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A Sustainability and Feasibility Assessment of Reusable Surgical Headgear implementation in an Orthopaedic Hospital

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Article

Keywords:

Posted Date: June 19th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9167228/v1

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Additional Declarations: No competing interests reported.

Abstract

Purpose

Our objective was to assess the sustainability and feasibility of implementing reusable surgical caps in an orthopaedic hospital setting by comparing them with the disposable caps currently in use.

Methods

A cradle-to-grave Life Cycle Assessment was conducted comparing disposable and reusable surgical caps in an orthopaedic hospital. The analysis included raw material sourcing, manufacturing, transportation, laundry, and end-of-life treatment. The functional unit was one year of surgical headwear provision, corresponding to 60 reusable caps or 18,000 disposable caps. Environmental impacts were assessed using SimaPro 9.6, Ecoinvent 3.10, and Environmental Footprint 3.1.

Results

Reusable caps showed lower impact in most categories over one year, including a 30% reduction in climate change impact, equivalent to around 91 kg CO2e. Laundry was the main contributor to reusable cap emissions, while polypropylene production dominated disposable cap impacts. Reusable caps had higher water use, land use, and some eutrophication impacts.

Conclusion

Reusable surgical caps appear to be a feasible strategy to reduce environmental burden, though pilot implementation is needed.

Introduction

Healthcare and medical practice is an exponentially evolving industry that has led to an insidious increase in Healthcare Facility Waste (HFW), which has become a major negative environmental impactor. Of the 1.47 billion tonnes of waste produced globally, 5.9 million tonnes are directly from HFW [1]. Ireland is a significant producer of HFW in Europe, with around 7.7 kg/bed/day of pollution[1].

Additionally, Operating Theatres (OR), especially those of orthopaedic surgery, have been major producers of CO_2 equivalents (CO_2e)[2].

There are multiple approaches to improve sustainability, one possible strategy is the implementation of reusable surgical headwear. Due to the large volumes of disposable surgical caps purchased and

disposed per year, as well as the relative feasibility of their implementation, reusable surgical caps can potentially have a major positive environmental impact.

Concerns regarding reusable caps have included their potential to transmit microbes more than disposable caps, however previous studies have found no increase in Surgical Site Infection (SSI) rates, further supporting their use[3].

We therefore present the sustainability and feasibility implementation assessment done in an orthopaedic hospital. We have conducted a Life Cycle Assessment of the disposable surgical caps currently used in the hospital, and of the reusable caps. We aim in this study to show that implementation of reusable surgical headgear is a feasible strategy at reducing environmental burden.

Materials and Methods

LCA approach

In this implementation assessment we retrospectively collected data on disposable and reusable surgical caps in the purpose of conducting an LCA. This involves identifying material types, product weights, transport distanced and methods, the type of end of life treatment and any emissions associated with use (primarily the emission of laundry for reusable caps) of the products we are comparing: the disposable and reusable surgical caps. Thus we perform a cradle to grave analysis of emissions of the lifecycle of the, based on five different stages of : (a)Raw material sourcing, (b)Manufacturing, (c)Transportation, (d)Running environmental costs (laundry) and (e)Disposal/waste management (Fig. 1). The data is then entered into an environmental and statistical software that calculates the pollutant effect of each of these five steps based on recognised environmental databases, and also allows us to visualise and compare the difference in pollution between the two caps.

The four steps of LCA methodology, as defined in ISO-14044 and ISO-14040[4, 5], were followed to perform this comparative assessment between reusable and disposable caps.

In the first step, which is goal and scope definition, the system boundaries were defined (i.e. Cradle-to-grave), as well as the functional unit and reference flow. Specifically, the functional unit was defined as providing all OR workers with surgical head gear over one year, which corresponds to the reference flow of 60 reusable surgical caps or 18,000 disposable caps, estimating the lifespan of reusable caps to be around 300 washes[6] .

The second step of LCA involves the collection of Life Cycle Inventory data for the two products under assessment. This was performed by gathering real world data on the different stages of the surgical caps' lifecycle. However, collection of primary data wasn’t possible for certain inputs and outputs, which therefore had to be estimated. An overview of the created inventory for the two products under assessment is shown in [Table 1], as well as whether the data was from the real world (RW) or assumed (A).

Table 1
Life Cycle data inventory that was used in analytical comparison of reusable and disposable caps

Data Category	Disposable	Reusable
Textile material type	100% nonwoven polypropylene (RW)	100% woven cotton (RW)
Textile material weight	3 grams (RW)	30 grams (RW)
Travel mode factory to hospital (road)	Freight, Lorry 3.5–7.5 metric ton (A)	Freight, lorry 3.5–7.5 metric ton (A)
Travel mode factory to hospital (ship)	Freight, Sea, container ship (A)	N.A. (difficult to say as not yet implemented)
Travel mode factory to hospital (ferry)	Freight, Sea, Ferry (A)	N.A (difficult to say as not yet implemented)
Transport mode to waste treatment	Freight, Lorry 3.5–7.5 metric ton (A)	Freight, Lorry 3.5–7.5 metric ton (A)
Transport mode to laundry service	N.A. (no laundry for disposable)	Freight, Lorry 3.5–7.5 metric ton (A)
Transport distance factory to hospital (road)	1000 km (A)	1500 km (A)
Transport distance factory to hospital (ship)	11,000 km (factory in Cambodia) (RW)	N.A.
Transport distance factory to hospital (ferry)	100 km	N.A.
Transport distance to waste treatment	20 km (RW)	20 km (RW)
Transport distance to laundry service (round-trip)	N.A.	58 km (RW)
Type of waste treatment	Domestic waste (Black Bins), Treatment of waste textile, soiled, municipal incineration (RW)	Domestic waste (Black Bins), Treatment of waste textile, soiled, municipal incineration (RW)

To note, that for the disposable caps we have considered 11,000 km from Cambodia to Rotterdam, and then 1,000 km from Rotterdam to our location for both Ferry and total Road transport. For the reusable it was difficult to estimate sea transportation so we chose an average of 1,500 km of road transportation considering that the caps would be sourced more regionally or from a closer country than the disposable caps.

The third step of the LCA methodology involves the Impact Assessment, wherein the environmental impacts are calculated for all flows between the technosphere and the ecosphere (identified within step 2), and converted into multiple environmental impact categories. This analysis was performed using SimaPro Software version 9.6, Ecoinvent database 3.10, and the impact assessment methodology Environmental Footprint (EF) 3.1. Impacts were calculated and reported along the 17 midpoint impact categories of the EF method which we have included in the [Table 2].

Table 2
Environmental outcomes of the LCA

EF 3.1 category	Unit	Indicator	
Climate change	kg CO_2 eq	GWP100 :	Heat-trapping impact over 100 years; all greenhouse gases converted to CO_2-equivalents and summed.
Ozone depletion	kg CFC-11 eq	ODP:	Potential to thin the stratospheric ozone layer relative to CFC-11 (refrigerants/halons).
Human toxicity — cancer	CTUh	Human toxicity (cancer):	Estimated increase in human cancer cases from toxic substance exposure via air, water, or soil.
Human toxicity — non-cancer	CTUh	Human toxicity (non-cancer):	Estimated increase in non-cancer disease cases from toxic substance exposure.
Particulate matter	disease incidences	PM health impact:	Health burden from $PM_{2.5}$ and precursors (NO_x, SO_2, NH_3), expressed as estimated cases.
Ionizing radiation — human health	kBq U-235 eq	Ionizing radiation (HH):	Potential human exposure to ionizing radiation across the energy/supply chain, expressed as U-235 equivalents.
Photochemical ozone formation — human health	kg NMVOC eq	POFP (HH):	Potential to form ground-level ozone (smog) affecting health; precursors expressed as NMVOC-equivalents.
Acidification (terrestrial)	mol H^+ eq	Acidification:	Potential for acidifying emissions (SO_2, NO_x, NH_3) to cause acid rain and soil/vegetation damage.
Eutrophication — terrestrial	mol N eq	Terrestrial eutrophication:	Potential nitrogen deposition to land causing nutrient overload (over-fertilization).
Eutrophication — freshwater	kg P eq	Freshwater eutrophication:	Potential phosphorus releases that promote algal blooms and oxygen depletion in freshwater.
Eutrophication — marine	kg N eq	Marine eutrophication:	Potential nitrogen releases that promote algal blooms and oxygen depletion in marine systems.
Ecotoxicity — freshwater	CTUe	Freshwater ecotoxicity:	Toxic pressure on freshwater ecosystems from chemicals/metals; comparative toxic units for ecosystems.
Land use	dimensionless (points)	Potential Soil Quality (LANCA):	Change in soil quality due to land occupation or transformation, based on the LANCA model.

EF 3.1 category	Unit	Indicator	
Water use	m³ world-eq deprived	AWARE (water scarcity):	Scarcity-weighted water consumption; volume of water effectively deprived from other users/ecosystems.
Resource use — minerals & metals	kg Sb eq	Minerals & metals depletion:	Potential depletion of mineral/metal resources, expressed as antimony-equivalents.
Resource use — fossils	MJ	Fossil resource use:	Cumulative use of fossil energy resources (energy content extracted).

And finally, the fourth step of LCA consists of interpretation of the results from the previous three steps, in this case, to identify areas where each of the disposable and reusable caps are most environmentally impactful, and compare them against each other to deduce whether reusable caps are environmentally friendlier than disposable caps.

The study informs internal procurement decisions and does not include comparative assertions intended for public disclosure; under ISO 14044 close § 6, a formal critical review is not required. Methods, data sources, assumptions, and analyses are fully documented to support transparency and reproducibility.

Results

For reusable caps, the contribution of different input materials and processes to the overall environmental impact has been calculated, and the results are shown in (Fig. 2).

As can be observed, for reusable caps, the main contributor to impacts in most impact categories is the laundry process, with up to 94% contribution to the inorganic ecotoxicity impact category of 31.1 CTUe (Comparative Toxic Unit for Ecosystems) per cap. Laundry also made up 87% of ozone depletion (total of 7.17E-08 kg CFC11 eq per cap), and 87% of ionising radiation (0.209 kBq U-235 eq per cap). The second highest contribution to impacts can be observed for the manufacturing of the cap using woven cotton, particularly in the impact categories of water use. To note that 87% of water use or around 5.1485 m^3 depriv (cubic meters of water deprivation), came directly from manufacturing and only 13% which is 0.75 m^3 depriv, came from laundry. Manufacturing also accounted for 56% of marine eutrophication and 43% of organic freshwater ecotoxicity.

The total carbon emission of one reusable caps is 3.659kg CO_2e.

The overall impact for the production of one single use cap are shown in (Fig. 3).The main contributor of disposable caps to all impact categories was the non-woven polypropylene textile and production, with contribution ranging from 50% for marine eutrophication impacts (2.09E-05 kg N eq or kilograms of Nitrogen equivalent) to 95% for ionizing radiation potential (0.000695 kBq U-235 eq or Kilobecquerels of

Uranium-235 Equivalent). Production also contributed to 93% of eutrophication of freshwater, 92% of inorganic freshwater ecotoxicity and 89% of total fossil resource depletion.

The second highest contributor across most impact categories was transport, accounting for 10% of climate change and 21% of land use.

The total carbon emission of one disposable caps is 0.017kg CO_2e.

Besides the contribution of different processes to the overall impact of each type of cap, a comparative assessment was also performed between 60 reusable and 18,000 disposable caps, the results of the comparative assessment are shown in (Fig. 4). Here, the product with the highest impact in each impact category is identified, which is set at 100% impact, and the impact of the second product is expressed as a percentage compared to the impact of the first product.

As can be observed, based on our functional unit over the course of a year, the reusable cap has lower impacts compared to the disposable cap in most impact categories. A decrease of 30% in climate change impact can be observed compared to the disposable caps, with a total reduction of around 91kg of CO_2e in one year. Impact improvement is also seen ranging between 6% or 2.05E-06 less CTUh for non-cancer human toxicity, and 51% or 1.439 less kg NMVOC eq for photochemical ozone formation. The reusable caps have higher impact, compared to the disposable caps, in organic freshwater ecotoxicity potential, marine and freshwater eutrophication and land use and water use, with an increase of 292.446m^3 depriv. per year.

We have displayed the percentages of improvement across all categories along with the amount reduced per year [Table.4].

Table 3
Improvement across all impact categories for Reusable vs Disposable Caps

Impact category	Improvement	Reduction	units
Acidification	34%	-0.455151	mol H + eq
Climate change	30%	-91.97063	kg CO2 eq
Ecotoxicity, freshwater - inorganics	7%	-150.8091	CTUe
Ecotoxicity, freshwater - organics	-81%	+ 1123.58	CTUe
Particulate matter	35%	-4.59E-06	disease inc.
Eutrophication, marine	-39%	0.24298	kg N eq
Eutrophication, freshwater	-20%	0.01492	kg P eq
Eutrophication, terrestrial	27%	-0.969334	mol N eq
Human toxicity, cancer	18%	-1.64E-07	CTUh
Human toxicity, non-cancer	6%	-1.26E-07	CTUh
Ionising radiation	-1%	+ 0.0642	kBq U-235 eq
Land use	-50%	882.492	Pt
Ozone depletion	31%	-1.89E-06	kg CFC11 eq
Photochemical ozone formation	51%	-0.738401	kg NMVOC eq
Resource use, fossils	47%	-2726.551	MJ
Resource use, minerals and metals	49%	-0.000812	kg Sb eq
Water use	-82%	+ 292.446	m3 depriv.

Discussion

Although only 15% of total HFW is considered hazardous, all medical waste pollutes and impacts public health, which can be seen as counterproductive to the ultimate goal of healthcare[1].

Surgical theatres, contribute to around 30% of total HFW[2]. Among them, those of orthopaedic surgery, have been shown to have a greater environmental impact, likely because of of their greater emphasis on sterilisation compared to other surgical specialties, due its much higher infection-sensitive procedures, requiring large amounts of water and electricity consumption. Other contributors unique to orthopaedic surgery include a higher reliance on anaesthetics such as nitrous oxide, materials unique to orthopaedics such as implants and prosthetic materials, and potentially the use of allograft and xenograft[7].

Although there has been previous studies that showed reusable surgical caps significantly decrease carbon footprint, this remains a niche area within sustainability strategies in healthcare.

Our study suggests that over the course of a year, reusable surgical caps have lower carbon emission than disposable caps (91kgCO_2e reduction in one year). However, for the production of a single cap, disposable caps have lower emission(0.017kgCO_2e < 3.659kg CO_2e). This correlates with the literature and is expected as the the impact of disposable caps is primarily driven by the high volumes in which they are used and wasted[3, 6].

Laundry was identified as the main contributor of reusable caps. Specifically, this can be attributed to the different substances included in the laundry process, such as chlorine ions released to water, contributing to the total inorganic ecotoxicity impacts of the reusable cap, and likely related to bleaching components in the laundry detergents[8].

The second highest impacting stage of the cradle to grave process for reusable caps was manufacturing. The substances related to the production of woven cotton contributing to these impacts are mainly nitrate emissions to water, contributing to over 50% of the total marine eutrophication impacts of one reusable cap[9]. These are likely associated with the use of fertilizers for cotton cultivation, trichlorfon and chlorpyrifos emissions to soil, i.e., insecticides and pesticides, contributing to over 32% of organic freshwater ecotoxicity of one reusable cap[10, 11].

For the disposable caps, textile and production held the biggest environmental impact. Different substances were identified as contributors to the observed impacts resulting from the polypropylene textile material, such as phosphate emissions to water, resulting in 92% of total freshwater eutrophication potential for one disposable cap. Phosphorylation has been previously identified as a major contributor to eutrophication potential of polypropylene production[12]. Additionally, hydrogen sulphide emissions to air contribute to 61% of the total inorganic freshwater ecotoxicity impacts of one disposable cap, which is likely associated with the hydrogen sulphide content of crude natural gas, which serves as a feedstock for the production of propylene and thereafter polypropylene[13]. Crude oil consumption contributes to 38% of total fossil resource depletion of one disposable cap, and is due to the upstream production of polypropylene from fossil-based resources[14].

Higher freshwater organic toxicity, as well as freshwater and marine eutrophication were noted in the reusable caps, which is likely related to the use of pesticides for the cultivation of cotton. Land use and water use were also higher for reusable caps, which is likely related to the high demand for land and water for cotton cultivation[15].

Several studies have shown that switching to reusable caps has no effect on the number of Surgical Site Infections (SSIs)[16, 17]. However, it’s important to note that these studies did not mention any specific washing protocol. Previous LCAs done on the subject yielded lower emissions for the reusable caps partially due to accounting less for laundry (wash weekly or longer). Our study was done based on

washing the cap every three days, which prioritises sterility and in conjunction, notably raises the emission of reusable caps.

There are multiple strengths to this study. It is a comprehensive and robust cradle to grave LCA following ISO-14044 guidelines, that analyses key environmental impact categories such as climate change, water pollution and fossil fuel depletion as well as direct impactors on human health such as carcinogenic pollution, which allows for a complete holistic environmental perspective. It also uses real-world data on procurement, transport and waste, and doesn't solely rely on literature estimates.

There were also limitations to our study, such as the yet to be implemented reusable caps, which led to multiple assumptions when doing the analysis, and relied on database inventories in certain aspects. Some assumptions were made with regards to estimating some of the transport modes and distances for both caps. Another assumption was considering the reusable caps as 100% cotton. This was based on the widest availability at the time regionally.

However as the study shows, although reusable cotton caps are generally better for the environment, they have a high extraction emission with increased water use and biogenic toxicity over disposable caps, which could encourage hospital decision makers at NOHC to choose a more environmentally friendly material such as a recycled polyester or durable-poly cotton blends which may also have an increased lifespan of each cap, leading to less frequent purchasing.

Our functional unit was considered as providing one OR worker with one cap daily for a year, which assumed that each worker would require one disposable cap per day. In practice however, this is often not the case and OR workers tend to change caps multiple times a day, which will significantly increase their carbon footprint compared to reusable caps. Laundry was also assumed to be kept at the current frequency adopted by the Laundry department, of every three days, considering the importance of microbial stewardship in orthopaedic hospitals.

We therefore recommend the hospital to implement a small-scale pilot study that introduces reusable caps. This would allow for a more accurate tracking of usage and laundry, a more robust LCA with only real world data. Future efforts should also focus on a more robust microbiological tracking for caps, as although current studies show no increase in SSIs, there still is a gap with regards to proper acquisition of cap cultures and shedding in conjunction with specific washing protocols.

Conclusion

As healthcare systems continue to seek different sustainability strategies, this supports transitioning from disposable to reusable surgical headwear in an orthopaedic hospital setting. Through a comprehensive cradle-to-grave LCA analysis we found that there is potential for an annual decrease in 91kg CO_2e. This suggests that reusable caps are a feasible and impactful strategy in reducing carbon footprint. However given the reliance on assumptions in certain areas, we recommend a pilot study be implemented first to properly validate our findings. Furthermore, future studies should incorporate

microbiological tracking in accordance with different washing protocols to ensure proper infection control standards beyond SSI surveillance alone.

In summary, by integrating reusable caps, hospitals can reduce their environmental footprint.

Declarations

Ethics

Human Ethics and Consent to Participate declarations were not applicable

Funding

No funding was obtained for this study.

Author Contribution

Ciara Doran and John O'Byrne and helped procure data. Raphael Alsarma, Paul McCarroll, Ciara Doran, James Cashman and John O'Byrne helped write the manuscript. Statistical analysis was done by Raphael Alsarma.

Acknowledgement

The authors would like to thank the staff of the National Orthopaedic hospital Cappagh, Dublin, for their support and assistance in providing procurement, transport, waste management, and laundry-related information relevant to this study.

Data Availability

Data availability:The data that support the findings of this study are available from the corresponding author upon reasonable request. Certain underlying operational and procurement data are institutionally held and may be subject to access restrictions.

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Figures

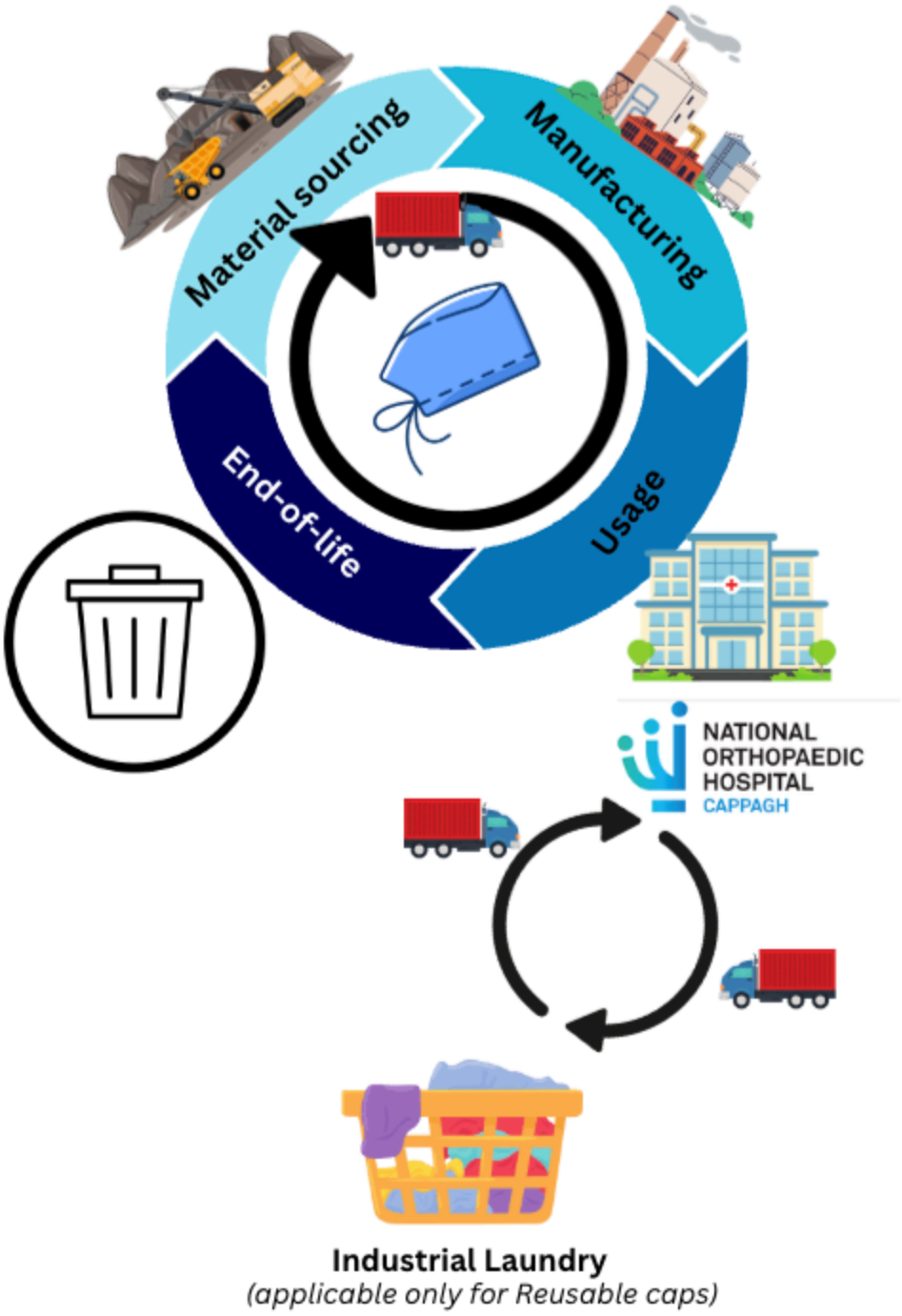


Figure 1

Infographic of the boundaries chosen for the LCA of the disposable and reusable surgical caps included in our analysis

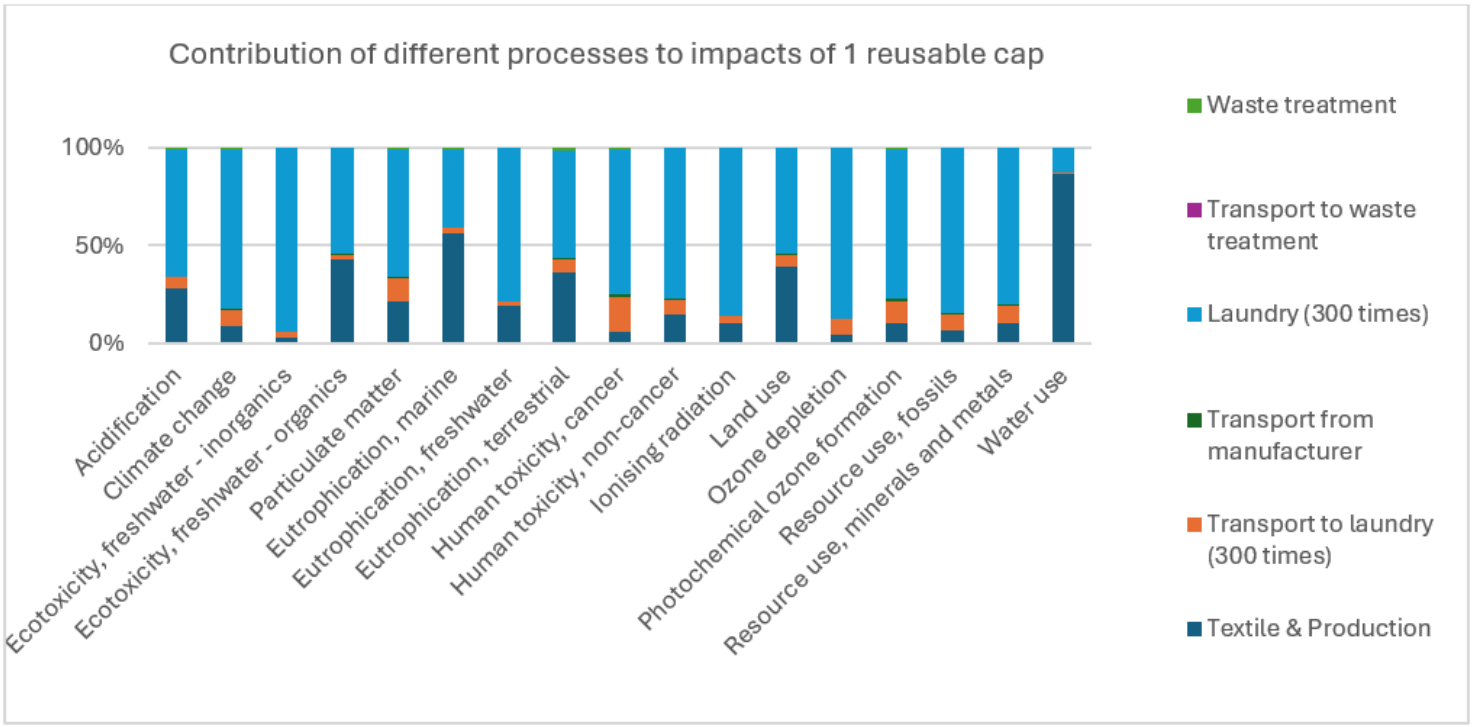


Figure 2

Stacked bar chart showing the environmental impact contribution of different processes for 1 reusable surgical cap.

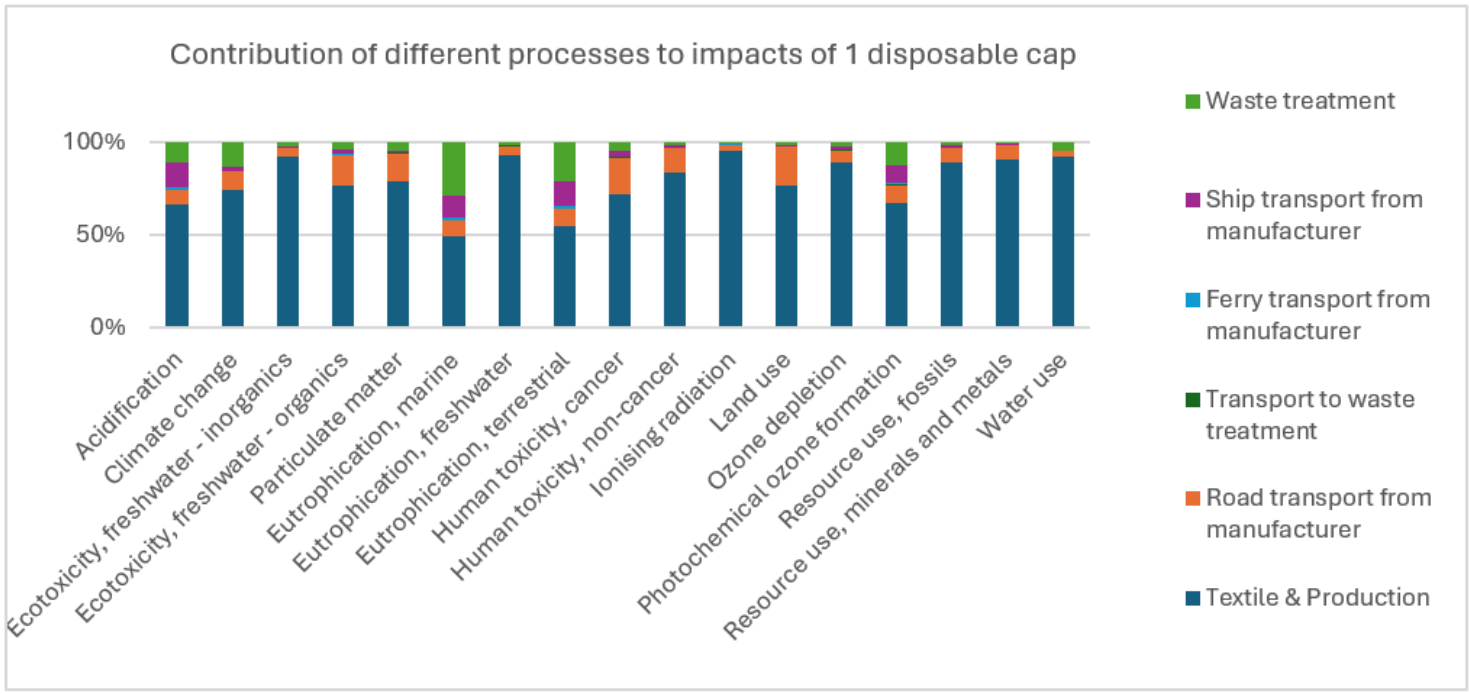


Figure 3

Stacked bar chart showing the environmental impact contribution of different processes for 1 disposable surgical cap.

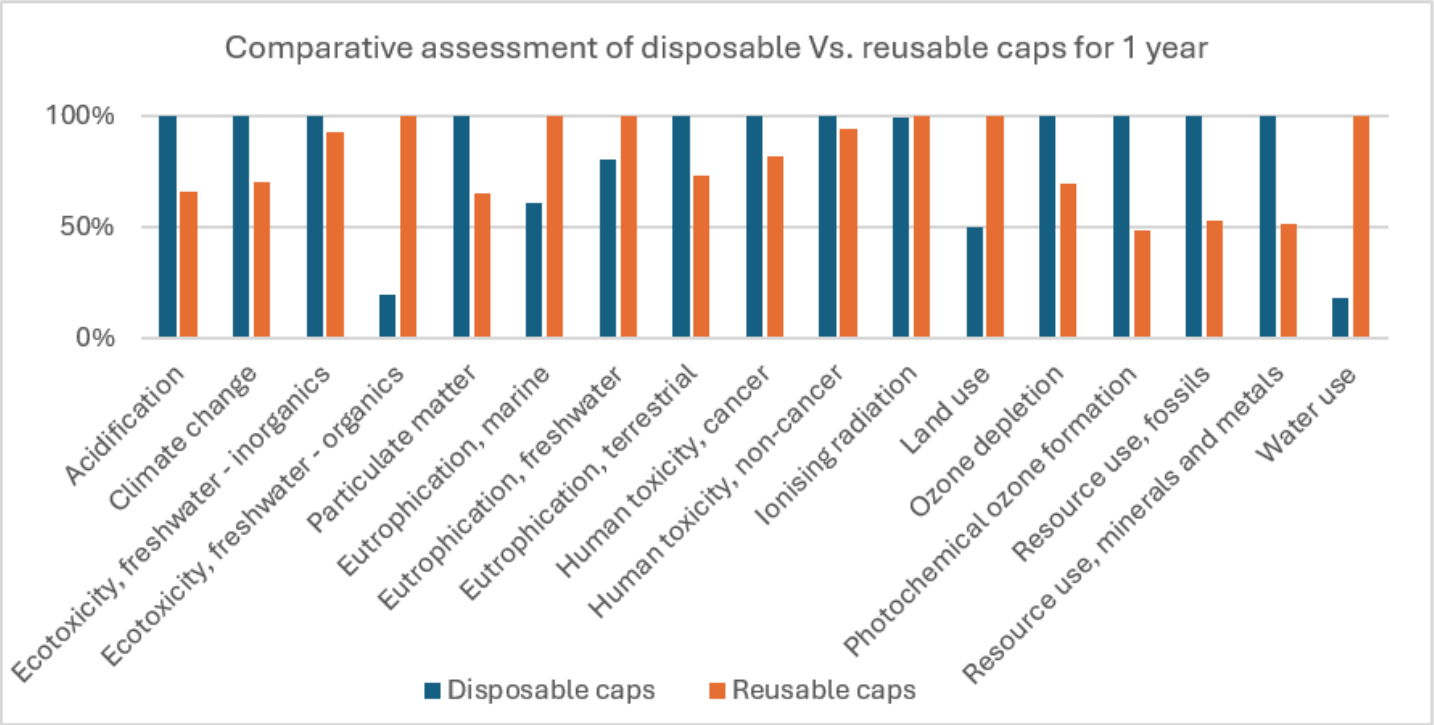


Figure 4

Cluster bar chart comparing environmental impact of Disposable vs Reusable caps for 1 year