent/UGent momenteel een exploratieve studie uit. Wij hopen hierbij ook op uw input en samenwerking te mogen rekenen.

In een eerste verkennende fase willen we veelgebruikte medische hulpmiddelen[1] met een hoge milieu- en kostenimpact in kaart brengen. Daarnaast gaan we samen op zoek gaan naar duurzamere en/of circulaire alternatieven, waarbij we de ecologische voetafdruk, veiligheidsaspecten, impact op de werking en de kostenbesparing in kaart zullen brengen.

Om deze oefening goed te starten vragen we uw medewerking. We wensen in eerste instantie inzicht te krijgen rond de *single use* materialen die de grootste fractie uitmaken van de afvalberg en/of de grootste kosten met zich meebrengen in de Belgische ziekenhuizen. We willen hierbij zowel het verbruik van zeer specialisatie-specifieke hulpmiddelen, alsook van bv. infuuszakken, wegwerphandschoenen, ziekenhuistextiel, etc. in kaart brengen.

Concreet werken we voor het jaar 2019 (het laatste pré-corona jaar) een overzicht uit van aangekochte medische hulpmiddelen, met deze bijhorende gegevens:

- Naam van het aangekochte medisch hulpmiddel
- Producent

[1] Een medisch hulpmiddel is een gezondheidsproduct dat een mechanische of fysieke werking heeft. Het is dus elk instrument, toestel of apparaat, software, implantaat, reagens, materiaal of ander artikel, dat bestemd is om, alleen of in combinatie, te worden gebruikt bij de mens voor specifieke medische doeleinden.

federale overheidsdienst
VOLKSGEZONDHEID,
VEILIGHEID VAN DE VOEDSELKETEN
EN LEEFMILIEU

- Aantal bestelde verpakkingseenheden
- Aankoopprijs per verpakkingseenheid (excl. BTW)
- Aantal items per verpakkingseenheden
- Voorts enkele optionele parameters, indien beschikbaar: gewicht/volume, bestemming, samenstelling en type (herbruikbaar of single use).

Deze gegevens zijn niet altijd met een eenvoudige vingerknip op te roepen, maar de coördinerende onderzoeksgroep bekijkt graag met u wat mogelijk is om bruikbare info uit de beschikbare data te puren.

Om de vertrouwelijkheid van de gegevens te waarborgen hebben de onderzoekers een protocol voor gegevensoverdracht uitgewerkt en vragen we u bovendien om de gegevens over te maken via singleuse@uzgent.be. Er is ook een eenvoudig excel-sjabloon beschikbaar om u bij deze inventarisatieoefening te helpen.

Mogen wij u vragen om uw interesse en/of engagement tot medewerking zo snel mogelijk door te geven aan projectmedewerker David van der Ha (david.vanderha@uzgent.be)?

Er zal vervolgens contact met u opgenomen worden om de verdere stappen te bespreken, toelichting te geven en documenten aan te leveren. We hopen deze eerste fase af te ronden tegen het einde van de zomer, waarna terugkoppeling naar de deelnemende ziekenhuizen volgt.

Voor verdere vragen of inlichtingen kan u steeds terecht bij Prof. Dr. Norbert Fraeyman (norbert.fraeyman@uzgent.be) of bij projectmedewerker David van der Ha (david.vanderha@uzgent.be).

Tot slot willen we binnen de Belgische context geleidelijk aan een lerend netwerk opstarten. Hebt u zelf al duurzame initiatieven genomen rond afvalbeperking, wilt u er graag werk van maken en/of kent u een werknemer of collega die wenst mee te denken, laat u dit dan eveneens aan het onderzoeksteam weten via david.vanderha@uzgent.be?

We danken u alvast voor uw medewerking en hopen zo samen met u het startschot te geven van een impactvol project.

Hoogachtend,

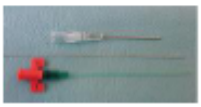
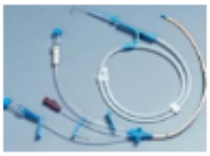
p.o.

Anne-France Rihoux
Diensthoofd – DGEM Afdeling Productbeleid en Chemische Stoffen

9.4 APPENDIX 4: List items excluded by FAMHP

Bijlage 2 bij bestek DGEM-DPPC-LE-20022

Medische hulpmiddelen waarvan werd aangegeven door FAGG gedurende Covid-19 crisis dat zij gezien de complexiteit niet herbruikt mogen worden

nr.	Product	Afbeelding
1	Aspirationpotten - bocaux d'aspiration - aspiration Pot (usage unique)	
2	Aspiratie zak (te gebruiken met multiple use pot) - sac d'aspiration (pour utilisation avec bocaux réutilisation) - aspiration bag (to use with multiple use bag)	
3	HEPA & bacterieel filer - Filtre HEPA & anti bactériel machine - HEPA & Bacterial filter machine	
4	Bloedgasspuiten met clave - seringues pour gazométrie - Blood gas analyser syringe	
5	Arteriële katheter - Cathéter artériel - arterial catheter	
6	thermodilutie katheter - cathéter à thermo dilution (Nomenclature Inami/ Riziv - 159541)	
7	Centraal veneuze Katheter- Cathéter veineux central- Central venous catheter (multilumen (Minimum 3 voies))	
8	Veneuze Katheter perifeer - Cathéter veineux périphérique - Venous catheter peripheral	
9	Gesloten aspiratiesysteem - système d'aspiration fermé - Closed aspirations system 24H	

10	Gesloten aspiratiesysteem - système d'aspiration fermé - Closed aspirations system 48 h	
11	Gesloten aspiratiesysteem - système d'aspiration fermé - Closed aspirations system 72 h	
12	CO2 absorber korrels / Granulés absorbeurs CO2 . CO2 Absorber grains / chaux sodée	
13	EKG elektrode - Electrode ECG - ECG electrodes	
14	ECMO cannula arterial	
15	ECMO cannula venous	
16	ECMO Cardiohelp	
17	Endotracheale tube maat - tube endotrachéal taille - Endotracheal tube size : 7-7,5 / 7,5 - 8/ 8,5 -9	
18	Maagsonde - sondage gastrique décharge salem - gastric feeding tube	
19	Nasogastrische voeding - Sonde nasogastrique entérale - Nasogastric feeding	
20	Filter HME- Filtre HME - HME filter : patient	

21	Tracheostomy introducer set	
22	Tracheo filter climatrach - filtre trachéo avec oxygène Climatrach	
23	*zuurstof nasale buis - sonde nasale à oxygène - oxygen nasal tube*	
24	*toedieningssysteem - système d'administration pour le gavage - gavage administration kit* ***= trousse Enfit administration entérale***	
25	Enfit Spuit (enteral voeding)- seringue Enfit (nutrition entérale)	
26	Seringue - syringe	

9.5 APPENDIX 5: List excluded items

Excluded items (non-exhaustive list)
Disinfectants and cleaning products
Toothpicks, earplugs
Toilet paper, coffee cups, paper pouches
Incontinence products for adults, monthly pads
Glucose monitoring equipment: glucose sticks, needles, plasters with needles
Blood tubes, specimen collecting jars (urine, faeces, …), wound swabs
Infusion (intravenous & enteral) therapy equipment: tubes, lines, infusion bags, syringes, taps, needle-free systems, connectors, caps, catheters, transfers needles
Masks (surgical masks/FFP2)
Medication, pre-filled syringes, contrast agents, anaesthetics
Wound care and related items: suture, compresses, gauze, tampons, bandages (transparent/adhesive non-transparent/postoperative)
Kits/Sets (with/without instruments)
Aspiration and ventilation equipment: aspiration pots, bags and probes, HEPA and humidity filters, oxygen nasal tubes
Other medical materials: EKG pads (foam), condoms for probes (ultrasound/temperature)

9.6 APPENDIX 6: Data provided by the included hospitals and overview of missing data

		Purchase department		Pharmacy department		OR material (laparoscopic devices/sets/ …)		Remarks
ID	Region	Amount	Cost	Amount	Cost	Amount	Cost	
1	Flanders	x	-	x	-	-	-	
2	Brussels	-	-	x	-	-	-	
3	Wallonia	x	x	x	x	-	-	
4	Brussels	x	-	x	-	-	-	
5	Flanders	x	x	x	x	x	x	
6	Flanders	x	-	x	-	-	-	
7	Flanders	x	x	x	x	-	-	
8	Wallonia	x	x	x	x	-	-	
9	Wallonia	x	-	x	-	-	-	Data 2022 (9 months)
10	Flanders	x	-	x	-	-	-	
11	Wallonia	x	x	-	-	-	-	Data 2022 (10 months)
12	Flanders	x	-	x	-	x	-	Items shortlist Data 2021

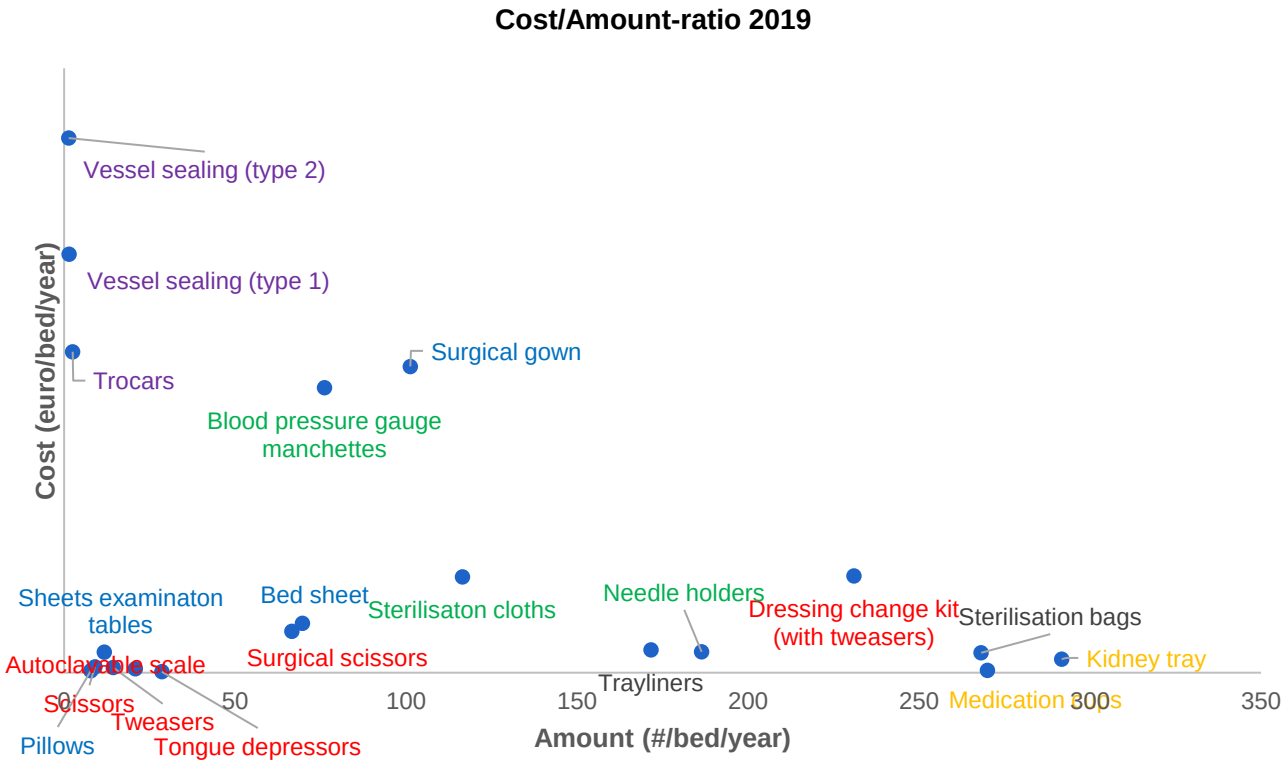
9.7 APPENDIX 7: Longlist of items

ITEM	VERWERKING
GLOVES (NS)	BEHAVOIUR
GLOVES (S)	N.A.
MEDICATION CUPS	TD/LLD
STERILISATION BAG	STERILISATION
COVERCAPS FOR TEMPERATURE MEASUREMENT	CHANGE OF ITEM/DEVICE
PLASTIC BAG (EXCL. TRASH CANS)	BEHAVOIUR
ABSORBING SHEET/TRAYLINER	LAUNDRY
SURGICAL AND OTHER CAPS	LAUNDRY
BASINS	LLD/HLD
STERILISATION DRAPES	STERILISATION
SHOE COVERS	BEHAVOIUR/LAUNDRY
MILK BOTTLES	STERILISATION
TONGUE DEPRESSOR (NS)	HLD
TONGUE DEPRESSOR (STERILE)	STERILISATION
BREAST(FEEDING) COMPRESS	LAUNDRY
SHEETS EXAMINATION TABLES	LAUNDRY
ANAESTHESIA MASKS	STERILISATION
NEEDLE BINS	WASTE
SPO2 SENSOR	LLD/(N/D)
BRUSH ENDOSCOPIC VALVES	HLD
GARROT LATEX FREE STRECH BLEU	LLD
SPECULUM	STERILISATION
GOWN (NS)	LAUNDRY
GOWN (S)	LAUNDRY
MOUTH RETRACTOR	HLD
DENTAL JAR	HLD
BIB	LAUNDRY
LID FOR DRINKING CUP	TD
PROTECTIVE COVER MATRESS	LAUNDRY
WASH CLOTH	LAUNDRY
WASH CLOTH (IMPREGNATED)	LAUNDRY
DIAPERS (BABY)	LAUNDRY
LID MEDICATION CUPS	LLD
PLASTIC GARGABE BAGS	BEHAVOIUR
SCISSORS (STERILE)	STERILISATION
SHARPS CONTAINERS	WASTE
SINK	LLD
TWEEZERS	STERILISATION
KOCHER (STERILE)	STERILISATION
LITE GLOVE	STERILISATION
LARYNGAL MASK	STERILISATION
OXYGEN MASK	HLD
INCONTINENCE PADS	LAUNDRY
SURGERY GOWNS	LAUNDRY
PLATE	LLD

TROLLEY COVERS	LAUNDRY
SCRUB BRUSH	STERILISATION
WARM-UP JACKET	LAUNDRY
WIPES	LAUNDRY
RX-COVERS	LLD
SURGICAL DRAPES	LAUNDRY
DRAPE	LAUNDRY
MESURING CUP	HLD
LARYNGOSCOOPBLADES	STERILISATION /HLD
NEEDLE HOLDER	LAUNDRY
BLOOD PRESSURE CUFFS	LLD
TRAY 250ML AUTOCLAV	STERILISATION
VESSEL SEALING (ECHELON)	STERILISATION
TABLE COVER	LAUNDRY
VESSEL SEALING (ENDO GLIA)	STERILISATION
TROCARS	STERILISATION
PILLOWCOVER	LAUNDRY
TELEMETRIE CARRYING BAG	LAUNDRY
STERILE CUP	STERILISATION
ASPIRATION JAR	HLD
AEROSOL MASK + JAR	STERILISATION /HLD
BREASTFEEDINGPUMP KIT	STERILISATION /HLD
MAYO TUBE	STERILISATION /HLD
VENTILATION TUBES	STERILISATION
NAPKIN	LAUNDRY
TRANSFER NEEDLES	STERILISATION
PAPER MEDICATION BOX	CHANGE OF ITEM/DEVICE
DESINFETION WIPE (SMALL)	LAUNDRY
WOODEN SPATULA	CHANGE OF ITEM/DEVICE
CARE KIT WITH INSTRUMENT	STERILISATION
BED PAN	HLD
TOWELETTES	LAUNDRY
IDENTIFICATION BRACELET	CHANGE OF ITEM/DEVICE

S: Sterile; NS: Not Sterile, HLD: High Level Disinfection; LLD: Low Level Disinfection; T.D: Thermal disinfection, N.A.: Not Applicable

9.8 APPENDIX 8: Example amount/cost ratio for one hospital



9.9 APPENDIX 9: Consumption of medical single-use items per bed per year for all participating hospitals

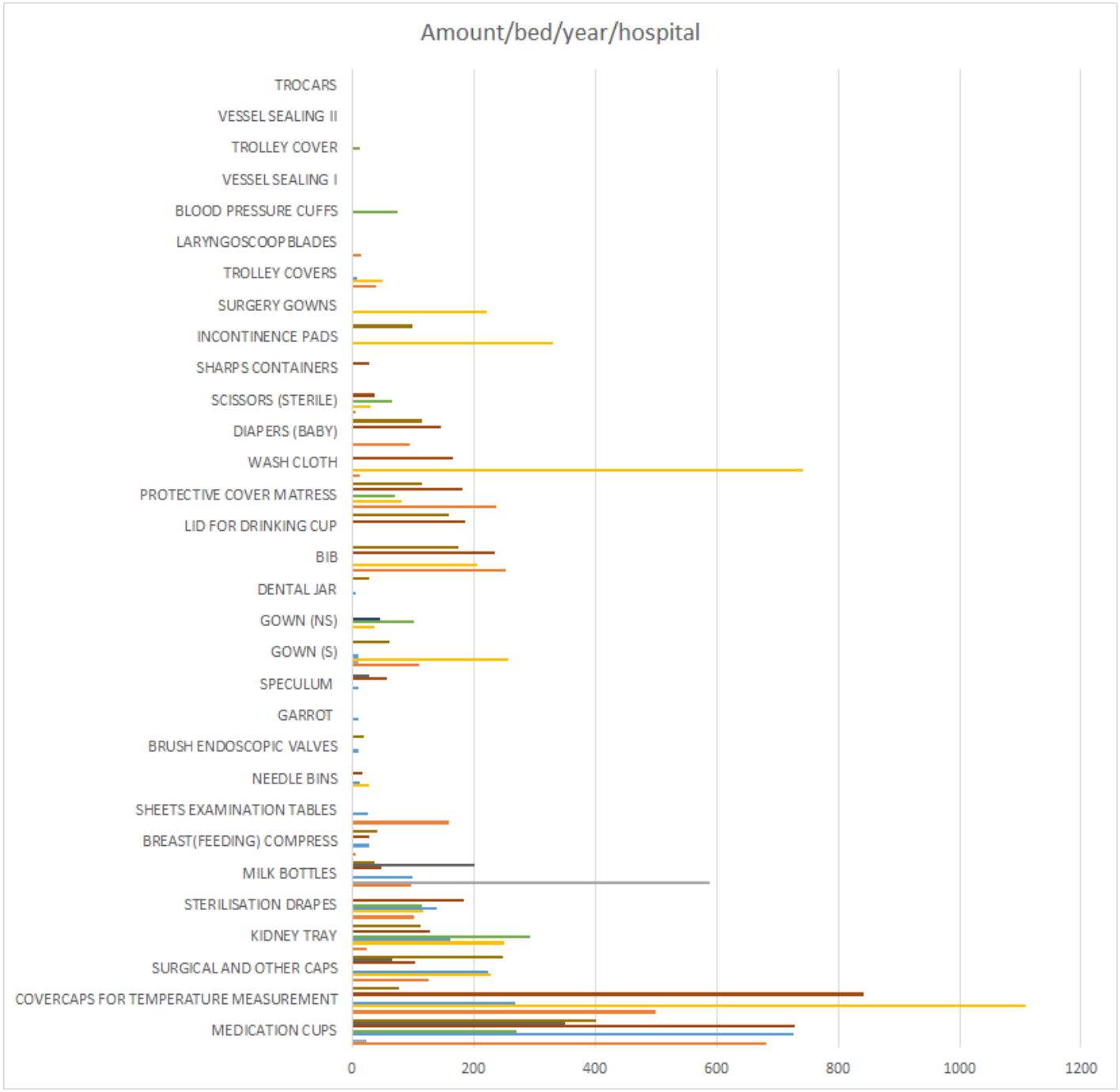


Figure 9: Overview of consumption of medical single-use items per bed per year

9.10 APPENDIX 10: Amount/Cost (catalogue prices) - rate

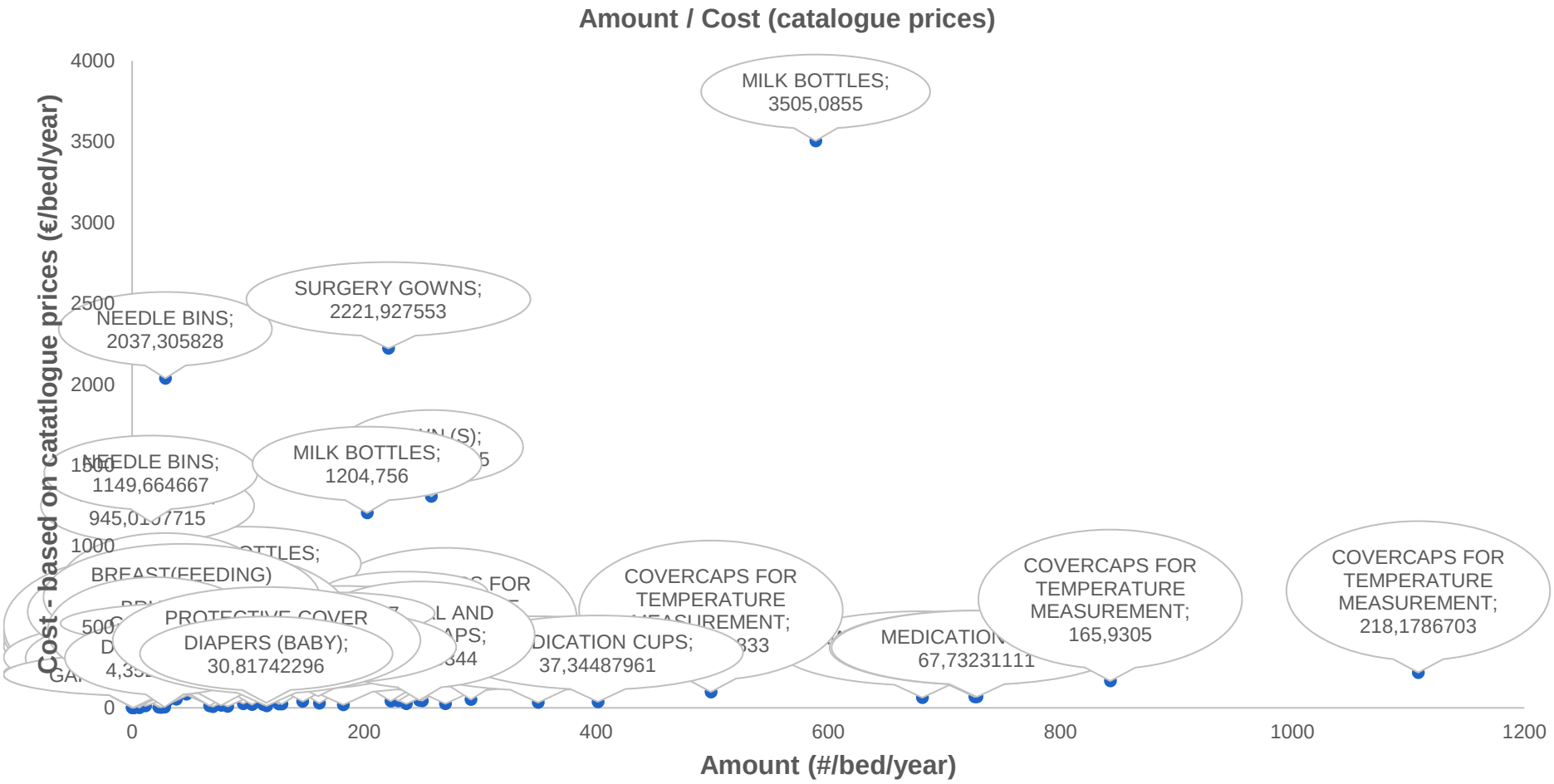


Figure 10: Amount/Cost – rate procurement data based on catalogue prices

9.11 APPENDIX 11: Considerations on sustainability of raw materials

Paper pulp

Paper(board) is made from different forms of pulp, which in turn is obtained mainly from wood, recycled paper or other cellulose-bearing material such as straw, grass, cotton or other (e.g. bamboo, reeds, jute, etc.). Pulp can be also produced by repulping of the recycled paper (Moya and Pavel 2018).

Pulp preparation and product production (moulding process) account for the highest environmental impact in the life cycle of manufacturing moulded pulp products (Didone et al. 2017 in Zhang et al. 2022) As the paper industry is an energy and carbon intensive industrial sector, some points of consideration need to be made (Federaal Instituut voor Duurzame Ontwikkeling 2016).

Deforestation

Numerous organisations promote sustainable forest management through establishing independent certification schemes, the two largest and most well-known certification programs are PEFC (Programme for the Endorsement of Forest Certification) and FSC (Forest Steward Council). Choosing for paper made from fibers derived from sustainably managed forests contributes to the preservation of forests, the protection of biodiversity and respect the rights of indigenous peoples (Federaal Instituut voor Duurzame Ontwikkeling 2016).

Energy and water consumption during production

There is a huge difference in energy consumption depending on the type of paper. Three times more energy is required to produce white paper (with fresh fibres) than recycled paper (Federaal Instituut voor Duurzame Ontwikkeling 2016). Consequently, an important focus is the percentage of recycled paper used in the kidney tray.

Besides energy, water is also an essential ingredient for making paper pulp and removing impure ingredients. The toxic constituents added to water for the production of pulp (especially in recycling) is one of the most significant impacts of the paper industry.

Emissions toxic substances during production

Chemical additives (bleaching products, dyes, glues, etc.) are needed to produce new paper and for removing the dyes and inks from the used paper. As a result, the paper industry is one of the most water-polluting industries (Federaal Instituut voor Duurzame Ontwikkeling 2016). Certain labels focus on the use of chemicals and production process-related aspects such as emissions to air and water. The most commonly used production labels are EU Ecolabel, Nordic Swan Ecolabel and Der Blaue Engel (Milieu Platform Zorgsector).

Bleaching of paper is still done mainly by using chlorine gas. However, chlorine gas is a dangerous and toxic product, both for human health and the environment. Paper can be certified as TCF or ECF. The abbreviations ECF (Elemental chlorine free) indicates that the paper concerned is bleached by using chlorine dioxide instead of using the environmentally less acceptable chlorine gas method of bleaching. TCF (Totally Chlorine Free) indicates that the bleaching of the paper has been done by using hydrogen peroxide, thus no chlorine or chlorine derivates. This is the most environmentally acceptable method of bleaching (Federaal Instituut voor Duurzame Ontwikkeling 2016).

Circular economy

Paper products can be reused via reprocessing into pulp by adding water and chemical ingredients to remove of inks and impurities. Usually, this recycled pulp is added to new pulp with a view to ensuring product quality. With each recycling cycle, the fibre gets smaller. On average, paper can be recycled up to 7 times. Recent research in Germany showed that paper can be recycled 25 times (Federaal Instituut voor Duurzame Ontwikkeling 2016)

Besides reducing waste, recycling paper ensures that CO_2 stays in the fibres longer. Europe is forerunner in paper recycling. The Confederation of European Paper Industries (CEPI) calculated the European paper and paperboard recycling rate for 2022 at 71.4% (Confederation of European Paper Industries 2022).

Plastics

Plastics are synthetic organic polymers formed by many small molecules (monomers). Different polymers are created through different production methods; they have different chemical structures and varying properties.

Different types of plastic are used for medical devices such as polyethylene (PE) divided into high-density polyethylene (HDPE) or low-density polyethylene (LDPE), polyvinyl chloride (PVC), polypropylene (PP) and polyethylene terephthalate (PET) . Figure 11 gives an overview the greenhouse gas emissions along the life cycle of the different forms of plastics (ETC/WMGE 2021).

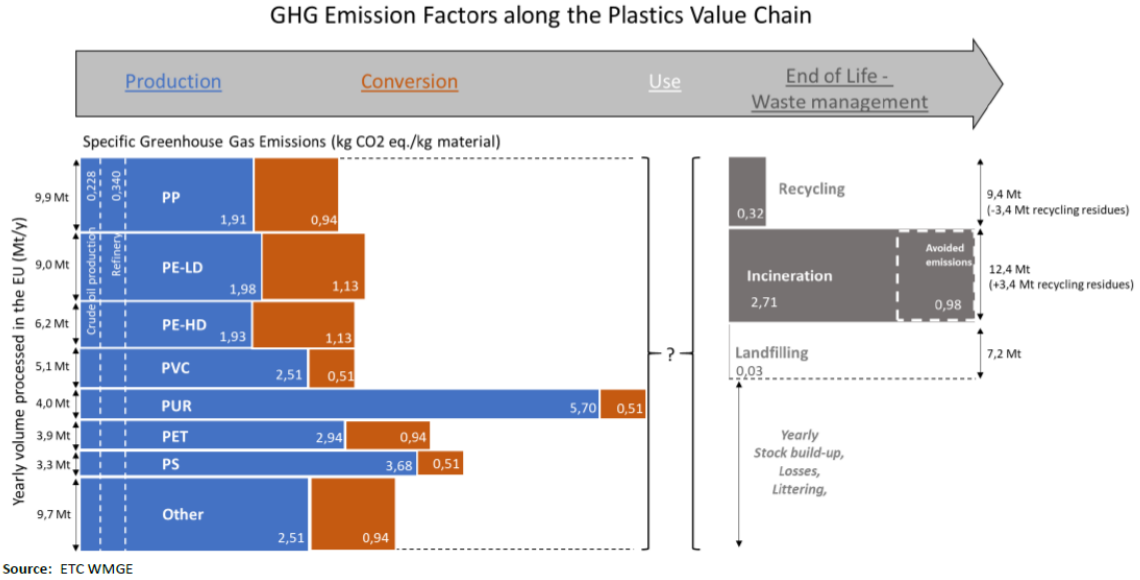


Figure 11: Greenhouse gas emissions intensity factors and material flows in (ETC/WMGE 2021)

Both PE and PP are standard medical grade plastics (Ashter 2022)

- PE is a versatile and durable thermoplastic. Properties such as excellent impact resistance and resistance to chemicals, along with zero moisture absorption making it a preferred material for medical applications.
- PP: certain medical grades of polypropylenes are stable at high temperatures. As PP has an excellent chemical resistance, is dimensionally stability, and compatibility towards different sterilization methods, they are chosen for applications that requires steam sterilization.

The rapidly increasing production of (disposable) plastics, most of these fossil-derived plastics are non-biodegradable, will lead to more waste and to more negative impacts on both human health and environment. (Health Care Without Harm Europe 2021a) Among all of the globally produced plastics, one third is non-recyclable and half is used for single-use purposes (Zhang et al. 2022).

Environmental impacts

Plastics can have negative impacts in each stage of its life cycle (Health Care Without Harm Europe 2021a):

- Emissions and toxic chemicals from both oil and gas extractions and manufacturing.
- Microplastics, microfibers and additives can be released in the environment during the use phase.
- Plastics used in health care are not commonly recycled, most plastic waste is disposed. In Belgium medical waste is incinerated. This is a harmful process which generates carbon emissions and toxic gases. When plastics are landfilled they can persist for years and leaching toxic chemicals and microplastics to soil and water.

Recent years, biobased plastics are emerging as alternatives to the currently dominant fossil-based plastics. However, the share of biobased polymers is very small compared to the fossil-based plastics (ETC/WMGE 2021). Biobased, biodegradable and compostable plastics have the potential to reduce the greenhouse gas emissions, but also present other challenges as sustainable land use and competition with food to protect and maintain natural capital. The overall impacts of biopolymers need to be thoroughly evaluated case by case (ETC/WMGE 2021; European Commission 2022a).

Health impacts

Similar to the environmental impact, each stage of the plastics life cycle poses threat to human health. (Health Care Without Harm Europe 2021a)

- Toxic chemicals are used and released from both raw resource extraction and manufacturing.
- Harmful chemicals that are used as plastic additives.
- Toxic substances are released into air, water and soil if plastic is incinerated. If plastics are landfilled, it breaks down in microplastic and nanoplastic. These small particles can be inhaled or ingested with water or food.

Stainless steel / inox

Stainless steel is a steel alloy that contains high percentages of iron and chromium, making it resistant to corrosion and wear. These alloys are further classified into families and grades that are defined by their unique characteristics and chemical compositions.

Medical grade stainless steels are part of the austenitic stainless steel family, a category known for its high formability and exceptional corrosion resistance. Grades 304 and 316 stainless steels contain high levels of nickel which provide additional chemical properties, making them suitable for use within the extreme demands of the medical industry.

Most steel production in Europe and globally is primary production, converting iron ore to steel through the basic oxygen furnace (BOF) route. This emits, on average, just over 2 tonnes of CO_2 per tonne of steel produced. Secondary steel is made in electric arc furnaces (EAF), with one-fifth the CO_2 emissions of primary steelmaking even when much of the electricity comes from fossil fuels. (Material Economics Sverige AB 2018) Gas emissions and energy consumption are the major environmental concerns with steel production (Nidheesh and Kumar 2019). Furthermore, ecotoxicity impacts are among the most crucial consequences of iron and steel production (Liu et al. 2020).

Medical textiles

The different life cycle stages of medical textiles can cause significant negative environmental impacts. Greenhouse gases and other pollutants as well as the use of water, land, chemicals are harmful for the environment (Health Care Without Harm Europe 2021b).

Type of fibre

To produce fibres and fabrics, the textiles industry mainly relies on non-renewable resources (oil, fertilizers, chemicals) (ETC/WMGE 2019; Health Care Without Harm Europe 2021b). Different fibres have different environmental impacts during production. Cotton and polyester tend to have greater production impacts than some emerging fibres. Synthetic fibres can lead to marine microplastic pollution. Some fibres are more durable than others, for instance polyester or a polyester/cotton mix can survive more laundry cycles than 100% cotton. Synthetic fibres are easier to launder since they absorb less water and use less energy during drying. (Watson and Fisher-Bogason 2017).

Effect of chemicals

Numerous substances have been identified in textile production, of which some have been classified as hazardous for human health (carcinogenic, mutagenic, allergic or toxic to reproduction) and others as hazardous for the environment (f.i. for global water pollution) (Health Care Without Harm Europe 2021b) (REACH for chemicals). Per production stage there are problematic chemicals/chemical-related issues and also in textile finishes there are chemicals found. The legal limit for the use of chemicals may differ between countries, and product manufacturers can obtain textiles form anywhere in the world. The market for medical textiles is currently dominated by Europe, followed by North America and Asia-Pacific. Compliance of imported products is often a concern (Health Care Without Harm Europe 2021b).

Health Care Without Harm (2021b) focuses on reducing entire classes of problematic chemicals. Their chemicals of emerging concern are:

- Per-and polyfluordoalkyl substances (PFAS)
  - Primary function of PFAS: water, oil and dirt repellence.
  - PFAS are extremely persistent, often referred to as ‘forever chemicals’.
  - Leaching of PFAS out of textiles might not only have an environmental impact; PFAS in clothing may also form a direct exposure route to humans, since there is dermal contact with the textiles. It has been shown for example that PFOA can penetrate human skin.
- Flame-retardants
  - Harmful to human health and toxic to wildlife.

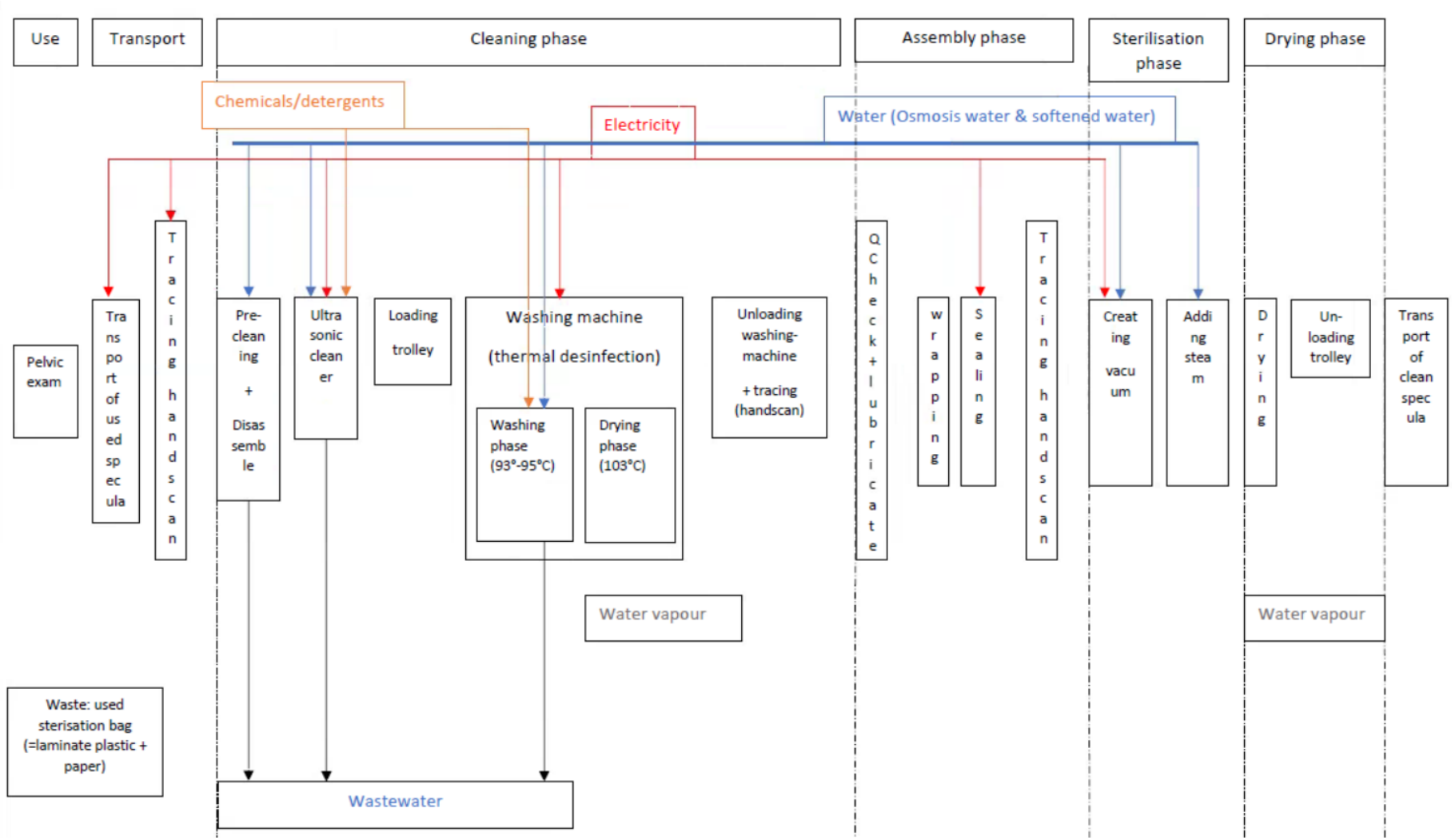
    - Leaking from products into dust and air where they may persist in the atmosphere and accumulate in living organisms.
- Antimicrobials
    - Risk from antimicrobial textiles are evaluated via acute and chronic toxicity, skin sensitization and irritation, and the disturbance of skin ecology.
    - Potential unintended consequences of biocidal substances/antimicrobial-impregnated textiles have not been explored fully, they must be critically reassessed for both safety and necessity.

Also for textiles, there are eco-labels which contain criteria such as natural fibres, water use, energy use, chemicals/detergents… , f.i. Nordic Swan and EU Ecolabel. (Watson and Fisher-Bogason 2017).

Recyling

Generally, approximately 20% of reusable textiles is recycled (downcycled), only 1% is used in new textile. Fibers are often blended with others, which makes recycling more difficult.

9.12 APPENDIX 12: Steps in reuse phase of reusable speculum in Ghent University Hospital



9.13 APPENDIX 13: Inventory analysis for LCA

Process	Inputs	Out-puts	Unit	Provider
Reusable speculum – Manufacturing and packaging				
Stainless steel	179		g/speculum	Steel, chromium steel 18/8 {GLO}| market for | Cut-off, U
Electricity for moulding				Metal working, average for chromium steel product manufacturing {RER}| processing | Cut-off, U_elec DE
packaging - plastic LDPE & LLDPE	4		g/package of 8-10, dubble packaged	Packaging film, low density polyethylene {GLO}| market for | Cut-off, U
packaging - cardboard	200		g/package of 8-10	Corrugated board box {RER}| market for corrugated board box | Cut-off, U
Reusable speculum – Distribution				
Land transport from Germany – Aspen to The Netherlands – Noord Holland	602		km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Reusable speculum –Treatment phase (Pre use phase)				
Cart wash				
Electricity	1,00		kWh/1 proces	Electricity, medium voltage {BE}| market for | Alloc Rec, U_Belgian energy supplier Green BE 2022
Detergent	0,09		L/1 proces	0,4 Alkylbenzene sulfonate, linear, petrochemical {GLO}| market for | Cut-off, U 0,1 Sodium tripolyphosphate {GLO}| market for | Cut-off, U 0,5 Tap water {RER}| market group for | Cut-off, U
Softend water	150,0		L/1 proces	Water, completely softened {RER}| market for water, completely softened | Cut-off, U
Rinsing agent	0,06		L/1 proces	0,2 Chemical, organic {GLO}| market for | Cut-off, U 5 0,2 Chemical, inorganic {GLO}| market for chemical, 5 inorganic | Cut-off, U 0,5 Tap water {RER}| market group for | Cut-off, U
Steam	28.00		kg/proces	Heat, from steam, in chemical industry {RER}| steam production, as energy carrier, in chemical industry | Cut-off, U_elec and heat from municipal waste incineration_BE_no recirculation tap water 2.75
Ultrasone cleaning				
Electricity	0,50		kWh/1 proces	Electricity, medium voltage {BE}| market for | Alloc Rec, U_Belgian energy supplier Green BE 2022
Softend water	17,50		L/proces	Water, completely softened {RER}| market for water, completely softened | Cut-off, U
Detergent	0,044		L/proces	0,4 Alkylbenzene sulfonate, linear, petrochemical {GLO}| market for | Cut-off, U 0,1 Sodium tripolyphosphate {GLO}| market for | Cut-off, U 0,5 Tap water {RER}| market group for | Cut-off, U
Washing machine				
Electricity	12,00		kWh/1 proces	Electricity, medium voltage {BE}| market for | Alloc Rec, U_Belgian energy supplier Green BE 2022
Detergent	0,22		L/1 proces	0,4 Alkylbenzene sulfonate, linear, petrochemical {GLO}| market for | Cut-off, U 0,1 Sodium tripolyphosphate {GLO}| market for | Cut-off, U 0,5 Tap water {RER}| market group for | Cut-off, U
Softend water	35,00		L/1 proces	Water, completely softened {RER}| market for water, completely softened | Cut-off, U
Washing mashine - osmose water	85,00		L/1 proces	RO water_elec Belgian energy supplier Green BE 2022
Sterilisation				
Compressed air	0,20		Nm^3/h	Compressed air, 700 kPa gauge {RER}| market for compressed air, 700 kPa gauge | Cut-off, U_elec Belgian energy supplier Green BE 2022
Fresh water (softend)	0,037		m^3/h	Water, completely softened {RER}| market for water, completely softened | Cut-off, U
Electricity	1,40		kWh	Electricity, medium voltage {BE}| market for | Alloc Rec, U_Belgian energy supplier Green BE 2022

Steam (Osmose water)	23,4		kg/h	Heat, from steam, in chemical industry {RER}| steam production, as energy carrier, in chemical industry | Cut-off, U_elec and heat from municipal waste incineration_BE_without water RO water_elec Belgian energy supplier Green BE 2022
Sealer				
Electricity	0,004		kWh/speculum	Electricity, medium voltage {BE}| market for | Alloc Rec, U_Belgian energy supplier Green BE 2022
Packaging1& 2 - PP	8		g	Packaging film, low density polyethylene {GLO}| market for | Cut-off, U_PP
Packaging1& 2 - PET	0,0025		kg/speculum	Packaging film, low density polyethylene {GLO}| market for | Cut-off, U_PET
Packaging1& 2 - Paper	10		g	Paper, woodfree, uncoated {RER}| market for | Cut-off, U
Waste water (cartwash, cleaning, sterilisation)		5,26	L	Wastewater, average {Europe without Switzerland}| treatment of wastewater, average, capacity 1E9l/year | Cut-off, U
Waste water (condensate steam)		3,52	kg/h	Wastewater, unpolluted {CH}| treatment of, capacity 5E9l/year | Cut-off, U
Waste packaging collection plastic		65	km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Waste packaging collection cardboard		65	km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Packaging plastic LDPE & LLDPE		4	g/package of 8-10	MATTER model recycling MATTER model recovered PE TS=0.98
Packaging cardboard		200	g/package of 8-10	Waste paperboard, sorted {Europe without Switzerland}| treatment of waste paperboard, unsorted, sorting | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, recycled | Cut-off, U_without waste sorting Containerboard, linerboard {RER}| containerboard production, linerboard, testliner | Cut-off, U_without waste sorting Containerboard, fluting medium {RER}| containerboard production, fluting medium, semichemical | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, kraftliner | Cut-off, U
Reusable speculum – Use phase				
Waste packaging collection paper		65	km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Waste packaging collection plastic		65	km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Waste management Paper		10	g	Waste paper, sorted {Europe without Switzerland}| treatment of waste paper, unsorted, sorting | Cut-off, U Paper, woodfree, uncoated {RER}| paper production, woodfree, uncoated, at integrated mill | Cut-off, U_no virgin input Paper, woodfree, uncoated {RER}| paper production, woodfree, uncoated, at integrated mill | Cut-off, U
Waste management packaging Plastic PP		8	g	Waste polypropylene {RoW}| treatment of waste polypropylene, municipal incineration | Cut-off, U Electricity, medium voltage {BE}| market for | Cut-off, U Heat, district or industrial, natural gas {BE}| heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical | Cut-off, U
Waste management packaging Plastic PE				Waste polyethylene terephthalate {RoW}| treatment of waste polyethylene terephthalate, municipal incineration | Cut-off, U Electricity, medium voltage {BE}| market for | Cut-off, U Heat, district or industrial, natural gas {BE}| heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical | Cut-off, U
Reusable speculum – End of Life phase				
Waste management speculum	179			Scrap steel {Europe without Switzerland}| treatment of scrap steel, municipal incineration | Cut-off, U

Landtransport (truck) to Antwerp	76			Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Bottom ashes from speculum		179	g	Pig iron {RER}| pig iron production | Cut-off, U
Single-use fossil plastic based (ABS) speculum				
Fossil plastic (ABS: Acrylonitrile butadiene styrene) +	34,40			Acrylonitrile-butadiene-styrene copolymer {GLO}| market for | Cut-off, U
Electricity for injection molding			g	Injection moulding {RER}| processing | Cut-off, U_elec NL
Packaging - plastic 1 LDPE & LLDPE	10		g	Packaging film, low density polyethylene {GLO}| market for | Cut-off, U
Packaging - plastic 2 LDPE & LLDPE	45		g/package of 200	Packaging film, low density polyethylene {GLO}| market for | Cut-off, U
Packaging - cardboard	1215		g/package of 200	Corrugated board box {RER}| market for corrugated board box | Cut-off, U
Landtransport from The Netherlands	236		km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Waste packaging collection cardboard		65	km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Waste packaging collection plastic		65	km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Waste management -Cardboard		1215	g/package of 200	Waste paperboard, sorted {Europe without Switzerland}| treatment of waste paperboard, unsorted, sorting | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, recycled | Cut-off, U_without waste sorting Containerboard, linerboard {RER}| containerboard production, linerboard, testliner | Cut-off, U_without waste sorting Containerboard, fluting medium {RER}| containerboard production, fluting medium, semichemical | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, kraftliner | Cut-off, U
Waste management plastic 1 LDPE & LLDPE		10	g	MATTER model recycling MATTER model recovered PE TS=0.98
Waste management plastic 2 LDPE & LLDPE		45	g/package of 200	MATTER model recycling MATTER model recovered PE TS=0.98
Waste management speculum - Fossil plastic (ABS: Acrylonitrile butadiene styrene)	34,4		kg	Waste polystyrene {RoW}| treatment of waste polystyrene, municipal incineration | Cut-off, U
Waste management - Landtransport (truck) to Antwerp	76		km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Energy recovered from speculum		34,4	g	Electricity, medium voltage {BE}| market for | Cut-off, U Heat, district or industrial, natural gas {BE}| heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical | Cut-off, U

Single-use biobased plastic (PLA) speculum				
Bioplastic PLA	39,9		g	Polylactide, granulate {GLO}| market for | Cut-off, U
Transport from Thailand - freight ship Bangkok to Rotterdam	16888		km	Transport, freight, sea, container ship {GLO}| transport, freight, sea, container ship | Cut-off, U
Transport from Thailand - truck Rotterdam to Noord-Holland	100		km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Electricity for injection molding				Injection moulding {RER}| processing | Cut-off, U_elec NL
Packaging - plastic 1 LDPE & LLDPE	10		g	Packaging film, low density polyethylene {GLO}| market for | Cut-off, U
Packaging - plastic 2 LDPE & LLDPE	45		g/package of 200	Packaging film, low density polyethylene {GLO}| market for | Cut-off, U
Packaging - cardboard	1215		g/package of 200	Corrugated board box {RER}| market for corrugated board box | Cut-off, U
Landtransport from The Netherlands	236		km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Waste packaging collection cardboard		65	km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Waste packaging collection plastic		65	km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Waste management -Cardboard		1215	g/package of 200	Waste paperboard, sorted {Europe without Switzerland}| treatment of waste paperboard, unsorted, sorting | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, recycled | Cut-off, U_without waste sorting Containerboard, linerboard {RER}| containerboard production, linerboard, testliner | Cut-off, U_without waste sorting Containerboard, fluting medium {RER}| containerboard production, fluting medium, semichemical | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, kraftliner | Cut-off, U
Waste management plastic 1 LDPE & LLDPE		10	g	MATTER model recycling MATTER model recovered PE TS=0.98
Waste management plastic 2 LDPE & LLDPE		45	g/package of 200	MATTER model recycling MATTER model recovered PE TS=0.98
Biobased plastic (PLA)	39,90			Waste plastic, mixture {RoW}| treatment of waste plastic, mixture, municipal incineration | Cut-off, U
Landtransport (truck) to Antwerp	76			Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Energy recovered from speculum		39,90	g	Electricity, medium voltage {BE}| market for | Cut-off, U Heat, district or industrial, natural gas {BE}| heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical | Cut-off, U
Ethylene oxide sterilised single-use speculum consisting of polystyrene blades and polyethylene bolt				
Blades: Fossil plastic (polystyrene)	29		g	Polystyrene, general purpose {GLO}| market for | Cut-off, U

Bolt: Fossil plastic (poly-ethylene)	2		g	Polyethylene, high density, granulate {GLO}| market for | Cut-off, U
Electricity for injection molding				Injection moulding {RER}| processing | Cut-off, U_elec PL
Ethylene oxide (EO) sterilization	276		g/cyclus	Ethylene oxide {RER}| market for ethylene oxide | Cut-off, U
Electicity for EO sterilisation	4,50		kW/cyclus	Electricity, medium voltage {PL}| market for | Cut-off, U
Packaging - plastic 1 LDPE & LLDPE	4		g/speculum	Packaging film, low density polyethylene {GLO}| market for | Cut-off, U
Packaging - plastic 2 LDPE & LLDPE	45		g/package of 200	Packaging film, low density polyethylene {GLO}| market for | Cut-off, U
Packaging - cardboard	1215		g/package of 200	Corrugated board box {RER}| market for corrugated board box | Cut-off, U
Landtransport from Poland to Antwerp	1165		Km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Landtransport from Antwerp to UZ Ghent	57		Km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Waste packaging collection cardboard		65	Km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Waste packaging collection plastic		65	Km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Cardboard		1215	g/package of 200	Waste paperboard, sorted {Europe without Switzerland}| treatment of waste paperboard, unsorted, sorting | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, recycled | Cut-off, U_without waste sorting Containerboard, linerboard {RER}| containerboard production, linerboard, testliner | Cut-off, U_without waste sorting Containerboard, fluting medium {RER}| containerboard production, fluting medium, semichemical | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, kraftliner | Cut-off, U
Packaging 1-plastic plastic LDPE & LLDPE		4	g/package of 1	MATTER model recycling MATTER model recovered PE TS=0.98
Packaging 2-plastic plastic LDPE & LLDPE		45	g/package of 200	MATTER model recycling MATTER model recovered PE TS=0.98
Waste management blades:(polystyrene)	29		g	Waste polystyrene {RoW}| treatment of waste polystyrene, municipal incineration | Cut-off, U
Waste management bolt: polyethylene	2		g	Waste polyethylene {RoW}| treatment of waste polyethylene, municipal incineration | Cut-off, U
Landtransport (truck) to Antwerp	76		km	Transport, freight, lorry, unspecified {RER}| transport, freight, lorry, all sizes, EURO6 to generic market for | Cut-off, U
Energy recovered incineration blades		29	g	Electricity, medium voltage {BE}| market for | Cut-off, U Heat, district or industrial, natural gas {BE}| heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical | Cut-off, U
Energy recovered incineration bolt		2	g	Electricity, medium voltage {BE}| market for | Cut-off, U Heat, district or industrial, natural gas {BE}| heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical | Cut-off, U

9.14 APPENDIX 14: Assumptions for inventory analysis of LCA

Reusable stainless steel speculum		Data source
Number of uses of one speculum	500 (baseline)	Assumption (See (Snijder and Broeren 2022))
Substitutability recovered steel scrap for pig iron	1	Rigamonti et al. 2010 (Rigamonti et al. 2010)
Steel sorting efficiency	0,92	Rigamonti et al. 2010
Substitutability recovered paper	0,90	Merrild et al. 2008 (Merrild et al. 2008)
Paper recycling efficiency	0,83	Merrild et al. 2008
Substitutability recovered paperboard	0,90	Merrild et al. 2008
Paperboard recycling efficiency	0,91	Merrild et al. 2008
Energy content steam from waste incineration (MJ/kg)	2,75	steam table 5 bar en 159°C
Energy content cleansteam (MJ/kg)	2,73	steam table 3.3 bar en 145°C
Electricity recovered from PP incineration (kWh/kg dry)	1,39	ecoinvent dataset
Heat recovered from PP incineration (MJ/kg dry)	9,69	ecoinvent dataset
Electricity recovered from PET incineration (kWh/kg dry)	0,83	ecoinvent dataset
Heat recovered from PET incineration (MJ/kg dry)	5,82	ecoinvent dataset
Loading cartwash	100 pc = 1 process	expert opinion- staff CSA
Loading ultrasone	10,00 pc = 1 process	expert opinion- staff CSA
Loading washingmachine	60,00 pc = 1 process	expert opinion- staff CSA
Loading sterilisation	60,00 pc = 1 process	expert opinion- staff CSA

Single-use fossil based plastic speculum (ABS)		
substitutability recovered paperboard	0,90	Merrild et al. 2008
paperboard recycling efficiency	0,91	Merrild et al. 2008
electricity recovered from PS incineration (kWh/kg dry)	1,40	ecoinvent dataset
heat recovered from PS incineration (MJ/kg dry)	9,73	ecoinvent dataset
electricity recovered from ABS incineration (kWh/kg dry)	1,44	
heat recovered from ABS incineration (MJ/kg dry)	9,66	
gross electricial efficiency (%)	15,84	Doka, et al., 2013 (Doka 2013)
gross thermal efficiency (%)	28,51	Doka, et al., 2013
internal electricity consumption (kWh/kg)	0,13	Doka, et al., 2013
internal heat consumption (MJ/kg)	0,49	Doka, et al., 2013
combustion value ABS (MJ/kg)	35,6	CE Delft report
carbon content ABS worst case (%)	88	CE Delft report; own calculation confirms based on Wikipedia ABS
content styrene worst case (%)	60	Wikipedia ABS
content butadiene worst case (%)	25	Wikipedia ABS
content acrylonitrile worst case (%)	15	Wikipedia ABS
dry mass content waste PS (kg/kg)	0,998	ecoinvent dataset
injection moulding yield (kg/kg)	0,994	ecoinvent dataset

Single-use biobased plastic speculum (PLA)		
substitutability recovered paperboard	0,90	Merrild et al. 2008
paperboard recycling efficiency	0,91	Merrild et al. 2008
electricity recovered from PLA incineration (kWh/kg dry)	0,66	
heat recovered from PLA incineration (MJ/kg dry)	4,62	
gross electrical efficiency (%)	15,84	Doka, et al., 2013
gross thermal efficiency (%)	28,51	Doka, et al., 2013
internal electricity consumption (kWh/kg)	0,13	Doka, et al., 2013
internal heat consumption (MJ/kg)	0,49	Doka, et al., 2013
combustion value PLA (MJ/kg)	17,9	CE Delft report
carbon content PLA (%)	50	CE Delft report; own calculation confirms
dry mass content waste plastic mixture (kg/kg)	0,847	ecoinvent dataset
carbon content (dry mass) waste plastic mixture (kg/kg)	0,634	ecoinvent dataset
injection moulding yield (kg/kg)	0,994	ecoinvent dataset

Ethylene oxide (EO) sterilised single-use speculum consisting of polystyrene blades and polyethylene bolt		
Loading sterilisator type Labtron LEOS A14	1200	
Injection moulding yield (kg/kg)	0,994	ecoinvent dataset
Substitutability recovered paperboard	0,90	Merrild et al. 2008
Paperboard recycling efficiency	0,91	Merrild et al. 2008
electricity recovered from PE incineration (kWh/kg dry)	1,55	ecoinvent dataset
heat recovered from PE incineration (MJ/kg dry)	10,73	ecoinvent dataset
electricity recovered from paperboard incineration (kWh/kg dry)	0,62	ecoinvent dataset
heat recovered from paperboard incineration (MJ/kg dry)	4,44	ecoinvent dataset
electricity recovered from PS incineration (kWh/kg dry)	1,40	ecoinvent dataset
heat recovered from PS incineration (MJ/kg dry)	9,73	ecoinvent dataset
dry mass content PE (kg/kg)	0,996	ecoinvent dataset
dry mass content paperboard (kg/kg)	0,896	ecoinvent dataset
dry mass content waste PS (kg/kg)	0,998	ecoinvent dataset

9.15 APPENDIX 15: Distribution details for reusable and single-use specula

	Reusable speculum	Single-use speculum from fossil plastic	Single-use speculum from biobased plastic	Ethylene oxide sterilised single-use speculum
Speculum: raw materials to manufacturer	Ecoinvent database	Ecoinvent database	Transport by boat Thailand (Bangkok) to The Netherlands (Rotterdam) 16888 km + Land transport by truck average size vehicle Rotterdam to Noord-Holland 100 km	Ecoinvent database
Packaging materials (raw materials to manufacturer)	Ecoinvent database	Ecoinvent database	Ecoinvent database	Ecoinvent database
Chemicals/electricity/water input	Ecoinvent database	Ecoinvent database	Ecoinvent database	Ecoinvent database
Wrapped speculum from manufacturer to Ghent University Hospital	Land transport by truck average size vehicle Form Germany (Tuttlingen, Aspen) to Belgium (Ghent) 602 km	Land transport by truck average size truck From The Netherlands (Noord-Holland) to Belgium Ghent 236 km	Land transport by truck average size truck From The Netherlands (Noord-Holland) to Belgium (Ghent) 236 km	Land transport by truck average size truck From Poland to Antwerp (Belgium) and from Antwerp to Ghent (Belgium) 1165 km
Waste from Ghent University Hospital to Antwerp – **Incinerator (speculum)** – **Recycling (packaging materials)**	Land transport by truck average size vehicle 76 km 65 km			

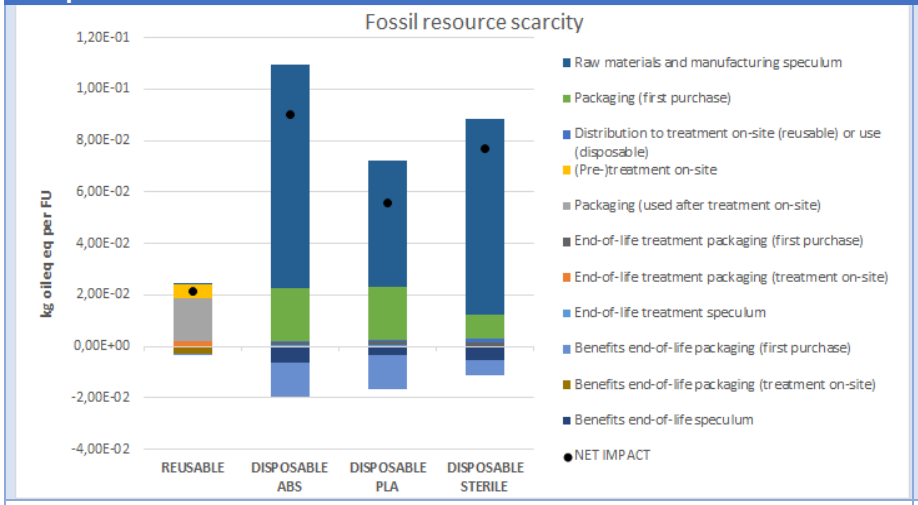
9.16 APPENDIX 16: Overview of all mid- and endpoint estimates for reusable and single-use specula

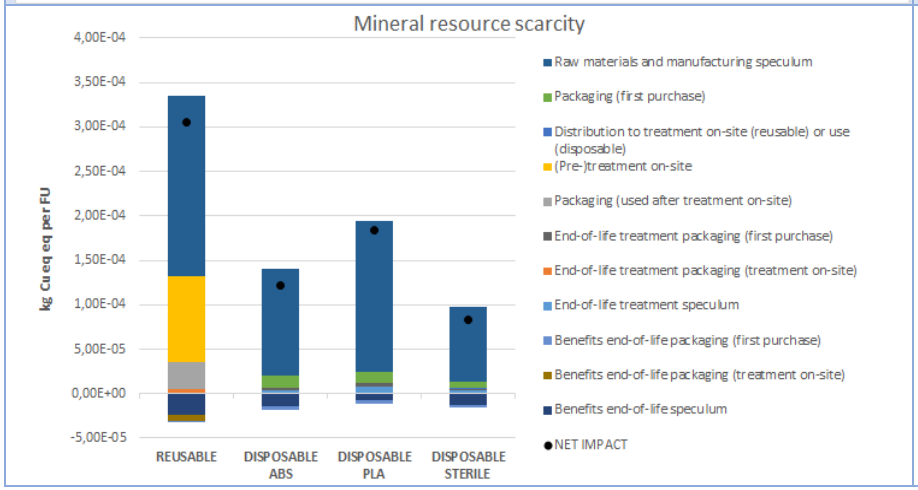
Impact category	Reusable specula	SU ABS specula	SU PLA specula	EO SU specula
Midpoints				
Global warming ($kgCO_2eq$)	7.13-02	3.25E-01	2.03E-01	2.80E-01
Fossil resource scarcity (kg oil eq)	2.16E-02	8.99E-02	5.57E-02	7.70E-02
Mineral resource scarcity (kgCu eq)	3.05E-04	1.22E-04	1.83E-04	8.26E-05
Water consumption (m^3)	2.14E-03	2.69E-03	6.04E-03	3.37E-03
Stratospheric ozone depletion (kg CFC11 eq)	1.12E-07	4.09E-08	5.16E-07	2.82E-08
Ionizing radiation (kBq Co-60 eq)	1.21E-03	-1.06E-02	4.07E-03	-1.41E-02
Ozone formation, Human health (kg NOx eq)	1.38E-04	3.57E-04	5.36E-04	3.95E-04
Fine particulate matter formation (kg PM2.5 eq)	8.81E-05	1.75E-04	2.83E-04	2.02E-04
Ozone formation, Terrestrial ecosystems (kg NOx eq)	1.42E-04	3.82E-04	5.56E-04	3.53E-04
Terrestrial acidification (kg SO2 eq)	2.19E-04	4.88E-04	7.53E-04	5.97E-04
Freshwater eutrophication (kg P eq)	3.57E-05	6.07E-05	9.34E-05	8.79E-05
Marine eutrophication (kg N eq)	2.78E-05	9.93E-06	6.02E-05	9.05E-06
Terrestrial ecotoxicity (kg 1,4-DCB)	3.61E+04	1.37E+04	1.37E+04	1.37E+04
Freshwater ecotoxicity (kg 1,4-DCB)	3.72E-03	5.39E-03	7.53E-03	5.96E-03
Marine ecotoxicity (kg 1,4-DCB)	5.08E-03	7.48E-03	9.80E-03	8.32E-03
Human carcinogenic toxicity (kg 1,4-DCB)	6.64E-03	8.07E-03	5.62E-03	6.75E-03
Human non-carcinogenic toxicity (kg 1,4-DCB)	1.41E+04	1.41E-01	1.72E-01	1.72E-01
Land use (m2a crop eq)	1.47E+03	-6.46E-04	2.14E-02	-3.67E-04
Impact category	**Reusable specula**	**SU ABS specula**	**SU PLA specula**	**EO SU specula**
Endpoints				
Human Health (DALY's)	1.65E-07	4.76E-07	5.16E6-07	4.53E-07
Ecosystem Quality (species.yr)	4.09E-10	1.14E-09	1.351E-09	1.05E-09
Resource Scarcity (USD2013)	7.90E-03	3.37E-02	1.65E-02	2.71E-02

SU ABS: single-use fossil based plastic; SU PLA: Single-use biobased plastic; EO SU specula: ethylene oxide sterilised single-use specula consisting of polystyrene blades and polyethylene bolt
Figures are expressed according to LCA-standards; E-01= x 0.1;E-02= x 0.01; E-03= x 0.001; E-04= x 0.0001; …; E+01= x10; E+02= x 100; E+03= x 1000; E+04= x 10 000; ….

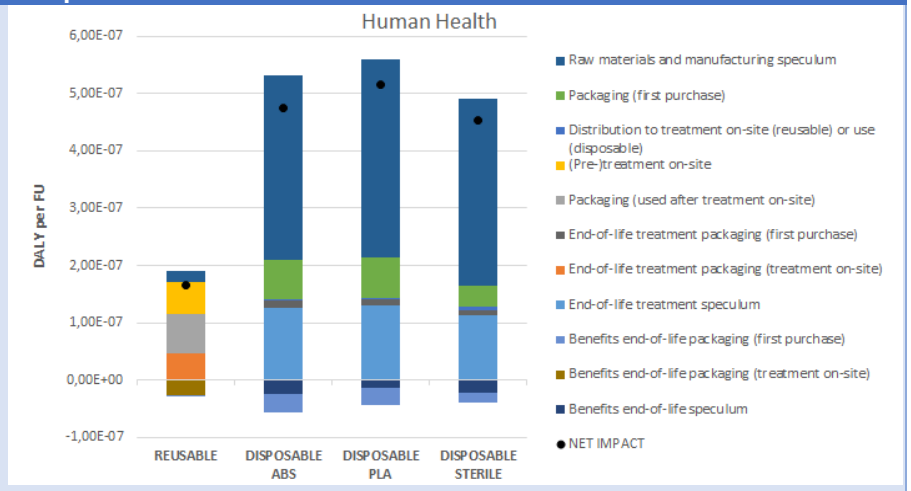
9.17 APPENDIX 17: Graphs midpoint and endpoint estimates

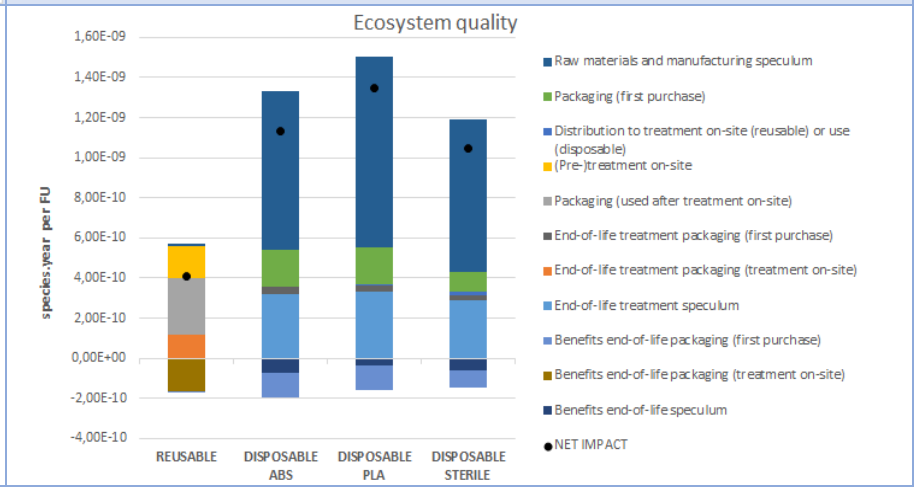
Midpoint estimates





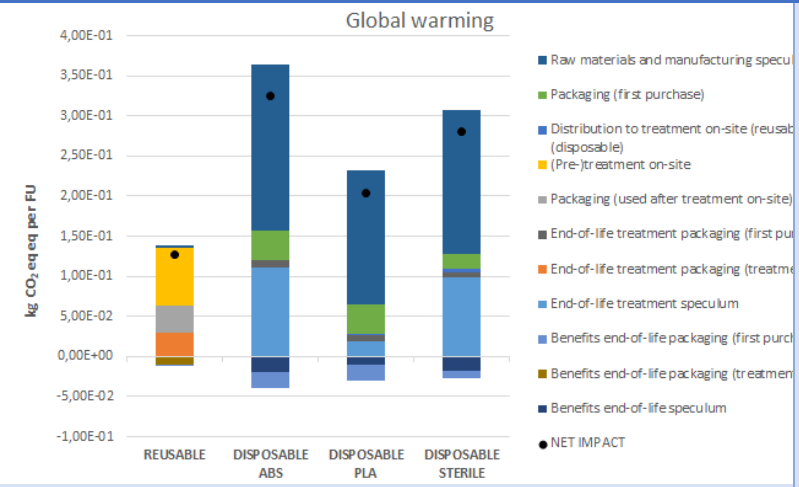
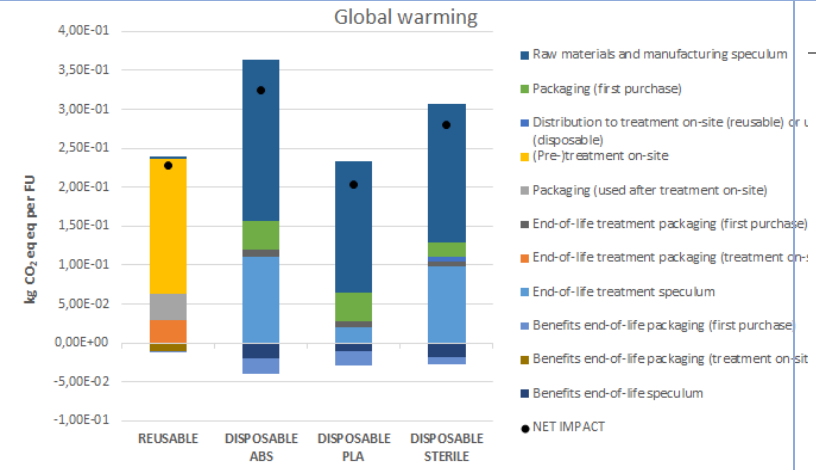
Endpoint estimates



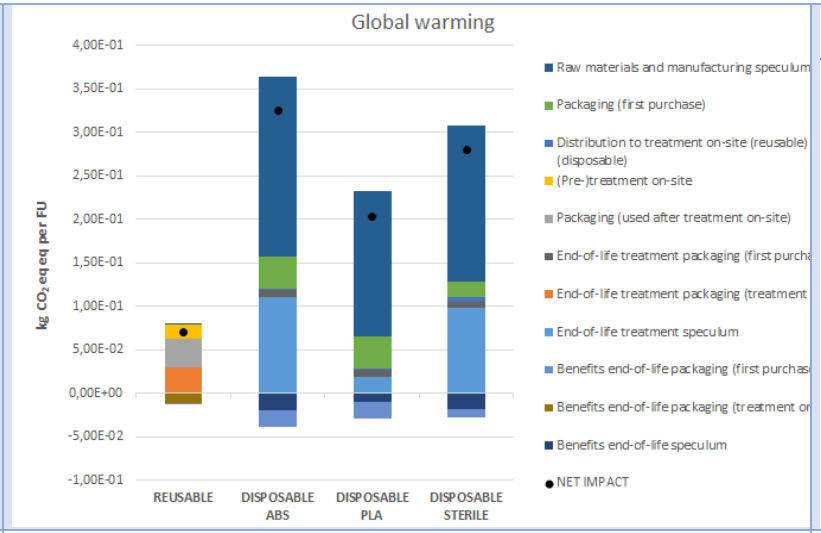


Figures are expressed according to LCA-standards; E-01= x 0.1;E-02= x 0.01; E-03= x 0.001; E-04= x 0.0001; …; E+01= x10; E+02= x 100; E+03= x 1000; E+04= x 10 000; ….

9.18 APPENDIX 18: Scenario analyses

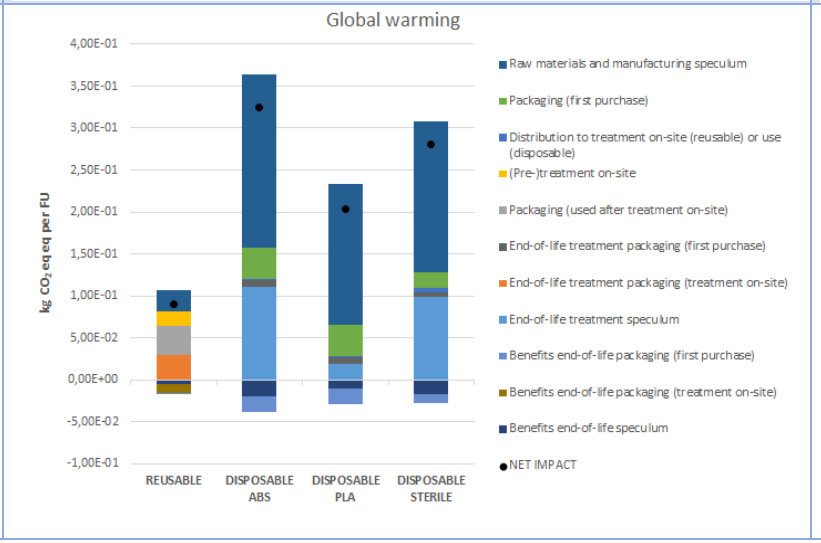
Scenario	Graph	Impact category	Reusable specula	SU ABS specula	SU PLA specula	EO SU specula
Average Belgian Energy mix		***Midpoints***				
		Global warming (kgCO_2eq)	1.28E-01	3.25E-01	2.03E-01	2.80E-01
		Fossil resource scarcity (kg oil eq)	3.78E-02	8.99E-02	5.57E-02	7.07E-02
		Mineral resource scarcity (kgCu eq)	3.75E-04	1.22E-04	1.83E-04	8.26E-05
		Water consumption (m^3)	2.75E-03	2.69E-03	6.04E-03	3.37E-03
		Endpoints*				
		Human Health (DALY's)	2.33E-07	4.76E-07	5.16E-07	4.53E-07
		Ecosystem Quality (species.yr)	5.76E-10	1.14E-09	1.35E-09	1.05E-09
		Resource Scarity (USD2013)	1.30E-02	3.37E-02	1.65E-02	2.71E-02
Average steam production		***Midpoints***	**RU**	**SU ABS**	**SU PLA**	**EO SU**
		Global warming (kgCO_2eq)	2.28E-01	3.25E-01	2.05E-01	2.80E-01
		Fossil resource scarcity (kg oil eq)	7.63E-02	8.99E-02	5.57E-02	7.70E-02
		Mineral resource scarcity (kgCu eq)	3.11E-04	1.22E-04	1.83E-04	8.26E-05
		Water consumption (m^3)	2.27E-03	2.69E-03	6.04E-03	3.37E-03
		Endpoints*				
		Human Health (DALY's)	3.93E-07	4.76E-07	5.16E-07	4.53E-07
		Ecosystem Quality (species.yr)	9.27E-10	1.14E-09	1.35E-09	1.05E-09
		Resource Scarity (USD2013)	2.72E-02	3.37E-02	1.65E-02	2.71E-02

1000 Reuses



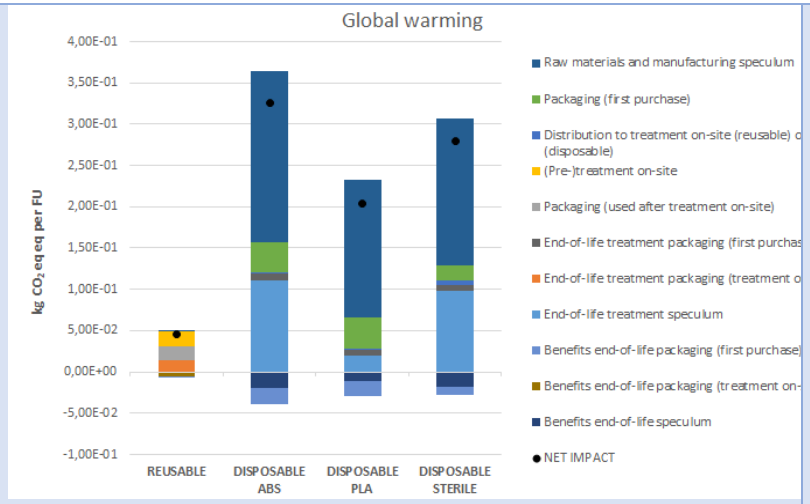
Midpoints	**RU**	**SU ABS**	**SU PLA**	**EO SU**
Global warming ($kgCO_2eq$)	7.03E-02	3.25E-01	2.03E-01	2.80E-01
Fossil resource scarcity (kg oil eq)	2.13E-02	8.99E-02	5.57E-02	7.07E-02
Mineral resource scarcity (kgCu eq)	2.15E-04	1.22E-04	1.83E-04	8.26E-05
Water consumption (m^3)	2.13E-03	2.69E-03	6.04E-03	3.37E-03
Endpoints*				
Human Health (DALY's)	1.55E-07	4.76E-07	5.16E-07	4.53E-07
Ecosystem Quality (species.yr)	4.03E-10	1.14E-09	1.35E-09	1.05E-09
Resource Scarcity (USD2013)	7.82E-03	3.37E-02	1.65E-02	2.71E-02

50 Reuses



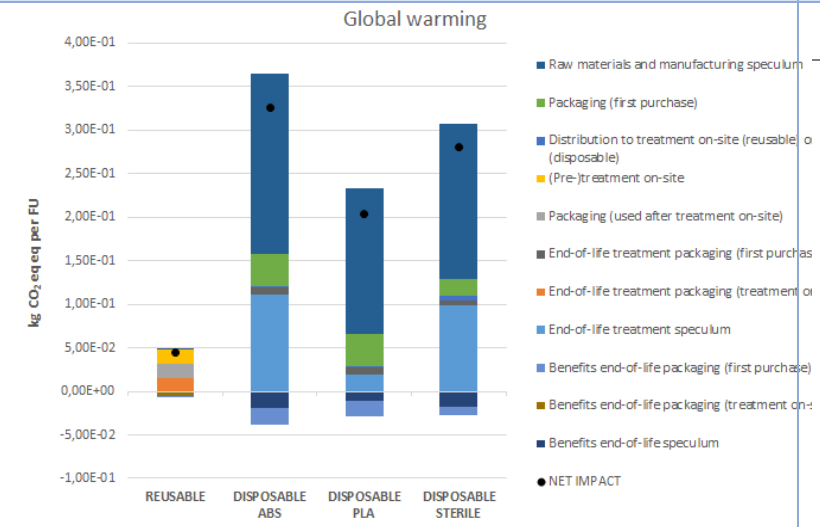
Midpoints	**RU**	**SU ABS**	**SU PLA**	**EO SU**
Global warming ($kgCO_2eq$)	9.06E-02	3.25E-01	2.03E-01	2.80E-01
Fossil resource scarcity (kg oil eq)	2.62E-02	8.99E-02	5.57E-02	7.07E-02
Mineral resource scarcity (kgCu eq)	1.92E-03	1.22E-04	1.83E-04	8.26E-05
Water consumption (m^3)	2.36E-03	2.69E-03	6.04E-03	3.37E-03
Endpoints*				
Human Health (DALY's)	3.44E-07	4.76E-07	5.16E-07	4.53E-07
Ecosystem Quality (species.yr)	5.11E-10	1.14E-09	1.35E-09	1.05E-09
Resource Scarcity (USD2013)	9.42E-03	3.37E-02	1.65E-02	2.71E-02

One sterilisation bag



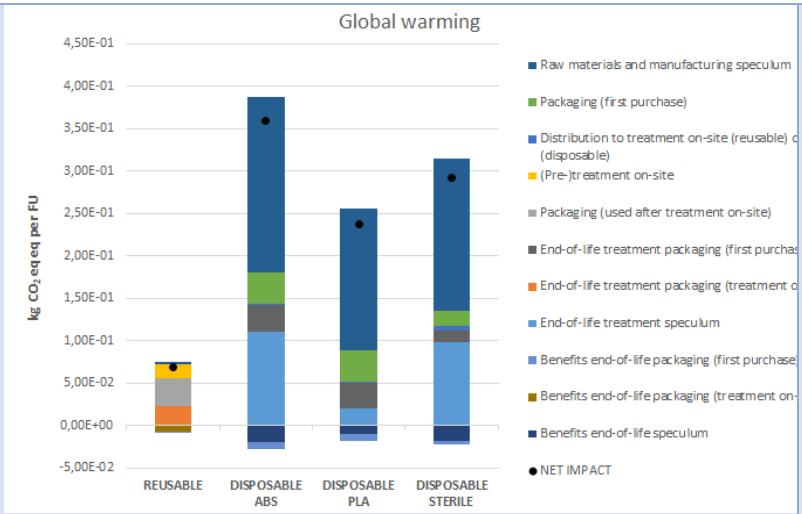
Midpoints	**RU**	**SU ABS**	**SU PLA**	**EO SU**
Global warming ($kgCO_2eq$)	4.53E-02	3.25E-01	2.03E-01	2.80E-01
Fossil resource scarcity (kg oil eq)	1.37E-02	8.99E-02	5.57E-02	7.07E-02
Mineral resource scarcity (kgCu eq)	2.91E-04	1.22E-04	1.83E-04	8.26E-05
Water consumption (m^3)	1.71E-03	2.69E-03	6.04E-03	3.37E-03
Endpoints*		**SU ABS**		
Human Health (DALY's)	1.20E-07	4.76E-07	5.16E-07	4.53E-07
Ecosystem Quality (species.yr)	2.89E-10	1.14E-09	1.35E-09	1.05E-09
Resource Scarcity (USD2013)	4.96E-03	3.37E-02	1.65E-02	2.71E-02

Best Case Scenario



Midpoints	**RU**	**SU ABS**	**SU PLA**	**EO SU**
Global warming ($kgCO_2eq$)	4.42E-02	3.25E-01	2.03E-01	2.80E-01
Fossil resource scarcity (kg oil eq)	1.34E-02	8.99E-02	5.57E-02	7.70E-02
Mineral resource scarcity (kgCu eq)	2.01E-04	1.22E-04	1.83E-04	8.26E-05
Water consumption (m^3)	1.70E-03	2.69E-03	6.04E-03	3.37E-03
Endpoints*				
Human Health (DALY's)	1.10E-07	4.76E-07	5.16E-07	4.53E-07
Ecosystem Quality (species.yr)	2.83E-10	1.14E-09	1.35E-09	1.05E-09
Resource Scarcity (USD2013)	4.87E-03	3.37E-02	1.65E-02	2.71E-02

Incineration of all packaging materials



Midpoints	**RU**	**SU ABS**	**SU PLA**	**EO SU**
Global warming ($kgCO_2eq$)	6.86E-02	3.60E-01	2.38E-01	2.93E-01
Fossil resource scarcity (kg oil eq)	2.08E-02	9.95E-02	6.53E-02	8.04E-02
Mineral resource scarcity (kgCu eq)	3.03E-04	1.18E-04	1.80E-04	8.06E-05
Water consumption (m^3)	2.10E-03	2.89E-03	6.24E-03	3.45E-03
Endpoints*				
Human Health (DALY's)	1.63E-07	5.22E-07	5.62E-07	4.72E-07
Ecosystem Quality (species.yr)	5.00E-10	1.29E-09	1.50E-09	1.13E-09
Resource Scarcity (USD2013)	7.65E-03	3.77E-02	2.05E-02	2.86E-02

RU: reusable stainless steel speculum; SU ABS: single-use fossil based plastic; SU PLA: Single-use biobased plastic; EO SU specula: ethylene oxide sterilised single-use specula consisting of polystyrene blades and polyethylene bolt; DALY's: disability adjusted life years
Figures are expressed according to LCA-standards; E-01= x 0.1;E-02= x 0.01; E-03= x 0.001; E-04= x 0.0001; …; E+01= x10; E+02= x 100; E+03= x 1000; E+04= x 10 000; ….