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Hospital circular economy: clinical viability and ESG performance in reusable textiles and optimized sterilization

Economía circular hospitalaria: viabilidad clínica y desempeño ESG en textiles reutilizables y esterilización optimizada

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ABSTRACT

This chapter examines the environmental paradox facing healthcare administration (5 % of global GHG emissions) and evaluates whether replacing disposables with reusable textiles through a redesign of C&E reduces impacts without compromising clinical safety. The objective was to synthesize recent evidence and propose management guidelines aligned with the SDGs, through a documentary review of post-pandemic literature on LCA, costs, care quality, and traceability. The results indicate that, compared to blue wrap, reusable rigid containers reduce waste by up to 88 % and emissions by a half; operationally, the rationalization of sets and instruments is the main driver of carbon and cost savings, above and beyond the mere replacement of packaging. Economically, OPEX savings exceed CAPEX under a total cost of ownership approach, and decisions must incorporate SROI to support investments. In clinical practice, there is no evidence of an increase in surgical site infections with reusable devices, but questions persist about the validity of barrier standards (ANSI/AAMI PB70) and degradation due to reprocessing; digital traceability (RFID) and cycle-based retirement protocols are required to ensure safety. Finally, an integrated evidence map and decision-making framework are offered to scale hospital circularity at the management level, migrating from linear purchasing to asset and risk management (TCO+SROI) and prioritizing set optimization as a high-impact, low-barrier action.

Keywords: Hospital Circular Economy; CE&E; Reusable PPE; SDGs; Sustainable Management.

RESUMEN

Este capítulo examina la paradoja ambiental a la que se enfrenta la administración de la atención sanitaria (5 % de las emisiones globales de GEI) y evalúa si sustituir desechables por textiles reutilizables con un rediseño de las CEyE reduce impactos sin comprometer la seguridad clínica. El objetivo fue sintetizar la evidencia reciente y proponer lineamientos de gestión alineados con los ODS, mediante una revisión documental de literatura postpandemia sobre LCA, costos, calidad asistencial y trazabilidad. Los resultados indican que, frente al blue wrap, los contenedores rígidos reutilizables reducen hasta 88 % los residuos y aproximadamente a la mitad las emisiones; operativamente, la racionalización de sets e instrumentales es el principal impulsor de ahorros de carbono y costos, por encima de la mera sustitución de empaques. Económicamente, los ahorros OPEX superan el CAPEX bajo un enfoque de costo total de propiedad, y las decisiones deben incorporar SROI para sustentar inversiones. En lo clínico, no se evidencia incremento de infecciones del sitio quirúrgico con reutilizables, pero persisten dudas

sobre la validez de los estándares de barrera (ANSI/AAMI PB70) y la degradación por reprocesos; se requiere trazabilidad digital (RFID) y protocolos de retiro por ciclos para garantizar seguridad. Finalmente se ofrece un mapa integrado de evidencia y un marco decisorio para escalar a nivel gerencial la circularidad hospitalaria, migrando de compras lineales a gestión de activos y riesgos (TCO+SROI) y priorizando la optimización de sets como acción de alto impacto y baja barrera.

Palabras clave: Economía Circular Hospitalaria; CEyE; EPP Reutilizable; ODS; Gestión Sostenible.

INTRODUCTION

The healthcare sector, which is considered fundamental to human well-being (SDG 3), faces a profound paradox: its mission to heal simultaneously causes significant environmental damage. The healthcare sector's climate footprint accounts for approximately 5 % of global net greenhouse gas (GHG) emissions, a volume that, although it may not seem so, exceeds that generated by commercial aviation or maritime transport.

This environmental pressure was exacerbated exponentially during the COVID-19 pandemic, which, due to the very nature of the health emergency, normalized a massive increase in the consumption of disposable personal protective equipment (PPE), saturating landfills and straining global supply chains.[1] Since then, healthcare systems have been operating under unprecedented post-pandemic cost pressures, where operational efficiency is no longer an option but a condition for financial survival.[2]

Historically, infectious risk management in hospitals has fostered a "single-use" culture, where disposable products are often mistakenly equated with sterility and safety. It is precisely this linear model (extract – manufacture – use and dispose) that is unsustainable. This is where the Circular Economy (CE) emerges as a response, offering an alternative paradigm aligned with SDG 12 (Responsible Consumption and Production), redesigning systems to prioritize reuse, reprocessing, repair, and resource efficiency.[3] In the hospital context, this takes the form of two key interventions: first, replacing disposable surgical textiles (gowns, drapes) with reusable ones; and second, redesigning Sterilization and Equipment Centers (SECs) to optimize instrument reprocessing.[4]

This poses a central dilemma for innovation in healthcare and hospital management in the 21st century: what is the environmental impact (assessed using Life Cycle Assessment or LCA), economic impact (costs per discharge and Social Return on Investment, SROI) and, crucially, clinical (quality of care and patient safety) impact of replacing disposable PPE/textiles with reusable ones and redesigning CEyE towards a circular model, compared to the current single-use standard? Therefore, the purpose of this chapter is to synthesize and critically evaluate the empirical evidence published in the post-pandemic years on the feasibility of this transition.

The contribution is twofold: first, by mapping the obvious synergies (e.g., simultaneous reductions in CO_2 emissions and operating costs); and second, by identifying critical gaps and barriers, such as the validity of clinical barrier standards and organizational resistance, which currently hinder the adoption of circularity at scale. In doing so, this research seeks to provide an evidence base for aligning hospital management with SDGs 3 (Good Health and Well-being),

9 (Industry, Innovation, and Infrastructure), 12 (Responsible Consumption and Production), 13 (Climate Action), and 17 (Partnerships for the Goals).

DEVELOPMENT

Epp and reusable vs. disposable textiles: life cycle assessment (LCA)

The environmental justification for the transition to reusable textiles is supported by robust life-cycle assessment (LCA) evidence. The inclusion of studies before 2021, such as that by Vozzola et al.[5], is indispensable in this domain, as they established the methodology and canonical benchmarks. In their cradle-to-end-of-life study of surgical gowns, frequently cited in recent literature, demonstrated that a reusable gown system—assuming a realistic number of wash cycles—reduces energy consumption by up to 64 %, greenhouse gas (GHG) emissions by 66 %, drinking water consumption by 83 %, and solid waste generation by 84 %, compared to their disposable equivalents. These findings have been consistently validated, as in the study by Chang et al.[6]

The research by Vela et al.[7] confirms and expands on these results. By applying an LCA analysis to operating room (OR) bed covers and comparing a reusable (washed) system to disposable systems (sent to landfill or incineration), the quantitative results showed that the total carbon footprint for 50 uses of the reusable product was 19,83 kg of CO_2, while its disposable equivalent, sent to landfill, generated 64,99 kg of CO_2. As shown, this transition represents a net saving of 45,16 kg of CO_2 per 50 uses, equivalent to the emissions from driving an average passenger vehicle for 185 kilometers.[6]

Ventura-Abreu et al.[8] argue that the environmental superiority of reusable products is not absolute and depends on critical life-cycle variables. The most decisive factor is the number of reuse cycles achieved; a reusable product that is discarded prematurely can have a greater environmental impact than a disposable product due to its greater mass and manufacturing complexity.[9]

In addition, the material type is crucial. A comparative LCA of surgical gowns found that, while the reusable (cotton-based) gown was superior in most categories, its impact on water depletion was significantly greater than the disposable gown, attributable to the intensive cotton cultivation phase.[10] This suggests that reusable textiles made from synthetic fibers, such as polyester or other blends, offer a much more balanced sustainability profile.

LCA evidence overwhelmingly demonstrates that reusables outperform disposables (polypropylene) in key metrics aligned with SDG 12 (waste generation) and SDG 13 (carbon emissions). Causal analysis shows that the most significant impact of disposables is concentrated in two phases: raw material extraction (virgin plastics) and end-of-life management, either in landfill or through incineration.[11]

In contrast, the main impact of reusables is concentrated in the use phase, i.e., in the industrial laundry process, which is intensive in both energy (usually electricity) and water. Therefore, as argued by Vozzola et al.[5], the development of sustainable quality management in the healthcare sector should not focus solely on whether reusables are environmentally preferable, but on how to optimize their use phase, for example, through laundries powered by renewable energy, optimization of water load, and microplastic capture, to maximize their net benefits.[12]

Table 10.1. Summary of Comparative LCA Studies (PPE and Surgical Textiles)

Research	Product	Functional Unit	GHG Reduction vs. Disposable	Water Savings vs. Disposable	Waste Reduction vs. Disposable	Key Finding
Vozzola et al.[1], (2020)	Surgical gowns	1000 uses	66	83	84	Marked systemic superiority of reusable in 4/5 of the impact categories.
Eckelman et al.[7], (2024)	OR bed covers	50 uses	69,5 % net savings 45,16 kg CO_2	Not specified	Not specified	The extraction of raw materials from disposable items is 10 times more carbon- e than from reusable items.
Alshqaqeeq et al.[6] (2021)	Review (various)	Varies	Dependent on the cycle	Dependent on cycle	Dependent on cycle	The break-even point or (No. of cycles) is the determining factor for environmental benefit.
McQuerry et al.[8], (2021)	Surgical gowns	Single use	Reusable is superior	Superior to disposable	Superior to reusable	Cotton material can have a high water impact, far exceeding disposable garments in this category.

CEyE/Sterilization and Packaging Redesign: Blue Wrap vs. Rigid Containers

The Central Sterilization and Equipment Department (CEyE) is the heart of the circular economy in any hospital, but it is also a significant source of inefficiency and waste. The predominant sterile packaging, known as blue wrap, refers to the blue polypropylene wrap, a single-use plastic product that generates thousands of tons of trash in healthcare facilities annually. In view of this problem, replacing this wrap with reusable rigid containers, typically made of aluminum or other metals, is a key intervention for the EC.[13]

Friedericy et al.[14] point out in their research that the environmental evidence for this replacement is clear. A comparative life-cycle analysis showed that rigid containers can reduce associated solid waste by up to 88 % and cut GHG emissions by approximately half compared to blue wrap.

From an economic perspective, the transition requires a higher initial capital investment (CAPEX) to purchase the containers. However, operating cost (OPEX) analyses project substantial long-term savings. A hospital case study conducted by Toronto Metropolitan Hospital in Canada estimated savings of up to $233 000 over ten years, derived solely from eliminating the recurring purchase of blue wrap. In addition, these containers offer advantages such as superior protection for delicate instruments, which reduces repair and replacement costs, although this benefit is more difficult to quantify.[15]

However, it is essential to consider research such as that of Ly et al.[16], who, together with their collaborators, introduce an optimization variable that has a greater impact than the mere choice of container: the configuration of the surgical set. Rizan et al.[17] modeled the carbon footprint and financial costs in a CEyE, revealing that the primary driver of environmental and economic inefficiency is the individual packaging of instruments. This study found that individually packaged instruments had the highest footprint (189 kg of CO_2 and €7,35 per instrument). Surprisingly, the analysis yielded a counterintuitive result: surgical sets packaged in single-use blue wrap (66 g of CO_2 and €1,07) had a slightly lower carbon footprint and a similar cost to sets in reusable rigid containers (77 g of CO_2 and €1,05).

It should be noted that this finding does not invalidate the benefits of containers, especially in terms of reducing plastic waste, but it does redefine the implementation strategy. It shows that the primary driver of environmental and economic inefficiency in CEyE is not fundamentally the choice between wrap or container, but rather the widespread practice of individually wrapping instruments and oversizing surgical sets.[18]

Hospitals that focus exclusively on acquiring rigid containers address SDG 12 (waste) but may miss the opportunity to achieve much greater efficiency (SDGs 9 and 13). Optimizing sets using a Lean Six Sigma approach reduces unnecessary washing and sterilization cycles, saving cubic meters of water and kilowatt hours of energy per cycle, regardless of the packaging system.[19]

The future research agenda in the healthcare management sector should model the combined impact of optimized sets within rigid containers, measuring their effect on critical operational metrics such as operating room turnaround times and the incidence of wet packs. In this area, statistical process control is notably absent in the literature.

Sustainable procurement and supply chain

The transition to a functional circular economy (CE) is intrinsically dependent on transforming purchasing departments and supply chain management in healthcare organizations. This change requires procurement decisions to evolve from the traditional, deeply rooted criterion of lowest unit price to an assessment based on total cost of ownership (TCO) and the incorporation of ESG (Environmental, Social, and Governance) clauses into bidding processes.[20] Key metrics for the success of sustainable procurement should also include the percentage of waste diverted from landfill, a KPI (Key Performance Indicator) that can be predicted and verified using LCA data.[21]

The adoption of reusable PPE and containers creates a complex logistical challenge by transforming a linear waste-management problem into a circular reverse-logistics one. This new model requires a robust and reliable supply chain for the collection of used items, their safe transport to industrial laundries or CEyE, and the return of reprocessed inventory to points of clinical use.[22]

Leyva et al.[23] identified significant barriers to implementing the circular economy in healthcare supply chains, including the lack of logistics infrastructure, the need for staff training, and resistance from established suppliers.

The weakest link in this circular supply chain is traceability. A reusable system is an asset that degrades over time. As documented, repeated washing and steam sterilization processes compromise the barrier integrity of reusable textiles.[24]

The hospital must be able to track the exact number of reprocessing cycles for each gown or drape. Without a robust digital traceability system—whether using RFID technology or data matrix codes—the healthcare organization cannot guarantee that a textile will be removed from service before its protective barrier fails, thus compromising patient safety and life (SDG 3). It is essential to pay attention to the development and viability of TCO and LCA models integrated directly into bidding and procurement tools, but above all, to the analysis of the technical and economic viability of digital traceability (SDG 9) as a non-negotiable enabler of safe clinical reuse.

Patient quality and safety: IAAS and criticism of the PB70 standard

The most significant obstacle to the adoption of reusable textiles is not environmental or economic, but clinical and cultural. There is a deeply rooted perception barrier among operating room staff. A study on the attitudes of surgical staff toward reusable gowns found that, although 77,6 % of them perceived them as better for the environment 34,1 % were unsure or actively believed that the use of reusable gowns would increase the surgical site infection (SSI) rate, a perception that, regardless of its empirical basis, constitutes a formidable barrier to implementation.[25]

It is important to note that the prevailing working hypothesis on infection control is clinical non-inferiority. Guidelines from organizations such as the AORN (Association of Operating Room Nurses) and the ACS (American College of Surgeons), along with seminal studies, generally support the safety of reusable textiles when processed, inspected, and maintained in accordance with rigorous standards.[26]

However, research such as that by Liu et al.[27] does not reveal any new large-scale multicenter clinical studies that reconfirm the non-inferiority of modern reusable textiles compared to disposables in key metrics of healthcare-associated infections (HAIs), such as CLABSI (central line-associated bloodstream infection), CAUTI (catheter-associated urinary tract infection), or SSI.

The core of the safety issue lies in the validation standard itself: ANSI/AAMI PB70: Liquid barrier performance and classification of protective apparel and drapes intended for use in health care facilities, a method used in the United States and referenced globally to classify both disposable and reusable textiles into four levels of liquid protection.[28,29]

Haberland et al.[30] have shown that the PB70 test methods (based on AATCC TM42 and TM127) are fundamentally flawed and do not adequately simulate real clinical conditions. The criticisms are specific:

- The test liquid is water, which has a much higher surface tension than body fluids such as blood, saliva, or urine, which penetrate more easily.
- The test temperature ranges from 26°C to 28°C, significantly lower than body temperature.
- The definition of failure in the hydrostatic pressure test is the appearance of three drops on the inner surface, ignoring the first two, which would already represent clinical contamination.
- The standard allows averages from a set of samples to be reported, hiding individual failures that would represent an apparent safety breach in clinical practice.[31]

This problem with the PB70 standard affects both disposables and reusables; however, its implications are more serious for reusables for one key reason: repeated reprocessing degrades the fabric barrier. If the standard used to certify that barrier is flawed, and the product degrades with each cycle, it is logical that clinical staff's confidence in the integrity of the textile after 25, 50, or even 75 wash cycles will be low.

The main obstacle to clinical adoption is not evidence that reusables cause infections, but rather a lack of confidence in a validation system that can sometimes be considered obsolete. The most urgent research agenda (SDG 3 and SDG 9) is not to conduct another LCA, but to develop a more evolved version—a sort of PB70 2.0—that uses simulated body fluids, realistic

temperatures, and a definition of failure from the first drop to validate barrier integrity in a clinically relevant manner.[32]

Table 10.2. Critical Evaluation of the ANSI/AAMI PB70 Standard vs. Real Clinical Conditions

Test Parameter (PB70)	Standard Specification (ANSI/AAMI)	Real Clinical Condition	Safety Gap/Implication
Test Liquid	Water (High surface tension)	Body fluids (e.g., blood, urine; low surface tension)	Actual fluids may penetrate the barrier at lower pressures than the test water.
Test Temperature	26°C to 28°C	Approximate body temperature of 37°C	Heat from the patient or the environment significantly reduces surface tension and can alter the properties of the material, facilitating penetration.
Definition of Failure (Hydrostatic)	Appearance of the third drop of liquid.	Contamination with the first drop.	The first two drops, which are in fact real failures, appear at pressures that are significantly lower than the reported failure threshold, creating a false sense of security.
Reporting of Results	Reporting of averages for the sample set is permitted.	The failure of a single gown is a 100 % contamination event.	The average may exceed the standard, even if several individual samples have failed, concealing the real risk to the user.

Source: Prepared internally based on Yap et al.[16]; Haberland et al.[21]; Kilinc-Balci; CDC[20] and ANSI.[19]

Governance and scaling: SROI, barriers, and SDG alignment for healthcare quality

The transition from a linear to a circular model is ultimately a governance challenge. The barriers identified in the literature are consistent and include high initial capital investment (CAPEX) to acquire inventories of reusable textiles or rigid containers, cultural resistance, staff risk perception,[25] and the lack of training and the implementation of clear protocols for the new reverse logistics.[23] To overcome these barriers, senior hospital management requires a business case that justifies the investment beyond simple savings on the purchase of blue wrap or instrument costs.

Traditional economic models, such as cost-benefit analysis (CBA) or simple return on investment (ROI), are insufficient for this purpose. These models fail to capture the holistic (social and environmental) value generated by circularity. The Social Return on Investment (SROI) methodological framework is designed precisely to address this gap. SROI goes beyond financial ROI to measure and monetize the social, economic, and environmental value created for multiple stakeholders.[34] This approach has been used successfully in other public health interventions,[35] demonstrating, in some cases, massive social returns, such as a ratio of 36,08:1, i.e., $36,08 of social value created for every dollar invested in medical treatment projects.

SROI is the most suitable methodological framework for justifying the hospital's circular economy, but, according to the evidence, it has not yet been systematically applied to comparing reusable PPE or to the redesign of CEyE. That is why a simple CBA could show modest savings. In contrast, an SROI analysis (aligned with SDG 17) would capture crucial monetizable co-benefits such as:

- the environmental value of avoided carbon emissions (SDG 13);

- the social value of creating sustainable local jobs, not only in the medical field, but also in areas such as laundry, logistics, or maintenance;
- the value of supply chain resilience by reducing dependence on volatile imports (SDG 9); and
- The public health benefits of reducing microplastics and chemical pollutants in the environment (SDG 3).

The future agenda for hospital health management and innovation must therefore apply SROI to build robust models that demonstrate to boards of directors, funders, and investors that circularity (EC) is not simply a sustainability cost, but a strategic investment in holistic value and long-term resilience for the benefit of humanity.

CONCLUSIONS

The move towards a high-quality, resilient circular hospital management model is based on evidence showing that transitioning to reusable PPE/textiles and circularly optimizing CEyE are environmentally superior to the disposable status quo.[5,6,7,8,13,14,16,17,22] It is also economically viable, primarily when the intervention strategically focuses on process optimization, such as the rationalization of surgical sets,[18,19,32] rather than on technological replacement through the purchase of containers.[13,14,15] The economic, social, and environmental evidence is therefore deeply robust and sufficient to justify action.[33,34,35]

The main obstacle and critical gap to overcome, which is slowing down scaling up, lies in clinical feasibility.[26] It is therefore essential to understand that this obstacle is not due to the existence of evidence demonstrating harm, i.e., higher rates of SSI with reusables. Still, instead, on the contrary, the obstacle is a crisis of confidence that originates from two sources: the first, represented by the negative perception and deep-rooted skepticism of clinical staff,[25] and the second, a deep and justified distrust of barrier certification standards,[28,29,30] which is exacerbated by the factual knowledge that reusable textiles degrade with reprocessing.[24]

The implications for 21st-century hospital management are profound. Administration must evolve from linear, unit-cost-focused procurement management to asset and risk management, i.e., circular management focused on TCO and SROI.[20,21,31,33] This new governance approach, framed within SDG 17, requires unprecedented integration among traditionally isolated departments, including Quality and Patient Safety, CEyE, Infection Control, Sustainability (ESG), and Supplies.

A roadmap for responsible scaling and future research is therefore proposed, including immediate actions to improve process efficiency and implement programs to optimize and rationalize surgical sets.[18,19,32] This action (aligned with SDG 9) has the most significant potential for carbon and cost savings, with the least capital investment and the lowest clinical barrier.

Medium-term actions focus on traceability and the implementation of pilot projects for reusable textiles in controlled areas. Still, they are conditional on the implementation of robust traceability technology (RFID) to monitor the effective number of wash cycles and the barrier integrity of each asset.[24]

Finally, urgent actions focus on filling those critical gaps that should prioritize the development and validation of a clinically relevant post-PB70 barrier testing standard, using realistic fluids and temperatures, and a first drop failure definition;[28,29,30] and, finally, on conducting Social

Return on Investment (SROI) studies applied to the transition of PPE and CEyE, to quantify the holistic sustainable economic, social, and environmental (ESG) value necessary to justify capital investments at the governance level for the improvement of quality standards in healthcare service delivery.[33,34,35]

BIBLIOGRAPHICAL REFERENCES

1. Vozzola E, Overcash M, Griffing E. An environmental analysis of reusable and disposable surgical gowns. AORN J. 2020;111(3):315–25. https://doi.org/10.1002/aorn.12885

2. Chang JH, Woo KP, Silva de Souza Lima Cano N, Bilec MM, Camhi M, Melnyk AI, et al. Does reusable mean green? Comparison of the environmental impact of reusable operating room bed covers and lift sheets versus single-use. Surgeon. 2024;22(4):236–41. https://doi.org/10.1016/j.surge.2024.05.003

3. Vela Saavedra R, Coronel Alarcón A, Palomino Alvarado GP. Disposición final de residuos sólidos hospitalarios. Cienc Latina Rev Cient Multidiscip. 2021;5(3):2622–46. https://doi.org/10.37811/cl_rcm.v5i3.478

4. Ventura-Abreu RL, Ortiz-Gil MÁ. Manejo de desechos hospitalarios e implicaciones: revisión sistemática de estudios durante y pospandemia de COVID-19. J Sci MQRInvestigar. 2024;8(4):4040–61. https://doi.org/10.56048/MQR20225.8.4.2024.4040-4061

5. Burguburu A, Tanné C, Bosc K, Laplaud J, Roth M, Czyrnek-Deletre M. Comparative life cycle assessment of reusable and disposable scrub suits used in hospital operating rooms. Clean Environ Syst. 2021;4:100068. https://doi.org/10.1016/j.cesys.2021.100068

6. Alshqaqeeq F, Griffing E, Twomey J, Overcash M. Comparing reusable to disposable products: life cycle analysis metrics. J Adv Manuf Process. 2020;2:e10065. https://doi.org/10.1002/amp2.10065

7. Eckelman MJ, Weisz U, Pichler PP, Sherman JD, Weisz H. Guiding principles for the next generation of health-care sustainability metrics. Lancet Planet Health. 2024;8(8):e603–9. https://doi.org/10.1016/S2542-5196(24)00159-1

8. McQuerry M, Easter E, Cao A. Disposable versus reusable medical gowns: a performance comparison. Am J Infect Control. 2021;49(5). https://doi.org/10.1016/j.ajic.2020.10.013

9. Toronto Metropolitan University. The hidden cost of hospital sterilization: finding a greener, smarter solution. 2025 Feb 18. https://www.torontomu.ca/environmental-applied-science-management/news-events/2025/02/enscimanblog-gina-vaccaro/

10. Friedericy HJ, Van Egmond CW, Vogtländer JG, Van der Eijk AC, Jansen FW. Reducing the environmental impact of sterilization packaging for surgical instruments in the operating room: a comparative life cycle assessment of disposable versus reusable systems. Sustainability. 2022;14(1):430. https://doi.org/10.3390/su14010430

11. Ly JA, Wang WL, Liss FE, Ilyas AM, Jones CM. Comparative cost analysis of single-use sterile versus reprocessed distal radius volar plate sets. Arch Bone Jt Surg. 2022;10(5):420–5. https://doi.org/10.22038/ABJS.2021.57852.2872

12. Rizan C, Lillywhite R, Reed M, Bhutta MF. Minimising carbon and financial costs of steam sterilisation and packaging of reusable surgical instruments. Br J Surg. 2022;109(2):200–10. https://doi.org/10.1093/bjs/znab406

13. Eussen MMM, Logghe E, Bluiminck S, Comes DJ, Kimman ML, Essers BAB, et al. Reducing surgical instrument usage: systematic review of approaches for tray optimization and its advantages on environmental impact, costs and efficiency. BJS Open. 2025;9(3):zraf030. https://doi.org/10.1093/bjsopen/zraf030

14. McDermott O, Antony J, Bhat S, Jayaraman R, Rosa A, Marolla G, et al. Lean Six Sigma in healthcare: a systematic literature review on motivations and benefits. Processes. 2022;10(10):1910. https://doi.org/10.3390/pr10101910

15. Rothrock J. Alexander's care of the patient in surgery. 17th ed. Elsevier; 2023.

16. Yap A, Wang K, Chen E, Melhado C, Ahmad T, O'Sullivan P, et al. A mixed-methods study on end-user perceptions of transitioning to reusable surgical gowns. Surg Open Sci. 2022;11:33–9. https://doi.org/10.1016/j.sopen.2022.10.003

17. Rezaei AR, Zienkiewicz D, Rezaei AR. Surgical site infections: a comprehensive review. J Trauma Inj. 2025;38(2):71–81. https://doi.org/10.20408/jti.2025.0019

18. Liu CQ, Ren HF, Wang C, Li J, Tang L, An JJ, et al. Novel designed surgical drapes reducing fluid permeability in the surgical critical area of a sterile operation interface: a randomized controlled trial. J Nurs Manag. 2023;2023:9295307. https://doi.org/10.1155/2023/9295307

19. American National Standards Institute; Association for the Advancement of Medical Instrumentation. ANSI/AAMI PB70:2022. Liquid barrier performance and classification of protective apparel and drapes intended for use in health care facilities. AAMI; 2022.

20. Centers for Disease Control and Prevention. NIOSH personal protective equipment information (PPE-Info). 2024 Feb 21. https://wwwn.cdc.gov/PPEInfo/Standards/Info/ANSI/AAMIPB70

21. Haberland K, Miller J, Davis J, Mutunga M, Suggs J. Evaluating disposable isolation gown liquid barrier test methods for relevance to healthcare. Biomed Instrum Technol. 2025. https://doi.org/10.2345/0899-8205-59.1.108

22. Killinc-Balci FS. Investigation of the barrier performance of disposable isolation gowns. Am J Infect Control. 2023;52(12). https://doi.org/10.1016/j.ajic.2023.09.003

23. Džajić Uršič E, Fric U, Rončević B. The circular economy: recent debates and research trends. J Infrastruct Policy Dev. 2024;8(3):2855. http://dx.doi.org/10.24294/jipd.v8i3.2855

24. Leyva S, Pancorbo J. Implementación de la economía circular en la gestión de la cadena de suministro: un análisis bibliométrico. Región Científica. 2024;3(2):2024315. https://doi.org/10.58763/rc2024315

25. Saha K, Farhanj Z, Kumar V. A systematic review of circular economy literature

in healthcare: transitioning from a post-waste approach to sustainability. J Clean Prod. 2025;505:145427. https://doi.org/10.1016/j.jclepro.2025.145427

26. Barrutia J, Echebarria C. Effect of the COVID-19 pandemic on public managers' attitudes toward digital transformation. Technol Soc. 2021;67:101776. https://doi.org/10.1016/j.techsoc.2021.101776

27. Martínez Castuera-Gómez C. Reflexión y oportunidad: economía circular y salud en el sector público mexicano. Rev Med IMSS. 2025;63(3):e6654. https://doi.org/10.5281/zenodo.15178438

28. Bahk MS. Smart sterilization container technology: blue wrap innovation. J Orthop Exp Innov. 2024;5(1). https://doi.org/10.60118/001c.87966

29. Agudelo Alzate SM, Díaz Cano MJ, Ocampo del Río C, Correa-García JA. Relación entre criterios ESG y el costo de capital en empresas latinoamericanas pertenecientes a los Dow Jones Sustainability Index. Rev Univ Empresa. 2024;27(48):1–33. https://doi.org/10.12804/revistas.urosario.edu.co/empresa/a.14241

30. El Haouat Z, Essalih S, Bennouna F, Amegouz D. Development of a global framework for an integrated life cycle assessment (LCA) model in quality, safety and environmental (QSE) management systems. Sustainability. 2025;17(8):3521. https://doi.org/10.3390/su17083521

31. Orellana K, Samsi K. Day centres resources hub. NIHR ARC South London; NIHR Policy Research Unit on Health and Social Care Workforce; 2024. https://doi.org/10.18742/pub01-174

32. Turner HC, Hori Y, Revill P, Rattanavipapong W, Arai K, Nonvignon J, et al. Analyses of the return on investment of public health interventions: a scoping review and recommendations for future studies. BMJ Glob Health. 2023;8(8):e012798. https://doi.org/10.1136/bmjgh-2023-012798

33. Jones L, Abdelgawad M, Bellis M. Identifying policy options to tackle health inequalities: policy analysis and opportunities for learning for Wales. Liverpool John Moores University; 2025. https://phwwhocc.co.uk/adnoddau/identifying-policy-options-to-tackle-health-inequalities/

34. Yoon S, Watts E, Constenla D, Brenzel D, Patenaude B. Return on investment from immunization against 10 pathogens in 94 low- and middle-income countries, 2011–2030. Health Aff (Millwood). 2020;39(8). https://doi.org/10.1377/hlthaff.2020.00103

35. Verdezoto Espinoza EM, Chiliquinga Guerra DA, Enriquez Illanes LI, Vallejo Tixi JF. Evaluación del impacto ambiental de los residuos de los equipos de protección industrial: revisión sistemática postpandemia. Conciencia Digital. 2024;7(2):91–107. https://doi.org/10.33262/concienciadigital.v7i2.2991

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