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The impact of switching from single-use to reusable healthcare products: a transparency checklist and systematic review of life-cycle assessments

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Background: Replacing single-use products with reusable ones may reduce the environmental impact of healthcare. This study aimed to broadly assess the environmental effects of that substitution. **Methods:** A systematic review of comparative cradle-to-grave life-cycle assessments (LCAs) of single-use and reusable healthcare products was conducted. The main outcomes assessed were changes in the environmental impact that resulted after switching from single-use to reusable products. As no standardized transparency checklist was available, one was developed here using DIN ISO 14040/14044. The final checklist included 22 criteria used to appraise the included studies. **Results:** After screening, 27 studies were included in the analysis. The healthcare products were assigned to four categories: invasive medical devices, non-invasive medical devices, protection equipment and inhalers. The outcomes revealed a reduction in mean effect sizes for all environmental impacts except water use. Non-invasive medical devices have greater relative mitigation potential than invasive devices. On average, information on 64% of the transparency checklist items was reported. Gaps included the reporting of data quality requirements. **Conclusions:** Switching to reusable healthcare products is likely to reduce most impacts on the environment except water use, but the effect size differs among product categories. Possible study limitations include location bias, no systematic search of the grey literature and small samples for some impacts. This study's strengths are its approach to product categories and developed transparency catalogue. This catalogue could be useful to inform and guide a future process towards creating a standardized transparency checklist for the systematic reviews of LCAs.

Introduction

To combat climate change and mitigate its consequences, it is imperative we reduce the emissions of greenhouse gases (GHGs). Given that the healthcare systems of Western countries are responsible for 4–8% of their respective national GHG emissions,[1] they present a particularly worthwhile target for climate change mitigation activities. Besides global warming, healthcare systems also contribute to other impacts that are ecologically detrimental, such as nitrous oxide emissions, sulphur dioxide emissions and excessive water use.[2]

One approach to reducing environmental impact might be switching from single-use to reusable healthcare products. Single-use products are defined as those products disposed of after one use, whereas reusable goods can be used at least twice. Reusable products potentially need less material and energy in their production and create less waste. However, to avoid cross-contamination, reusable healthcare products must be treated after each use, which could be linked to the higher use of resources and energy.

Life-cycle assessment (LCA) is a quantitative and comprehensive method to evaluate environmental impacts. An LCA studies a product over its whole life cycle, ideally following a 'cradle-to-grave' approach (i.e. from the extraction of the raw materials to the disposal, including production, transport and use phases). LCAs are standardized and described in the ISO norms 14040 and 14044.

In the last few years, several systematic reviews concerning the environmental impact of healthcare products—surgical operations,[3] patient care alternatives,[4] or laparoscopic instruments[5] or with larger scopes[6–8]—have been published. Yet only one review compared single-use and reusable healthcare products, finding the latter had less environmental life-cycle impacts.[8] Two reviews did include a critical appraisal of their included studies by relying on checklists.[3,8] Unfortunately, a standardized checklist for critically appraising LCA studies does not yet exist.

This article aims to examine the changed environmental impact that results when single-use healthcare products are replaced by reusable alternatives. To enhance our understanding of this connection, analyses were performed to determine the environmental effects of different product subgroups, the proportion of the overall effect attributable to each phase of the life cycle and the mitigation potential gained when using reusable products. The existing comparative LCA evidence was systematically reviewed to address the research objective. Importantly, this included the development of a checklist to enable a critical, objective appraisal of the studies.

Methods

We conducted a systematic review by following the preferred reporting items for systematic reviews and meta-analyses (PRISMA)[9] framework as far as possible, because that framework was designed for systematic reviews and meta-analyses of clinical studies. In addition to the PRISMA framework, we used an established standardized technique for assessing and reporting reviews of LCA data (STARR-LCA). These respective checklists can be found in Supplementary appendix S1.

Search strategy

Full Boolean search strings tailored to the targeted databases can be found in Supplementary appendix S2. To cover all scientific outlets

in which LCAs of healthcare goods may have been published, we chose three databases: PubMed, ProQuest and Web of Science. The database search was carried out on 9 September 2021. Further literature was considered/added via an iterative reference tracking process during the full-text assessment. Search alerts were used to not overlook any studies published after this date.

Screening

Two reviewers (M.K. and K.H.) performed the screening process in two stages. The first stage was a title-abstract screening of all studies identified in the database search; the second stage was a full-text assessment. Screenings were performed independently and compared before moving onto the next stage. Disagreements were resolved by deliberation and consent between both reviewers.

Studies were included if they were written in English or German, compared single-use and reusable healthcare products with similar functions, and reported quantitative outcomes for at least one type of impact on the environment. Studies lacking a full cradle-to-grave analysis were excluded. Healthcare products were defined as goods or services within the core healthcare segment according to the World Health Organization system of health accounts.[10]

Data extraction and coding

M.K. extracted the full life-cycle-impact results from every study for both reusable and single-use products. All available data were used, including sensitivity and scenario analyses, so long as quantitative results were reported. If various scenarios for the single-use alternative were reported, a conservative assessment was followed and that scenario exerting the smallest environmental impact was chosen. This was done to avoid bias towards reusable products and to guarantee that every possible mitigation potential from single-use products is utilized. To investigate location bias, the reference region was documented. Finally, bibliographic data, such as year of publication and information on the examined product, were also extracted.

Critical appraisal

Critically assessing studies in systematic reviews usually relies on a standardized checklist (e.g. CHEERS checklist for health economic evaluations). Such checklists are developed by a variety of stakeholders, in a deliberative process. Yet unfortunately, no standardized checklist for LCAs could be identified. Therefore, a checklist was constructed here, based on the norms DIN ISO 14040 and DIN ISO 14044, and oriented towards the checklist for carbon footprint assessments of Lange *et al.*[11] Our proposed checklist aims to explore transparency in the communication of methods, results, and possible biases; it consists of 22 criteria (described in detail in Supplementary appendix S3) within five groups based on the LCA phases.

Data synthesis and analysis

The effect sizes were measured as the ratio of change when replacing the single-use product with a reusable alternative in percentage values: $x_i = \frac{I_r - I_s}{I_s}$, where x_i is the ratio of change, and I_r is the environmental impact of the reusable product, while I_s is that of the single-use product.

As far as possible, the LCAs were clustered into groups of similar technologies based on the European Nomenclature on Medical Devices' (EMDN) distinction between invasive and non-invasive medical goods.[12] Protective equipment (PE) and inhalers were excluded from non-invasive medical devices which were grouped accordingly. The grouping is described in Supplementary appendix S4. The impact categories were grouped when a similar impact was described (e.g. terrestrial acidification and freshwater acidification were clustered together as *acidification*). A full list of impact groups is in Supplementary appendix S5. An analysis was only done when at least three studies reported relevant data for a given impact.

Results

A total of 2458 records were found through the database search. After removing 1218 duplicates, 1240 studies were included for the title-abstract screening, by which 1146 records were excluded, leaving 94 records for retrieval and eligibility assessment. All 94 records were retrieved, of which 75 records were excluded: 1 because of its language barrier, 31 because they did not report original research, 39 because they did not compare reusable and single-use healthcare products and 4 because they did not report quantitative results. Another study was excluded because it was a pre-print version of a peer-reviewed paper, already included in the review. Although Dettenkofer *et al.*[13] appeared to meet the inclusion criteria, it was excluded due to its 9-year time lag (Dettenkofer *et al.* published in 1999[13]; Carre published in 2008[14]) and low fulfilment (29.55%) of transparency criteria. Hence, 18 records from the database search were finally included in our systematic review and meta-analysis. Four additional records were found and included by search updates.

Twelve more records were found by reference tracking. Three of these were excluded because they did not report original research; another two were excluded because reusable and single-use healthcare products were not compared; and two more were excluded because they lacked numerical results. This left five studies obtained by reference tracking for inclusion in the systematic review. Figure 1 presents an overview of the search results in the format of a PRISMA flowchart.

Study characteristics

The study characteristics are listed in Table 1. Evidently, all studies were published after 2008. Except for Lee *et al.*[21] whose reference region was Singapore, all studies referred to healthcare products in Western industrial nations. Eleven studies referred to the USA, 5 to Australia and 10 to European countries. Six studies were grouped here as non-invasive medical devices, 2 as inhalers, 10 as invasive medical devices and 9 as PE.

Critical appraisal

The transparency assessment is documented in Supplementary appendix S6, which provides the assessment items and their number, the corresponding assessment question, and guidance on how to extract the item as well as further background information. On average, the studies reported information on 64% of the items (min and max: 36% and 93%). The least met criteria were 'data quality requirements' and 'critical review' which were (partially) met by only two papers. Seven studies did not report their functional unit, and one study did not relate their results to the reported functional unit.

Non-invasive medical devices

Both Grimmond *et al.*[18] and McPherson *et al.*[25] investigated sharps containers in the USA, and likewise, Grimmond *et al.*[37] in the UK. McGain *et al.*[24] assessed anaesthetic drug trays and Sanchez *et al.*[31] considered blood pressure cuffs. Friedericy *et al.*[38] examined sterilization packaging for surgical instruments. Four of those six papers reported reductions in GHG emissions (13–100%), waste (99%) and water use (61–70%) when switching from single-use to reusable equipment. Sanchez *et al.*[31] provided the most comprehensive analysis and concluded that reusable blood pressure cuffs are ecologically superior single-use cuffs under all impact categories, overall applications and cleaning scenarios.

Inhalers

With a budget impact model, Ortsäter *et al.*[27,28] assessed the environmental impact of adopting reusable inhalers; however, neither were classical LCA studies. Both reported reductions in GHG

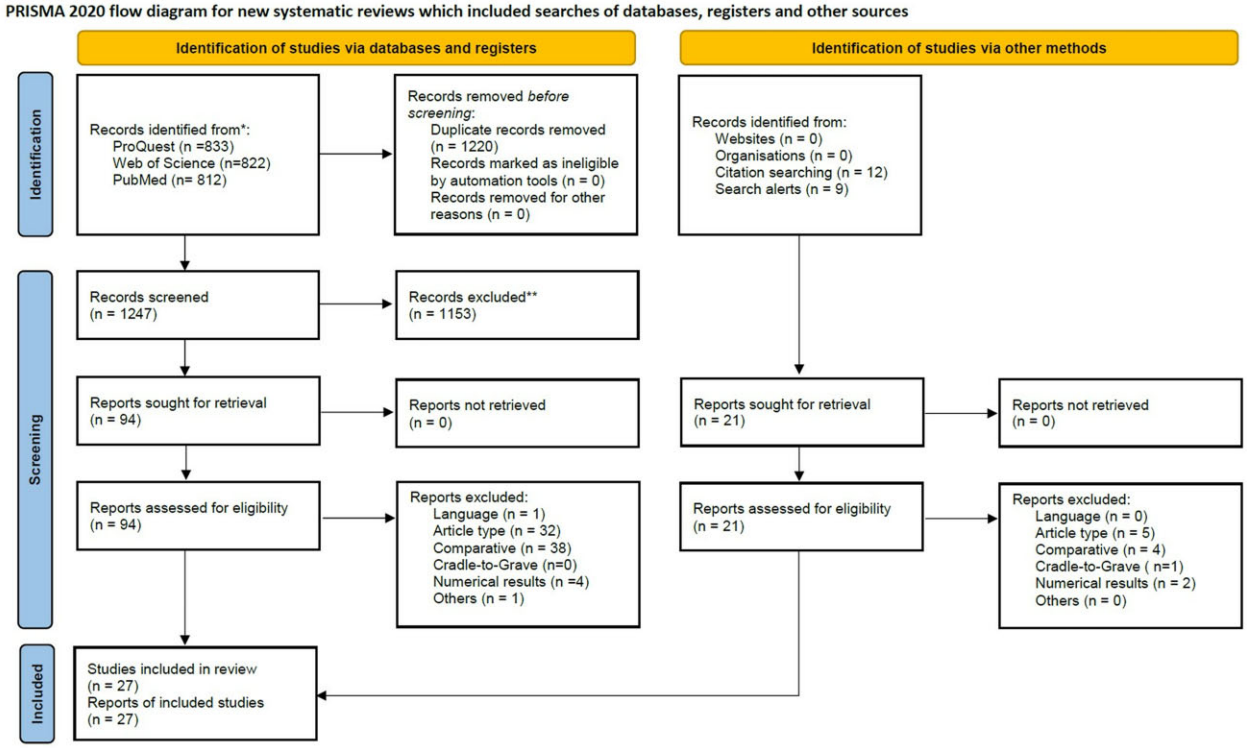

Figure 1 PRISMA 2020 flow diagram

emissions of 50% and 63%, respectively, when switching from single-use RESPIMAT inhalers to reusable ones.

Invasive medical devices

The category of invasive medical devices was the most heterogeneous group. Examined here were ureteroscopes, by Davis *et al.*[15]; vaginal specula, by Donahue *et al.*[16]; laryngeal mask airways, by Eckelmann *et al.*[17]; laryngoscopes, by Sherman *et al.*[32]; central venous catheters, by McGain *et al.*[22]; dental burs, by Unger *et al.*[33]; and scissors, by Ibbotson *et al.*[19] Furthermore, McGain *et al.*[23] assessed anaesthetic equipment. Rizan and Bhutta[39] examined instruments in laparoscopic cholecystectomy, and Morris and Hicks[40] considered specula. Most of these 10 studies reported GHG emissions only. The effect on GHG emissions ranged from a reduction of 99% and an increase of 227%, whose mean value was −47%. Only two studies within the invasive medical devices category examined water use; one concluded that using reusable central venous catheter insertion kits increased water use by 980–1829%[22] and the other that reusable anaesthetic equipment doubles water use.[23] McGain *et al.*[23] reported a 9% increase in GHG emissions. The effect on GHG emissions reversed when using energy mixes from the UK/EU or the USA, instead of the assumed coal-based Australian energy mix. In these scenarios, GHG emissions were reduced by 84% or 47%, respectively.

Protective equipment

Most studies within the PE category assessed the environmental impact of facemasks[21,30,34] or textile gowns.[14,20,35,36] One study did examine surgical scrub suits,[26] and Rizan *et al.*[29] broadened the product system by considering PE in general. While all studies found reductions in impacts on the environments, only one study reported larger effects with respect to land use (+38%) and marine ecotoxicity (13%) after switching to reusable PE equipment.[29]

Full life-cycle results

Impacts

Quantitative results from this analysis can be found in Supplementary appendix S7. After aggregating all healthcare products, the results showed that switching from single-use to reusable products is capable of decreasing the mean and median environmental effects for all impact categories, except water use, whose mean impact is increased. Data from Moriss and Hicks[40] revealed a greater ozone depletion potential of 7300–7500%, while the other five studies considered this impact reported an average reduction of 43%.[26,30,31,34,39]

Comparative subgroup analysis

The results varied not only between product groups but also across impacts (figure 2). Most of the boxplots show a reduced environmental impact and greater mitigation potential for invasive medical devices compared to PE. On average, GHG emissions were reduced between 38% and 56%. For invasive medical devices, their median water usage impact increased, however.

Mitigation potential to reduce the impact of reusable products

The environmental impact of reusable products is sensitive to their handling in the use phase, i.e. the number of uses and the cleaning process involved. Accordingly, there is great potential for further impact mitigation but also a risk of undoing and spoiling the environmental benefits of replacing single-use products with reusable ones.

Activities to reduce the impacts on the environment from reusable products include the utilization of the full-loading capacity of autoclaves and increasing the life-cycle length of products, i.e. using the products more often. Fully loading the autoclave increased the

Table 1 Study characterictics

Author	Year	Title	Reference	Location	Product	Percentage of items reported
Carre	2008	Life cycle assessment comparing laundered surgical gowns with polypropylene based disposable gowns	[14]	Australia	Surgical gowns	86
Davis *et al*.	2018	Carbon footprint in flexible ureteroscopy: a comparative study on the environmental impact of reusable and single-use ureteroscopes	[15]	Australia	Ureteroscopes	36
Donahue *et al*.	2020	A comparative carbon footprint analysis of disposable and reusable vaginal specula	[16]	USA	Vaginal specula	66
Eckelman *et al*.	2012	Comparative life cycle assessment of disposable and reusable laryngeal mask airways	[17]	USA	Laryngeal mask airways	66
Grimmond *et al*.	2012	Impact on carbon footprint: a life cycle assessment of disposable versus reusable sharps containers in a large US hospital	[18]	USA	Sharp container	39
Ibbotson *et al*.	2013	Eco-efficiency of disposable and reusable surgical instruments—a scissors case	[19]	Germany	Scissor	59
Jewell and Wentsel	2014	Comparative life cycle assessment of reusable vs. disposable textiles	[20]	USA	Isolation gown	86
Lee *et al*.	2021	Life cycle assessment of single-use surgical and embedded filtration layer (EFL) reusable face mask	[21]	Singapore	Face masks	73
McGain *et al*.	2012	A life cycle assessment of reusable and single-use central venous catheter insertion kits	[22]	Australia	Central venous catheter insertion kit	55
McGain *et al*.	2017	Financial and environmental costs of reusable and single-use anaesthetic equipment	[23]	Australia	Anaesthetic equipment	57
McGain *et al*.	2010	The financial and environmental costs of reusable and single-use plastic anaesthetic drug trays	[24]	Australia	Anaesthetic drug tray	52
McPherson *et al*.	2019	The impact on life cycle carbon footprint of converting from disposable to reusable sharps containers in a large US hospital geographically distant from manufacturing and processing facilities	[25]	USA	Sharp container	77
Mikusinska	2012	Comparative life cycle assessment of surgical scrub suits: the case of reusable and disposable scrubs used in Swedish healthcare	[26]	Sweden	Surgical scrub suits	82
Ortsäter *et al*.	2019	A budget impact model to estimate the environmental impact of adopting RESPIMAT® re-usable in the Nordics and Benelux	[27]	Nordics + BeNeLux	Inhaler	41
Ortsäter *et al*.	2020	Incorporating the environmental impact into a budget impact analysis: the example of adopting RESPIMAT® re-usable inhaler	[28]	Germany	Inhaler	45
Rizan *et al*.	2021	Environmental impact of personal protective equipment distributed for use by health and social care services in England in the first six months of the COVID-19 pandemic	[29]	UK	PPE equipment	52
Boix Rodríguez *et al*.	2021	Engineering design process of face masks based on circularity and life cycle assessment in the constraint of the COVID-19 pandemic	[30]	Italy	Face masks	59
Sanchez *et al*.	2020	Environmental and economic comparison of reusable and disposable blood pressure cuffs in multiple clinical settings	[31]	USA	Blood pressure cuffs	70
Sherman *et al*.	2018	Life cycle assessment and costing methods for device procurement: comparing reusable and single-use disposable laryngoscopes	[32]	USA	Laryngoscope	64
Unger *et al*.	2014	Comparative life cycle assessment of reused versus disposable dental burs	[33]	USA	Dental burs	68
van Straten *et al*.	2021	A life cycle assessment of reprocessing face masks during the Covid-19 pandemic	[34]	Netherlands	Face masks	68
Vozzola *et al*.	2020	An environmental analysis of reusable and disposable surgical gowns	[35]	USA	Surgical gowns	64
Vozzola *et al*.	2018	Environmental considerations in the selection of isolation gowns: a life cycle assessment of reusable and disposable alternatives	[36]	USA	Isolation gown	61

(continued)

Table 1 Continued

Author	Year	Title	Reference	Location	Product	Percentage of items reported
Grimmond *et al.*	2021	Before/after intervention study to determine impact on life-cycle carbon footprint of converting from single-use to reusable sharps containers in 40 UK NHS trusts	[37]	UK	Sharp containers	93
Friedericy *et al.*	2021	Reducing the environmental impact of sterilization packaging for surgical instruments in the operating room: a comparative life cycle assessment of disposable versus reusable systems	[38]	Netherlands	Sterilization packaging for surgical instruments	64
Rizan and Bhutta	2021	Environmental impact and life cycle financial cost of hybrid (reusable/single-use) instruments versus single-use equivalents in laparoscopic cholecystectomy	[39]	UK	Instruments in laparoscopic cholecystectomy	77
Morris and Hicks	2022	Life cycle assessment of stainless-steel reusable speculums versus disposable acrylic speculums in a university clinic setting: a case study	[40]	USA	Speculums	70

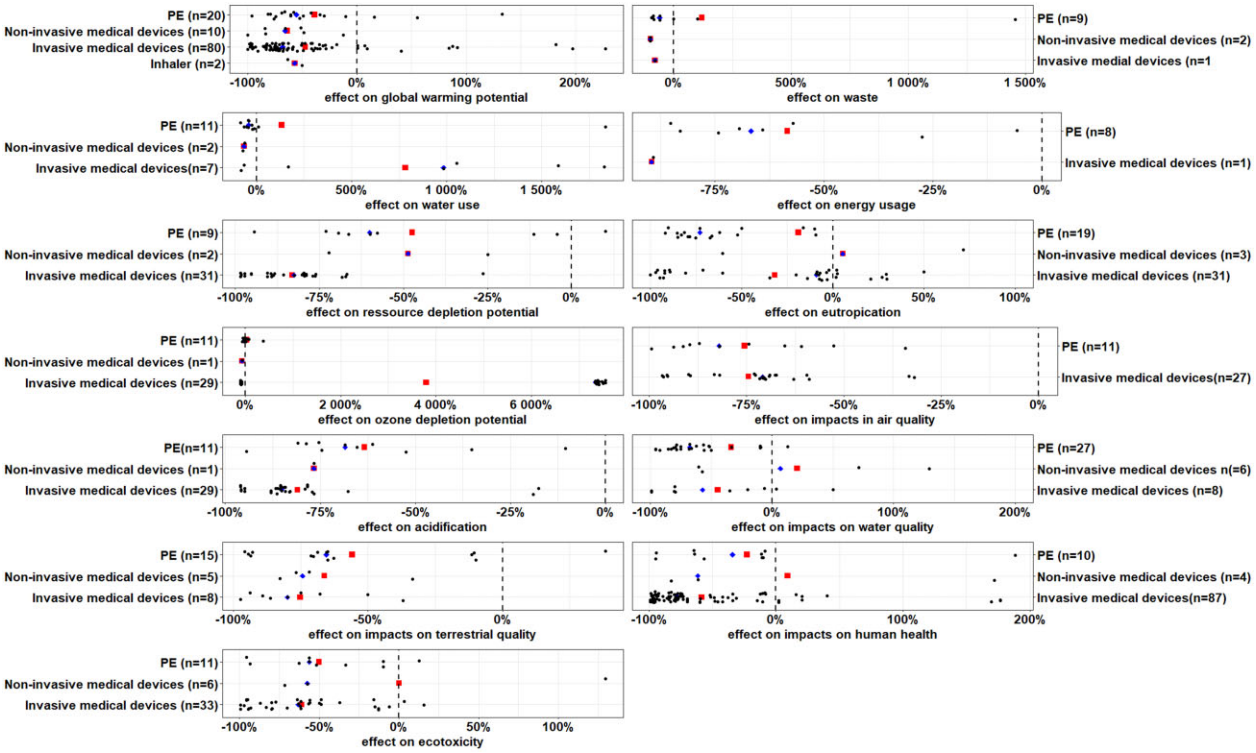

Figure 2 Effect on impacts per subgroup with mean (sqaure) and median (diamond)

reduction effect by 10–12% for vaginal specula[16] and 46% for laryngeal mask airways.[17] Relative to the base case, reducing the autoclave load to a single product decreased the reduction by 58% or 71% for vaginal specula[16] and shifted the effect from a 35% reduction to a 227% increase for laryngeal mask airways.[17] A 10% increase in autoclave efficiency augmented the effect of impact reduction by 15%.[17] A heightened hygiene protocol for face masks reversed the effect from a decrease of 42% to an increase of 56–133%.[21]

Increasing the number of uses per product can also lessen its environmental impact. Using the vaginal specula 500 times instead of the assumed 20 uses in the base case increased the reduction effect between 14% and 20%, depending on the steel grade; conversely, lowering the number to 10 uses decreased the effect by between 12.5% and 20%. Turning the reusable product into a single-use product changes the effect from −67.4% and −62.9% in the base case to +92% and +191.8%, respectively.[16] Similar effects are evident with laryngeal mask airways, in that an increase from 40 uses (i.e. base case) to 100 uses augmented the reduction by 20.5%, whereas a decrease to 10 uses altered the effect to one of 0.8% greater GHG emissions instead of their 34.5% reduction in the base case.[17] For surgical scrubs, lowering their lifetime usage from 100 (base case) to 40 uses decreased their reduction effect by 15.7%.[26] Results from

studies that included more impacts indicated similar effects on GHG emissions.

Discussion

The results indicate that switching from single-use healthcare products to reusable ones reduces ecological impacts in all categories but water use. The magnitude of reduction varies among different product types, however, with reusable invasive medical devices showing higher mitigation potentials than non-invasive ones. Scenario and sensitivity analysis revealed the impact of location and behaviour on the overall results.

The results confirm the previous findings of Drew *et al.*[8] but add a more detailed layer of analysis concerning the impacts of different product categories, the impacts of life-cycle phases and the possible mitigation potential associated with using each reusable product.

Some insights can be gained from these results. The reduced environmental impact shows that adopting reusable medical devices in healthcare is ecologically more sustainable than continuing with conventional single-use devices. Yet some impacts such as water use may increase. The most likely explanation for an increase in water use is the extra water demand required for cleaning reusable products. This result is especially pertinent for regions where water is a scarce resource and for future scenarios as water scarcity, especially in the summer months is rising globally When grouping products, the LCA indicates that invasive medical devices harbour a higher mitigation potential and might be prioritized when transitioning to a more sustainable healthcare system. Nevertheless, more LCA data, especially for comparable functional units and system boundaries, are needed to validate this conclusion and to investigate the total mitigation potential of both product groups. An explanation for this trend might be that stricter hygiene regulations apply to the sterilization of invasive medical devices. This stricter and more elaborate routine might lessen the effect of their reduced production inputs in comparison with reusable non-invasive products. When focusing on the consequences of global warming, certain behaviours such as increasing the lifetime uses of devices and fully loading autoclaves can further decrease their environmental impact and should be included in a transitional process.

In the scenario analysis, the importance of the reference region is evident; therefore, results from different regions should be interpreted and applied with caution. Generalizability is further limited by a potential location bias, as almost all data referred to products in industrialized, often Western, countries.

A systematic review is inherently limited by the limitations of the reviewed studies. The most frequently mentioned limitations were the lack of manufacturing data, the reliance on generic data from databases, the lack of location-specific data and the possible underestimation of results due to missing data. Another set of limitations includes those assumptions that had to be made about the waste treatment, recycling and sterilization of the examined products. Further limitations were the exclusion of social impacts, costing methods or assessments on comparability in comfort, usability and infection control.

The present study is also limited in part by its search for literature sources, in that a systematic search for grey literature was not conducted and the publication language was limited to English and German. The methodological choices were constrained by small samples for several impacts and missing information on confidence intervals and variance within the studies. Therefore, a full meta-analysis was impossible. The data in this systematic review comprised only a small fraction of all products used in healthcare, and products within the groups were not homogenous, so some results might be distorted. More LCA data that directly compare single-use and reusable healthcare products are needed for an in-depth assessment of individual devices as well as a more fine-scale and precise assessment of product groups. Nonetheless, the approach employed here, of considering relative effects instead of absolute changes, does facilitate the comparison of different LCA studies and the grouping of products. On the downside, small absolute changes can result in large relative effects when the absolute results of each product are small. This might explain why extreme values of ozone depletion potential were obtained. Some impact results might be overrepresented because they were grouped under two impacts (such as 'freshwater ecotoxicity' being grouped in both 'impacts on water quality' and 'ecotoxicity'), while other results are only grouped into one group.

The construction of a transparency checklist is usually a process in which multiple stakeholders and experts are involved. As such, the list used in this article can only serve as an intermediate solution. The next step in this process would be to establish transparency catalogues as a standard method when conducting systematic reviews of LCA. Moreover, the existing approaches should be discussed and refined. In the long run, stakeholders, such as LCA researchers and practitioners, as well as organizations representing LCA communities should jointly participate in a deliberative process to create a broadly accepted, standardized transparency catalogue.

Further LCA research is arguably needed, to provide more data, especially from non-Western countries. From an overall sustainability perspective, the social and economic implications of switching from single-use to reusable products could be of wide interest; e.g. consequences for the manufacturers of such products, staffing requirements in hospitals, or possible variability in comfort, usability and infection control. A full sustainability assessment or life-cycle sustainability analysis is, therefore, a valuable avenue for further research efforts.

These results build on existing evidence from Drew *et al.*[8] and lead us to conclude that switching from single-use to reusable healthcare products is an ecologically warranted and desirable move, but they also highlight why distinguishing between different product groups is imperative. The results regarding mitigation potential should be taken into account when considering the introduction of reusable healthcare products.

Policy-makers and practitioners can draw upon two key findings of this research from a comprehensive environmental perspective. Firstly, it is indeed worthwhile to switch to reusable products. Secondly, aspects such as the number of uses and the approach to cleaning and disinfection nonetheless have a crucial role to play.

Looking ahead, the next research step could be to expand the database to validate the results reported here. Furthermore, the relationship between disinfection effort and environmental impact could be investigated in greater detail, through which relevant savings potential in the usage of particular reusable products could be identified. Finally, further developing the transparency catalogue might be another promising research interest to pursue.

Supplementary data

Supplementary data are available at *EURPUB* online.

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Conflicts of interest: None declared.

Data availability

Data on impacts are incorporated into the article and its online supplementary material. all other data are available on request.

Key points

- No standardized transparency catalogue for life-cycle assessment yet exists; hence, a transparency catalogue was created and could be considered a first step towards a standardized checklist.
- On average, switching from single-use to reusable healthcare products reduces most impacts on the environment, except for water use.
- Switching to reusable products reduces the global warming potential by between 38% and 50%, on average, depending on the product group.
- Non-invasive medical devices have a higher relative mitigation potential than invasive medical devices. An explanation might be that the sterilization process of invasive products is stricter and resource intensive. Water use increases when switching from single-use to reusable invasive medical devices.
- The impact of reusable healthcare products is sensitive to handling in their use phase. By increasing the number of uses and changing the cleaning process, their greater mitigation potential can be realized.

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