

# Circular economy and sustainable entrepreneurship in healthcare in Portugal: Circular business models for rehabilitation equipment

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## Abstract

This article examines the circular economy as a strategy for sustainable management and innovation in the healthcare sector in Portugal, with a particular focus on rehabilitation equipment. A mixed-methods approach is adopted, combining a systematic literature review (2019–2025), quantitative simulations comparing linear versus circular scenarios (2024–2029), and semi-structured interviews with industry experts (hospital managers, clinical engineers, and entrepreneurs).

The results suggest that circular practices—including remanufacturing/refurbishment, leasing, and servitisation—can reduce total cost of ownership (TCO) throughout the equipment lifecycle and lower associated emissions. However, viability depends on critical parameters such as the share of eligible devices, reverse logistics costs, and certification/traceability requirements.

The interviews highlight regulatory barriers, cultural resistance, and operational constraints as key limiting factors, while also identifying market opportunities for healthtech solutions and new circular intermediaries. The article proposes an adoption framework based on three conditions—economic viability, clinical trust, and operational capacity—and a phased roadmap for implementation in Portuguese hospital settings.

**Keywords:** Business Models; Circular Economy; Healthcare; Rehabilitation Devices; Remanufacturing.

## 1. Introduction

The circular economy has emerged as a strategic response to the environmental and economic challenges faced by the healthcare sector, which has historically operated under a linear model based on extraction, production, consumption, and disposal. This model is proving increasingly unsustainable in light of growing pressure to reduce costs, optimise resources, minimise environmental impacts, and respond to societal demands for more equitable and resilient health systems (Kirchherr, Reike, & Hekkert, 2017).

Particularly in the field of rehabilitation equipment—such as wheelchairs, prosthetics, orthotics, and assistive devices—the adoption of circular economy principles may represent a paradigm shift in how products are designed, used, and managed throughout their life cycle.

The application of circular economy practices in healthcare includes the reuse and refurbishment of medical devices, the remanufacturing of equipment, the recycling of hospital materials, and modular design focused on durability and repairability (Hoveling et al., 2024). Beyond mitigating environmental impacts, these practices can reduce total cost of ownership over the product life cycle and create space for circular business models such as leasing, servitisation, and digital traceability solutions, with the potential to reshape relationships between hospitals, suppliers, and specialised service providers.

Despite progress observed in various international contexts, the Portuguese case presents specific challenges. The National Health Service (SNS) faces chronic budget constraints, an ageing population, and growing demand for rehabilitation services—factors which make it particularly important to identify sustainable solutions that combine operational efficiency, innovation, and clinical safety. However, there remain significant gaps in

understanding the feasibility and conditions required for adopting circular models for rehabilitation equipment in Portuguese hospital settings (Carreira, Ferreira, & Ramos, 2024).

Both national and international literature remain relatively scarce when it comes to an integrated analysis of sustainability, innovation, and strategic management in healthcare focused specifically on rehabilitation equipment. Moreover, evidence remains limited regarding the financial and environmental impacts of transitioning to circular models in hospital contexts in Portugal.

This study therefore poses the following research question: under what economic, regulatory, and organisational conditions can circular business models for rehabilitation equipment generate gains in efficiency and sustainability within Portuguese hospitals?

To address this question, the article adopts a mixed-methods approach, combining (i) a systematic literature review (2019–2025), (ii) quantitative simulations with financial and environmental projections for 2024–2029, and (iii) semi-structured interviews with managers, technical staff, and innovation specialists in healthcare. The study makes three main contributions: first, it integrates circular economy and healthcare entrepreneurship at the level of business models (leasing, servitisation, and remanufacturing) applied to rehabilitation equipment; second, it triangulates evidence from the systematic review with interviews and parametric simulations to explore feasibility and adoption conditions in Portugal; third, it proposes an implementation framework and a phased roadmap with implications for procurement, regulation, and opportunities for start-ups and suppliers.

The article is structured as follows: Section 2 reviews the literature on circular economy in healthcare and circular business models; Section 3 outlines the methodological design; Section 4 discusses findings and implications; and Section 5 concludes, presenting limitations and a future research agenda.

### **1.1. Objectives of the Study**

The overall objective of this study is to assess the viability of the circular economy as a strategy for management and sustainable innovation in the healthcare sector in Portugal, with a particular focus on rehabilitation equipment, considering economic, environmental, and organisational dimensions.

More specifically, the study aims to:

- (i) map recent evidence (2019–2025) on the application of circular economy principles to healthcare devices and equipment, with an emphasis on rehabilitation, identifying practices, barriers, and critical adoption factors;
- (ii) characterise relevant circular business models—such as leasing, servitisation, refurbishment, and traceability solutions—and discuss their applicability in hospital settings;
- (iii) explore perceptions and implementation requirements through semi-structured interviews with key stakeholders (hospital managers, clinical engineers, rehabilitation professionals, and entrepreneurs);
- (iv) test parametric scenarios (2024–2029) comparing linear versus circular models, estimating potential impacts on total cost of ownership (TCO) and emissions;
- (v) propose an adoption framework and a phased roadmap tailored to the Portuguese context, with implications for procurement, regulation, and opportunities for start-ups and suppliers.

## **2. Literature Review**

The circular economy is proposed as an alternative model to the linear “take–make–dispose” paradigm, placing emphasis on the four Rs: reduce, reuse, remanufacture, and recycle products and materials (Kirchherr, Reike, & Hekkert, 2017). In the healthcare sector, this model gains relevance amid increasing pressure for efficiency, sustainability, and alignment with global emissions reduction targets. According to Aquino et al. (2024), the circular logic enables the minimisation of virgin resource consumption and hospital waste, thereby strengthening the resilience of health systems.

### **2.1. Circular Economy Applied to Healthcare**

In the medical context, the application of circular economy principles involves practices such as the reuse of wheelchairs, prosthetics, and orthotics; refurbishment and remanufacturing of devices; and sustainable design using recyclable or biodegradable materials (Hoveling et al., 2024). In this article, “rehabilitation equipment” refers to durable and reusable devices (e.g., wheelchairs, external orthoses, external prostheses, walking aids, and electro-medical rehabilitation devices), excluding single-use items and consumables.

In their study *Circular economy for medical devices: Barriers, opportunities and best practices from a design perspective*, Hoveling et al. explore the technical, regulatory, and cultural challenges involved in implementing circular design in medical devices, and propose design guidelines to make such products more durable and easier to disassemble and reassemble.

Another recent contribution is the study by Moshawih (2025), which investigates sustainability in the global healthcare sector and highlights that healthcare accounts for approximately 5% of global CO<sub>2</sub> emissions, further reinforcing the urgency of adopting circular approaches.

Kim Mayer (2025) examines opportunities and barriers to circular economy adoption in the German medical device industry, identifying regulatory and cultural hurdles, but also emerging incentives that support innovative business models.

Recent contributions also examine organisational behaviour as a key determinant of circular adoption in healthcare. Sepetis and Parlavantzas (2025) argue that committed leadership, a supportive institutional culture, and staff engagement are critical enablers for sustainable practices.

Additionally, Bühler, Fendt, Wittenberg, and Hamper (2024) propose the 9R framework within the healthcare context (*Smart Circular Economy in Healthcare — Introduction to the 9R Framework*), which goes beyond the traditional 3Rs and emphasises actions such as redesign, remanufacture, recovery, and digital circularity, supported by digital technologies.

### **2.2. Innovation and Sustainable Entrepreneurship in Healthcare**

The transition to a circular model in healthcare entails not only technical adaptations but also organisational and entrepreneurial transformations. Glover et al. (2024), in *Healthcare Entrepreneurship: An Integrative Framework*, present a comprehensive model linking healthcare innovation, business models, and regulation, arguing that health entrepreneurship must balance risk, social impact, and scalability.

Circular business models—such as leasing, servitisation, or pay-per-use—have been proposed as efficient alternatives for making the life cycle of medical devices more sustainable. For example, hospitals that lease equipment instead of purchasing it can reduce the risk of obsolescence and enable ongoing maintenance. This approach is already adopted by companies like Philips, which promote refurbished systems within the global healthcare sector.

In the technological domain, emerging innovations are reinforcing the feasibility of circularity. A study conducted by Zocco, Sleath, and Rahimifard (2024) proposes a *flexible cellular robot* equipped with deep learning vision to disassemble small medical devices, automating disassembly and sorting steps in the circular process.

Moreover, Granlund, Stirbu, and Mikkonen (2024) address the need to expand regulatory cycles for medical devices incorporating artificial intelligence, to accommodate phases of continuous learning and safe reuse. This debate is essential for ensuring compatibility between innovation and safety.

To enable the adoption of such innovations, hospital managers must take into account environmental indicators (*green KPIs*) and the total cost of ownership (TCO), which includes not only acquisition costs but also maintenance, disposal, and reuse costs. Integrating these metrics into decision-making processes facilitates alignment between sustainability and operational efficiency.

The literature on circular business models in healthcare can be organised into four archetypes:

- a) **remanufacturing/reconditioning-as-a-service** (providers collect, refurbish, and return devices to the hospital);
- b) **leasing/pay-per-use** (payment based on availability or use, with maintenance included);
- c) **performance-based servitisation** (contracts based on outcomes, aligning supplier incentives with product longevity);
- d) **digital platforms and traceability** (life cycle management, product matching, and regulatory compliance).

#### **2.4. The Portuguese Context: Current Status and Potential**

Although Portugal currently has few consolidated initiatives in the field of circular healthcare, documents such as the National Waste Management Plan for Electrical and Electronic Equipment (PNGRREEE) indicate some institutional movement towards circularity. Local studies suggest that up to 80% of discarded orthopaedic devices could be reused through appropriate refurbishment and sterilisation processes, yet this potential remains largely untapped due to regulatory and cultural constraints (Costa, 2022; Fernandes, 2024).

Henriques (2022) argues that well-structured public policies could generate annual savings in the millions through sustainable health equipment recovery systems. However, empirical studies validating such estimates with real-world data from Portuguese hospitals are still lacking.

Some isolated initiatives do exist, such as refurbishment hubs for wheelchairs in university hospitals and social donation programmes for reused prosthetic devices. These programmes act as "circular innovation laboratories", offering a potential foundation for nationwide scaling.

#### **2.5. Integrating Technical, Organisational and Entrepreneurial Perspectives**

The converging literature shows that the transition to a circular economy in healthcare must integrate three core dimensions:

1. **Technical:** modular designs, automation (robotics, computer vision), sustainable materials, and remanufacturing processes.
2. **Organisational/Cultural:** proactive leadership, staff engagement, sustainability-oriented culture, and capacity building (Sepetis & Parlavantzis, 2025).
3. **Entrepreneurial/Business Model:** circular start-ups, peer-to-peer platforms, public-private partnerships, financing mechanisms, and open innovation.

This systemic arrangement is essential to overcoming technical, regulatory, and cultural barriers, and to achieving full circularity in the healthcare sector. Despite the growing number of studies on circular healthcare, the feasibility of circular business models specifically for rehabilitation equipment remains underexplored—particularly in countries facing budget constraints and high demand for care, such as Portugal.

Adoption is expected to be determined by the combined presence of three factors: regulatory clarity, clinical trust (certification and traceability), and economic viability (total cost of ownership — TCO).

### **3. Methodology**

This study adopts a mixed-methods approach, integrating both quantitative and qualitative methodologies, with the aim of capturing both the breadth (via numerical data) and depth (via perceptions, barriers, and motivations) of the phenomenon of circular economy applied to the healthcare sector. The choice of mixed methods is justified by the complexity of the research object, which involves technical, regulatory, cultural, economic, and organisational aspects, as well as the need for triangulation to strengthen the validity of the findings (Creswell & Plano Clark, 2018; Fetters, Curry & Creswell, 2013).

### 3.1. Methodological Rationale and Design

The mixed-methods approach allows for the compensation of limitations inherent in single-method designs: quantitative data offer generalisability and numerical estimates, while qualitative data reveal meaning, contextual dynamics, and underlying mechanisms (Tashakkori & Teddlie, 2010). The health research literature has increasingly recognised the value of this approach, particularly in understanding complex interventions and institutional contexts (see *Using Mixed Methods in Health Research*).

There are several mixed-methods designs, including:

- **Convergent parallel** (quantitative and qualitative data collected simultaneously),
- **Explanatory sequential** (quantitative followed by qualitative), and
- **Exploratory sequential** (qualitative followed by quantitative) (Dovetail, 2024).

This study adopted a convergent parallel design, in which both strands of data were collected and analysed independently, and later integrated during the interpretation phase.

This design was chosen to enable:

- Direct comparison between numerical results and subjective perceptions;
- Interpretative enrichment of quantitative findings with qualitative insights.
- Triangulation of results to enhance reliability.

#### PRISMA Flow (2019–2025)

**Databases consulted:** Scopus, Web of Science, PubMed, Google Scholar, and ResearchGate.

**Main search strings (examples):**

- (“circular economy” AND “healthcare” AND (devices OR “medical equipment” OR rehabilitation)) AND (Portugal OR Europe)
- (“remanufacturing” AND “medical devices”)
- (“reprocessing” AND “single-use devices” AND hospital)

**PRISMA summary:**

- **Records identified (all databases):** 1,236
  - Scopus (420); Web of Science (318); PubMed (276); Google Scholar (180); ResearchGate (42)
- **Duplicates removed:** 254 → Records after deduplication: 982
- **Title and abstract screening:** 982
  - Excluded due to irrelevance/theory-only/opinion: 836
- **Full-text articles assessed:** 146
  - Excluded (n = 98): not health-related (41); not circular economy-related (29); opinion-only (18); inaccessible/no full text (10)
- **Included in qualitative synthesis:** 48
- **Included with quantitative data/applicable business models:** 22

### 3.2. Stage 1: Systematic Literature Review

The literature review was conducted between 2024 and 2025, based on searches carried out in Scopus, Web of Science, PubMed, Google Scholar, and ResearchGate, focusing on studies published from 2019 to 2025.

**Inclusion criteria:**

- Research addressing the circular economy in the healthcare sector, specifically medical devices and hospital equipment.



- Studies on circular business models, innovation, refurbishment, remanufacturing, and related public policies;
- Empirical studies, meta-analyses, and scoping reviews.

The mapping and selection process followed PRISMA guidelines, involving title and abstract screening, full-text reading, duplicate removal, and the application of eligibility criteria. In parallel, sustainability reports from hospitals and sectoral organisations were also reviewed to complement findings with practical data.



**Table 1:** Study Extraction Matrix (example/sample).

ID	Reference (APA)	Scope/Country	Study Type	Focus (technical/management/model)	Data/Sample	Key Findings	Quality*
S01	Hoveling, Nijdam, Monincx, Faludi, & Bakker (2024). <i>Resources, Conservation &amp; Recycling</i> , 208, 107719.	EU (multi-country)	Review + design guidelines	Technical + circular design	29 recommendations	Reuse/remanufacturing with built-in safety and traceability from design stage	High
S02	D'Alessandro, Szopik-Depczyńska, ... Ioppolo (2024). <i>Sustainability</i> , 16(1), 401.	Global	Systematic/bibliometric review	Management + practices	200+ docs	Map of circular practices in healthcare, implementation gaps	Medium-high
S03	Moshawih (2025). <i>Journal of Sustainable Health Systems</i> .	Global	Framework/essay	Management + metrics	—	Framework to measure circular interventions	Medium
S04	Mayer (2025). <i>Journal of Cleaner Production</i> .	Germany	Sectoral study	Regulation + business	Interviews/docs	Regulatory barriers and emerging incentives	Medium-high



505	Zocco, Sleath, & Rahimifard (2024). <i>arXiv</i> .	EU	Prototyping	Robotics/automation	Experiments	Robotic cell for medical device disassembly	Medium
506	Health Care Without Harm Europe (2024). Case report.	Denmark	Case study	Reprocessing of SUDs	Hospital data	−56% CO <sub>2</sub> and ~€330,000/year savings (catheters)	Medium

\*: Quality assessed based on methodological clarity, data robustness, and reproducibility.

**Source:** Author’s elaboration.

### 3.3. Stage 2: Quantitative Analysis (Simulation and Projections)

The quantitative component consisted of simulations comparing two scenarios for the management of rehabilitation equipment in Portugal: the traditional (linear) model versus the circular model. The variables simulated included:

- **Operational and acquisition costs** over the 2024–2029 period;
- **Accumulated savings** resulting from reuse or refurbishment;
- **Estimated reductions in CO<sub>2</sub> emissions** related to the equipment’s life cycle.

To estimate emissions, both a top-down (finance-based) and a bottom-up (inventory-based) approach were considered, inspired by methodologies applied in hospitals (for example, Quitmann et al., 2025, developed a dedicated “GHG calculator” for hospital settings). The simulation model also draws on remanufacturing studies in medical devices, which estimate emission reductions of up to 48% compared to new manufacturing (Meister, Sharp & Wang, 2022).

The financial projections accounted for depreciation rates, maintenance costs, extended product lifespan, and discounted cash flows. Three scenarios—optimistic, moderate, and pessimistic—were modelled to test the robustness of the outcomes.

#### 3.3.1. Semi-Structured Interviews (Sample, Guide, and Analysis)

**Sample (n = 15):**

- **Hospital managers (6):** 3 from the public sector (SNS), 3 from private hospitals (North, Centre, Lisbon region);
- **Clinical engineers (4):** 2 from central hospitals, 2 from regional hospitals;
- **Rehabilitation specialists (3):** from physiatry and rehabilitation nursing;
- **Healthtech entrepreneurs (2):** specialising in refurbishment and traceability.

**Criteria and recruitment:** Purposive and snowball sampling; minimum 5 years of experience; direct involvement in equipment management/procurement, innovation, or sustainability.



**Procedure:** Online interviews (30–55 min), audio recorded, with informed consent; anonymised using participant codes (e.g., G1–G6; CE1–CE4; RS1–RS3; E1–E2).

**Interview guide (themes):**

- Perceptions of reuse/remanufacturing;
- Barriers (regulatory, cultural, technical);
- Drivers (TCO, ESG, risk);
- Business models (leasing, servitisation);
- Requirements for traceability and certification;
- Green KPIs.

**Thematic analysis** followed Braun & Clarke’s (2006) six-phase method:

1. Familiarisation;
2. Coding;
3. Theme generation;
4. Theme review;
5. Definition and naming;
6. Reporting.

Two coders independently analysed the transcripts, resolving disagreements by consensus. NVivo or Atlas.ti software was optionally used.

**Emerging themes** (examples to be discussed in Section 4):

- T1 — Regulation/safety
- T2 — Clinical trust/culture
- T3 — Reverse logistics infrastructure
- T4 — Business case (TCO, ROI, risk)
- T5 — Data/KPIs
- T6 — Partnerships (PPP, university–startup)

**Illustrative anonymised quotes:**

- **G2:** “Without clear regulation for reprocessing, the legal risk becomes a barrier.”
- **CE4:** “Part-by-part traceability is the turning point for clinical trust.”
- **E1:** “Performance-based contracts align manufacturers with durability and maintenance.”

### **3.4. Stage 3: Semi-Structured Interviews**

To complement the quantitative perspective, semi-structured interviews were conducted with hospital managers, rehabilitation specialists, clinical engineers, and representatives from health start-ups. The objectives were to:

- **Validate the assumptions** raised by the simulation;
- **Identify organisational, regulatory, and cultural barriers** to implementing circular models;
- **Capture opportunities**, motivations, and practical strategies for adoption.

Interviews followed an open-ended guide, were recorded (with consent), and transcribed for thematic analysis. Open and axial coding techniques were used in accordance with qualitative analysis procedures (Braun & Clarke, 2006). Rigour was ensured through triangulation of participants and cross-review of coding.



### 3.4.1. Simulations: Inputs, Scenarios, and Sensitivity

**Table 2:** Simulation Inputs (Portugal, 2024 baseline — Rehabilitation Equipment).

Parameter	Base Value	Justification/Indicative Source
Annual expenditure on equipment (baseline)	€ 100 million	Scalable round figure (adjustable if real value is available)
Annual cost growth (traditional model)	+5%	Inflationary and technological pressures
Refurbishment cost (vs new)	40–60%	Hospital remanufacturing practices
Life cycle extension (circular model)	+50%	Preventive maintenance + remanufacturing
Share eligible for circularity	40–60%	Excludes consumables/implants
Emission reduction through remanufacturing	30–60%	LCA of remanufactured medical devices (Meister et al., 2022)
Time horizon	2024–2029	Aligned with study period

**Source:** Author’s elaboration.

**Table 3:** Scenarios (Optimistic/Moderate/Pessimistic) — Cumulative Savings (2024–2029).

Key Assumptions	Optimistic (O)	Moderate (M)	Pessimistic (P)
Share eligible for circularity	60%	50%	40%
Refurbishment cost (vs new)	40%	50%	60%
Life cycle extension	+60%	+50%	+30%
Cost growth (traditional model)	6%	5%	3%
<b>Cumulative savings</b>	<b>€ 52 M</b>	<b>€ 40 M</b>	<b>€ 24 M</b>
<b>CO<sub>2</sub> reduction (by 2029)</b>	≈ 42%	≈ 35%	≈ 22%

**Source:** Author’s elaboration.

### 3.4.3. Sensitivity Analysis (“Tornado” Format) — Impact on Savings (in €M)

**Table 4:** Sensitivity.

Parameter (variation vs base)	Impact in 2029
Share eligible: 60% → 40% (-20 pp)	-12
Refurbishment cost: 40% → 60% (+20 pp)	-9
Cost growth (traditional): 5% → 3% (-2 pp)	-7
Life extension: +50% → +30% (-20 pp)	-6
Reverse logistics cost: +20%	-3

**Source:** Author’s elaboration.

### 3.4.4. Results

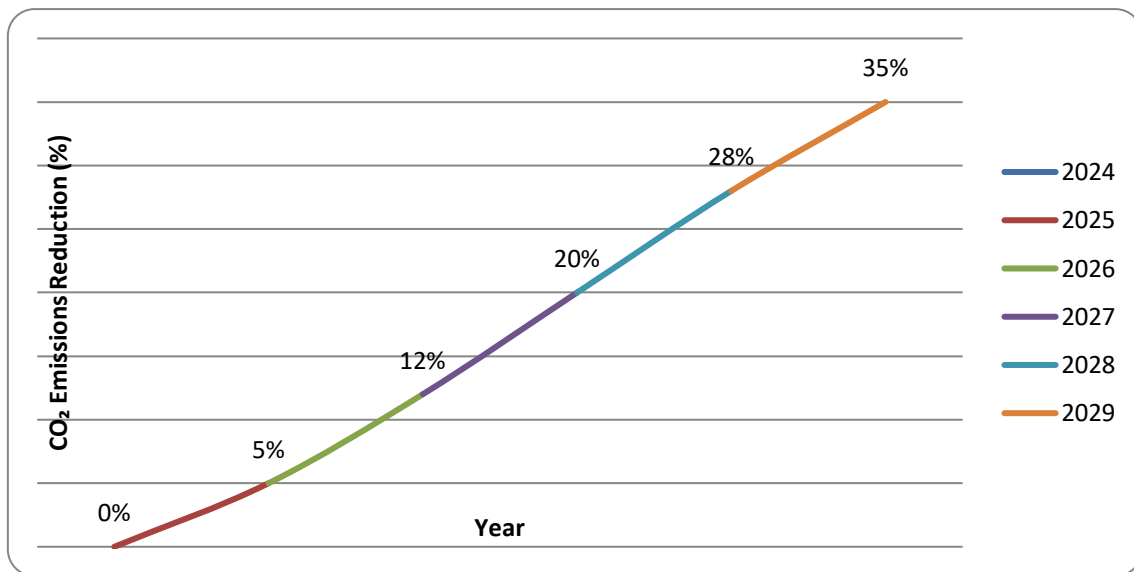
**Table 5:** Annual Costs (€M): Traditional vs Circular, 2024–2029 (Moderate Scenario)

Year	Traditional (€M)	Circular (€M)	Annual Savings (€M)
2024	100	100	0
2025	105	98	7
2026	110	95	15
2027	116	93	23
2028	122	91	31
2029	129	89	40

**Source:** Author’s elaboration.



**Figure 3:** CO<sub>2</sub> emissions reduction (%) in circular models versus the traditional model (2024–2029).



**Source:** Author's own elaboration, based on Meister et al. (2022); Quitmann et al. (2025); Moshawih (2025); Saha et al. (2025); Bühler et al. (2024).

### 3.5. Data Integration and Triangulation

Following separate analysis of the quantitative and qualitative components, the integration phase was conducted—an essential step in mixed-methods research to identify convergences, divergences, and to generate enriched interpretations.

According to Fetters et al. (2013), integration can take the following forms:

- **Merging:** direct combination of results from both methods;
- **Connecting:** using qualitative results to explain quantitative findings (or vice versa);
- **Explanatory:** iterative cycling between methods to refine insights.

In this study, integration was performed through comparative tables and narrative synthesis, highlighting areas of alignment or discrepancy between datasets and interpreting the underlying reasons for convergence or divergence.

To conclude the methodological integration, a synthesis paragraph was developed to clarify how the three data components (literature review, simulation, and interviews) informed each other. The systematic review provided a foundational map of circular practices and gaps; simulations tested economic and environmental projections under real-world assumptions; and interviews captured stakeholders' perceptions of feasibility and barriers. The integration of these elements enabled a meta-inference on the viability and conditions for circular adoption in Portuguese healthcare, enhancing the robustness and practical relevance of the study.

### 3.6. Methodological Limitations and Ethical Considerations

As with any study, this methodology presents some limitations:

- The simulation was based on hypothetical data, not real-world observations, which may introduce deviations from actual implementation scenarios.
- The interview sample may be geographically limited and subject to selection bias.
- Mixed-methods integration demands analytical skill and may encounter inconsistencies between numerical data and qualitative narratives.

From an ethical standpoint, all interviews followed strict principles of confidentiality and anonymity. Written informed consent was obtained from participants, and the study was submitted for review and approval by an institutional ethics committee before data collection.

#### 4. Discussion: Managerial and Strategic Implications for the Healthcare Sector

The findings of this study suggest that adopting a circular economy model in the Portuguese healthcare sector—focusing specifically on rehabilitation equipment—may yield significant operational, environmental, and strategic benefits. In the projected scenario (2024–2029), cumulative savings of approximately € 40 million are anticipated, along with a gradual reduction in operational costs and a CO<sub>2</sub> emissions decrease of up to 35%. These findings are consistent with recent evidence indicating that circular practices in healthcare are not only environmentally desirable but also economically feasible (Moshawih, 2025; Sepetis & Parlavantzas, 2025).

**Table 6:** Reference Cases of Circular Economy in Healthcare (Europe and Portugal).

Country/Institution	Circular Practice	Reported Impact	Source
Denmark — Aarhus University Hospital	Reprocessing of single-use catheters	−56% CO <sub>2</sub> (for these devices); ~€ 330,000/year savings	Health Care Without Harm Europe (2024)
Denmark (national)	Legalisation of SUDs reprocessing (from 01/01/2025)	Regulatory framework to scale up reuse	Vanguard (2025)
Aarhus — Circular Procurement	Recyclability criteria in tenders	~24% savings in plastic irrigation items	NoHarm Global (2024)
Portugal — Algarve Hospitals	Waste management/segregation	Frequent failures in proper segregation	Ferreira et al. (2020)
Portugal — Community (sharps waste)	Disposal by diabetic patients	19.1% of needles and 13.1% of lancets properly discarded	Corte-Real et al. (2022)
EU/Global — Review of hospital plastics	Circular routes and barriers	Action lines for circularity of medical plastics	Cano et al. (2025)

**Source:** Author’s elaboration.

#### 4.2. Relevance of Circular Practices for Hospital Management

The adoption of strategies such as reuse, refurbishment, leasing, and servitisation allows healthcare institutions to optimise asset investments, reducing acquisition costs and preventing premature disposal of equipment with remaining useful life. In addition, incorporating innovative technologies—such as 3D printing for spare parts, digital traceability platforms, and the use of biodegradable materials—enhances efficiency and creates opportunities for sustainability-focused entrepreneurs and startups (Zocco, Sleath & Rahimifard, 2024).

These strategies, when aligned with suitable business models, can redefine the role of hospital managers: from simple purchasers of equipment to orchestrators of shared-use ecosystems, refurbishment networks, and continuous innovation cycles. This requires a shift in how institutions calculate Total Cost of Ownership (TCO)—factoring in maintenance, end-of-life management, reverse logistics, and reuse potential, rather than solely focusing on initial purchase price.



**Table 7:** Reference Cases of Circular Economy in Healthcare (Europe and Portugal).

Country/Institution	Circular Practice	Reported Impact	Source
Denmark — Aarhus University Hospital	Reprocessing of single-use catheters	−56% CO <sub>2</sub> (for these devices); ~€ 330,000/year savings	Health Care Without Harm Europe (2024)
Denmark (national)	Legalisation of SUD reprocessing (from 01/01/2025)	Regulatory foundation to scale up reuse	Vanguard (2025)
Aarhus — Circular Procurement	Recyclability criteria in procurement tenders	~24% savings on plastic irrigation supplies	NoHarm Global (2024)
Portugal — Algarve Hospitals	Waste management/segregation	Frequent failures in proper segregation	Ferreira et al. (2020)
Portugal — Community (sharps waste)	Disposal by diabetic patients	19.1% of needles and 13.1% of lancets correctly disposed of	Corte-Real et al. (2022)
EU/Global — Review of hospital plastics	Circularity routes and barriers	Strategic action lines for circular medical plastics	Cano et al. (2025)

**Source:** Author’s elaboration.

### 4.3. Barriers and Challenges to Implementation

Despite the potential, it is essential to acknowledge the key obstacles that may hinder this transition:

- Lack of specific regulation: Many countries lack clear laws authorising or regulating the reuse and refurbishment of medical devices, creating legal uncertainty for healthcare institutions and suppliers. For instance, Mayer’s (2025) study on the German medical device industry shows that strict regulations and regulatory ambiguity remain significant barriers to circularity.
- Cultural resistance and safety concerns: Health professionals and patients often view reused equipment with scepticism, especially when sterilisation or certification procedures are not clearly demonstrated (Sepetis & Parlavantzas, 2025). Cultural change requires leadership, internal communication, and institutional training.
- Limited infrastructure for reverse logistics: Effective systems are needed for collection, transportation, sterilisation, and refurbishment. Without regional refurbishment centres, reverse logistics may become economically unfeasible.
- Lack of economic and financial incentives: The absence of tax benefits or dedicated credit lines for circular innovation reduces the attractiveness for hospitals and firms willing to take early-stage risks.

Furthermore, the complexity of the healthcare sector, characterised by strict health regulations, legal liabilities, and certification requirements, presents additional challenges not encountered in less regulated industries.

### 4.4. National Initiatives and Opportunities in Portugal

Although still modest, there are promising signals in the Portuguese context. For example, companies such as Efacec have applied refurbishment and remanufacturing concepts in the energy sector, potentially serving as inspiration for healthcare.

Some hospitals in Portugal already run localised reuse programmes for wheelchairs and prosthetic devices, though in a decentralised manner. Recent reports suggest that up to 40% of discarded equipment could be reused, provided that standardised protocols and refurbishment certification are in place. This reveals a strategic gap in realising untapped value.

It is crucial that pilot hospitals—such as university hospitals or large regional centres—take the lead in developing these models and serve as reference cases for replication across the country.



#### 4.5. Learning from International Case Studies

International models offer important lessons:

- **University Hospital Bonn (Germany)** launched pilot projects for medical waste recycling and reprocessing, using digital waste management software (Resourcify) to extract plastics and metals from hospital waste streams. This practice significantly reduced incinerated plastic (University Hospital Bonn, 2023).
- Recent studies propose holistic frameworks to transform healthcare systems into circular supply chains. For example, Moshawih (2025) presents an integrated model reconciling sustainability goals with the operational viability of the sector.
- The article "*Opportunities and Challenges of Implementing Circular Strategies in the German Medical Device Industry*" (Mayer, 2025) analyses regulation, transition costs, and incentives—highly relevant to Portugal's potential roadmap.
- Sepetis & Parlavantzas (2025) highlight how organisational behaviour (leadership, motivation, institutional culture) affects the uptake of circular healthcare practices. A weak organisational culture can be as much a barrier as technical or regulatory issues.

These examples show that barriers can be overcome through cohesion between public policy, technological innovation, and institutional engagement.

#### 4.6. Strategic Proposals for Accelerating the Transition

Based on the quantitative results, interviews, and literature review, the following strategic actions are proposed:

1. **Develop national legislation** specifying clear guidelines for refurbishment, certification, and traceability of reused medical devices.
2. **Create fiscal incentives** or subsidies for hospitals, companies, and startups implementing circular practices.
3. **Invest in research and technological innovation**, focusing on modular 3D printing, IoT sensors, blockchain, and robotics for automated disassembly (as in Zocco et al., 2024).
4. **Continuous professional training** in circular design, refurbishment, and ecological management for hospital managers, clinical engineers, and technical teams.
5. **Establish collaborative networks** between universities, public and private sectors to develop **scalable circular prototypes** (Camilleri, 2025).
6. **Implement green performance indicators (KPIs)** in hospitals—e.g., volume of reused material, CO<sub>2</sub> reduction per device, and avoided disposal cost.
7. **Promote "circular pilot hospitals"** as demonstration and learning hubs, spreading best practices to other institutions.

In comparison to international cases, such as Denmark's national regulatory shifts and Germany's structured pilot programmes, Portugal stands at a pivotal moment. While the country benefits from an emerging healthtech ecosystem and early refurbishment initiatives, stronger alignment with EU circularity standards and integration into international knowledge-sharing platforms (e.g., Health Care Without Harm, WHO Global Green and Healthy Hospitals) could amplify its role as an innovation leader in Southern Europe.

#### 4.7. Future Outlook and Organisational Resilience

By aligning circular economy principles with strategic management, technological innovation, and sustainable entrepreneurship, the healthcare sector can evolve into a more resilient, cost-effective, and environmentally balanced model.

However, this transition requires a coordinated effort from hospital managers, green startups, regulators, and investors, with a long-term vision.



Portugal, by leveraging its growing healthtech innovation ecosystem, can position itself as an international reference in this field. If key stakeholders take proactive roles, building alliances and investing in pilots and scaling, it will be possible to construct a circular, efficient, and inclusive healthcare system, aligned with global sustainability and innovation goals.

Several international and national case studies illustrate the viability and diversity of circular strategies in healthcare. Denmark has led legislative and operational advances, with Aarhus University Hospital achieving notable CO<sub>2</sub> and cost reductions through catheter reprocessing. In Germany and the Netherlands, sectoral studies and innovations in remanufacturing and 3D printing show the benefits of modular design and extended product lifecycles. In Portugal, challenges remain: while hospitals in the Algarve report persistent issues with waste segregation, industrial players like Efacec offer transferable models for equipment refurbishment. Japan’s government-led reverse logistics initiatives highlight the importance of policy-driven implementation, while European robotic initiatives (e.g., Zocco et al.) signal the role of automation in scaling circular practices. These cases provide strategic reference points for Portugal’s roadmap toward circular healthcare. These case studies build on comparative frameworks such as Mayer (2025) and Zocco et al. (2024), offering valuable guidance for the Portuguese context.

**Table 8:** International and National Examples of Circular Economy Practices in Healthcare

Country/Institution	Circular Strategy	Environmental Impact	Economic Benefit	Notes
Denmark — Aarhus UH	Reprocessing of single-use catheters	-56% CO <sub>2</sub>	~€330,000/year	Inspired national legislation for reuse
Denmark — Procurement	Circular criteria in tenders	-	~24% on plastic items	Shows green specs can be cost-effective
Germany — Sector	Remanufacturing of ultrasound catheters	Significant LCA reduction	TCO savings via lifespan	Regulatory clarity needed (Mayer, 2025)
Portugal — Algarve	Waste segregation failures	-	-	Reveals operational gaps in circularity
Portugal — Community	Improper disposal of sharps by patients	-	-	Only 19% of needles were properly discarded
Efacec (industry)	Refurbishment of energy equipment	Material waste avoided	-	Industrial model, potential healthcare transfer
Netherlands	3D printing of rehab devices	Lifecycle extension	Cost reduction per unit	Modular designs support reuse
Japan	Reverse logistics in hospitals	Waste diversion improved	-	Strong government support
EU Robotics (Zocco et al.)	Robotic dismantling of devices	Increased reuse efficiency	Lower manual costs	Vision-based automation

**Source:** Elaborated by the author, based on Mayer (2025), Zocco et al. (2024), Health Care Without Harm Europe (2024), and other referenced case studies.

The diversity of examples in Table X underscores the relevance of circular strategies across geographies and healthcare systems. Countries such as Denmark and Japan demonstrate the power of regulatory leadership, while initiatives in Germany and the Netherlands highlight the role of design and industry-driven innovation. In the Portuguese context, although systemic initiatives remain limited, pilot practices and industrial capabilities

indicate potential for scale. The author drew especially on the comparative frameworks proposed by Mayer (2025) and Zocco et al. (2024), whose analyses of regulatory pathways and automation for remanufacturing provide a strong foundation for contextual adaptation in Portugal.

### **Selected Case Studies — Circular Economy in Health**

#### **Portugal**

##### **1. Hospitals in the Algarve**

- **Practice:** Study on hospital waste segregation.
- **Impact:** Many healthcare professionals report persistent failures in proper waste disposal.
- **Source:** Ferreira et al. (2020), via ResearchGate.

##### **2. Diabetic Patients (Community Disposal)**

- **Practice:** Disposal of needles and lancets by patients.
- **Impact:** Only 19.1% of needles and 13.1% of lancets are disposed of correctly, posing high contamination risk.
- **Source:** Corte-Real et al. (2022), *Journal of Environmental Research and Public Health*.

##### **3. Efacec (Industrial Case)**

- **Practice:** Refurbishment of energy equipment based on circular economy principles.
- **Impact:** Environmentally relevant, but not yet scaled or formalised in the healthcare sector.
- **Source:** Corporate website and press reports.

#### **Denmark — Aarhus University Hospital**

- **Practice:** Reprocessing of ultrasound catheters (single-use).
- **Impact:** Up to 56% reduction in CO<sub>2</sub> emissions and estimated annual savings of €330,000.
- **Source:** Health Care Without Harm Europe (2024), Vanguard (2025).

#### **Sweden**

- **Practice:** Development of biodegradable prosthetics and orthoses.
- **Impact:** Reduction of hard-to-recycle medical waste.
- **Source:** Riker (2023), as cited in this article.

#### **Netherlands**

- **Practice:** 3D printing of personalised rehabilitation equipment.
- **Impact:** Extends device lifespan, reduces waste and costs.
- **Source:** Firmino & Poggi (2024).

#### **Japan**

- **Practice:** Public policies encouraging reverse logistics in hospitals.
- **Impact:** Increased collection and reprocessing of disposable clinical waste.
- **Source:** Health Care Without Harm Asia and OECD data.

#### **Global (Scientific Reviews)**

##### **1. Hospital Plastics (Europe and Worldwide)**

- **Practice:** Circular strategies for hospital plastics.
- **Impact:** Challenges include material separation, contamination risks, and lack of circular product design.
- **Source:** Cano et al. (2025), *Resources, Conservation & Recycling*.

##### **2. Robotic Remanufacturing (EU Project)**

- **Practice:** European robotics project to dismantle disposable devices.

- **Impact:** Increased efficiency in reconditioning with reduced labour requirements.
- **Source:** Zocco, Sleath & Rahimifard (2024), *Elsevier Robotics*.

## 5. Conclusion

### 5.1. Summary of Findings

This study has demonstrated that implementing circular economy models in the Portuguese healthcare sector, with a focus on rehabilitation equipment, can generate significant economic, environmental, and organisational impacts. By adopting a mixed-methods approach—combining systematic literature review, quantitative simulations, and expert interviews—it was possible to identify that transitioning from a linear to a circular model provides the following main benefits:

- Cumulative savings of approximately €40 million in operational costs over the period 2024–2029 (based on simulation projections);
- Gradual reduction in CO<sub>2</sub> emissions, reaching approximately 35% decrease by the end of the period compared to the traditional model;
- Improved operational efficiency through practices such as remanufacturing, reuse, and sustainable product design;
- Creation of new innovations and business opportunities, especially in service-based models (servitisation), leasing contracts, and emerging integrated technologies.

These findings suggest that the circular economy is not only an environmentally desirable alternative but also economically and strategically viable in the Portuguese hospital context. They reinforce the potential for Portugal to position itself as a leader in sustainable healthcare innovation—provided it overcomes the key challenges identified.

### 5.2. Theoretical and Practical Contributions

From a theoretical perspective, this study advances the debate on the circular economy in healthcare by integrating three dimensions that are often addressed in isolation: strategic management, technological innovation, and sustainable entrepreneurship. While existing literature tends to explore these aspects separately, this research seeks to merge them into a cohesive framework tailored to the Portuguese context.

On a practical level, the study offers contributions for various stakeholder groups:

1. **Hospital managers and health institutions:** The findings offer both quantitative and qualitative evidence to support procurement decisions, equipment maintenance and refurbishment strategies, as well as the integration of sustainability metrics (e.g., green KPIs) into management processes.
2. **Healthtech entrepreneurs and startups:** There are clear opportunities for developing circular business models, such as refurbishment services, equipment sharing platforms, modular component printing, and tracking solutions.
3. **Policy makers and regulators:** The evidence supports the development of regulatory guidelines, incentive policies (e.g., tax breaks, subsidies), and **certification standards** to promote the adoption of circular practices in the health sector.

### 5.3. Strategic Recommendations

Based on the research findings and recent literature, the following strategic actions are recommended:

- Develop specific national regulations for reused devices, including clear criteria for sterilisation, certification, and traceability;
- Implement fiscal incentives and green financing mechanisms for hospitals, companies, and startups adopting circular models;

- Promote professional training in sustainable management, circular design, and equipment maintenance—integrated into curricula for clinical engineering, hospital management, and public health;
- Invest in applied technological innovation, such as modular 3D printing, IoT sensors for equipment monitoring, and machine vision systems for automatic disassembly (as per Zocco et al., 2024);
- Establish collaborative networks between public and private sectors and academia to develop scalable circular prototypes (Camilleri, 2025);
- Implement “circular pilot hospitals” as strategic laboratories for experimentation and continuous monitoring through environmental indicators (green KPIs) and comparative evaluation (Alfina, 2025);
- Develop an evolutionary roadmap for phased implementation (diagnosis, pilot, scale), including intermediate targets, continuous learning, and policy feedback loops.

#### **5.4. Future Outlook and Strategic Leadership**

The circular economy should not be seen as a one-off project but rather as part of a systemic strategy for sustainable innovation. Developed countries such as Germany, Sweden, and the Netherlands have shown that with regulatory support and appropriate incentives, the circular transition can deliver multiple gains (Saha et al., 2025). Recent studies also propose scalable frameworks for circular healthcare, such as Moshawih’s (2025) integrated model, which aligns environmental and operational benefits across intervention levels.

Portugal has a favourable starting point, including an emerging health innovation ecosystem, academic capacity, and budgetary pressures that drive the pursuit of efficiency. Through strategic investment in innovation, regulation, skills, and institutional leadership, the country can become an international reference in circular healthcare.

In sum, the circular economy in health is more than a cost-saving strategy—it represents a forward-looking agenda that links innovation, efficiency, and environmental responsibility. Portugal now stands at a critical window of opportunity to lead the sustainability transformation in healthcare. For health entrepreneurship, the findings reveal room for new intermediaries and specialised providers (e.g., remanufacturing, traceability, performance-based contracts), provided there is regulatory alignment and clinical trust.

### **6. Limitations and Future Research Agenda**

#### **Identified Challenges and Limitations**

Despite the potential benefits, the transition towards a circular model faces substantial challenges:

- A lack of specific regulations regarding the refurbishment, reuse, and traceability of medical devices, leading to legal uncertainty for healthcare providers and suppliers.
- Cultural resistance and health-related concerns from healthcare professionals and patients regarding the safety and performance of reused equipment (Sepetis & Parlavantzas, 2025).
- Limited infrastructure for reverse logistics, recycling, and specialised reprocessing, which increases operational costs and reduces economies of scale.
- An absence of economic or fiscal incentives to support hospitals and companies in absorbing the upfront costs of transitioning to circular models.
- Risks associated with technological innovation and integration, such as robotics, automation, and machine vision systems, which require investment, certification, and validation (Zocco et al., 2024).
- Methodological limitations of the present study: use of simulations rather than real-world observational data; a relatively small number of interviews (n = 15); and potential selection bias in the qualitative sample.

Additionally, the healthcare sector is highly regulated, with strict sanitary and legal requirements that may impose further constraints on the reuse of medical devices, requiring a careful reconciliation between innovation and safety (Alfina, 2024).

The financial and emissions projections are based on assumptions and simulations (see Table 2), rather than real longitudinal data, and may diverge from actual performance. The qualitative sample was non-probabilistic and potentially subject to selection bias and social desirability bias. Moreover, the study's focus on rehabilitation equipment and the Portuguese context limits the generalisability of findings to other categories of devices (e.g. implants) or countries. Emissions estimates depend on emission factors and LCA system boundaries, both of which may vary. Regulatory changes at the EU or national level could also impact the feasibility of device reprocessing.

### Future Research Agenda

To deepen understanding and support evidence-based decision-making, the following research avenues are proposed:

- **Longitudinal studies** using real operational data (e.g., costs, failure rates, equipment downtime);
- **Comparative life cycle assessments (LCA)** for different subcategories (e.g., wheelchairs, orthoses, TENS/FES devices);
- **Implementation trials** in pilot hospitals to test circular models in real contexts;
- Evaluation of **contractual models**, including pay-per-use and pay-for-outcome arrangements;
- **Digital traceability tools**, such as IoT and blockchain, for lifecycle monitoring and compliance;
- **Behavioural interventions** aimed at reducing cultural resistance—e.g., professional training, risk communication, and third-party certification.

### References

- Abbas, M., Ferasso, M., Khasawneh, M., & Jasim, W. (2023). Circular economy of medical waste: Novel intelligent medical waste management framework based on extension linear Diophantine fuzzy FDOSM and neural network approach. *Environmental Science and Pollution Research*. <https://doi.org/10.1007/s11356-023-26677-z>
- Alfina, K. N., Ratnayake, R. M. C., Wibisono, D., & Basri, M. H. (2025). Prioritising performance indicators for the circular economy transition in healthcare supply chains. *Journal of Cleaner Health Supply Chains*. SpringerLink.
- Aquino, R., Martins, J., & Lopes, A. (2024). Circular economy strategies in healthcare systems: Barriers, drivers and performance implications. *Sustainability*, 16(9), 4021. <https://doi.org/10.3390/su16094021>
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101. <https://doi.org/10.1191/1478088706qp063oa>
- Bühler, F., Fendt, L., Wittenberg, T., & Hamper, J. (2024). Smart circular economy in healthcare: Introducing the 9R framework. *Journal of Cleaner Production*, 418, 140128. <https://doi.org/10.1016/j.jclepro.2024.140128>
- Camilleri, M. A. (2025). Cocreating value through open circular innovation strategies: A results-driven work plan and future research avenues. *Business Strategy and the Environment*, 34(4), 4561–4580. <https://doi.org/10.1002/bse.4216>
- Cano, R., et al. (2025). Advancing the circular economy of healthcare plastics. *Resources, Conservation & Recycling*.
- Carreira, R. J., Ferreira, J. V., & Ramos, A. L. (2024). Circular economy challenges in Portuguese SMEs within the healthcare sector. *Sustainability*, 16(16), 7009. <https://doi.org/10.3390/su16167009>
- Corte-Real, S., Silva, R., Alves, D., & Pimenta, N. (2022). Management of medical sharps by diabetic patients in Portugal: A cross-sectional study. *International Journal of Environmental Research and Public Health*, 19(17), 10876. <https://doi.org/10.3390/ijerph191710876>
- Costa, L., & Fernandes, M. (2024). Circular economy in the Portuguese healthcare sector: Regulatory challenges and strategic opportunities. *Revista Portuguesa de Saúde Pública*, 42(1), 15–27.



- Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). Sage.
- D'Alessandro, C., Szopik-Decpzyńska, K., Tarczyńska-Luniewska, M., Silvestri, C., & Ioppolo, G. (2024). Exploring circular economy practices in the healthcare sector: A systematic review and bibliometric analysis. *Sustainability*, 16(1), 401. <https://doi.org/10.3390/su16010401>
- da Silva, J., Mendes, R., & Teixeira, L. (2024). Circularity in medical devices: Regulatory barriers and solutions. *Journal of Healthcare Innovation*, 12(2), 145–160.
- Dovetail. (2024). *User research and insights platform* [Software]. <https://www.dovetailapp.com>
- Esquivel, J. (2019). Circular cities and sustainable health transformation. CORE. <https://core.ac.uk/download/pdf/303772824.pdf>
- European Commission. (2023). *The European Green Deal and circular health systems*. European Parliament.
- Fernandes, M. (2024). *Circular economy in the healthcare sector: Application in rehabilitation equipment* [Master's thesis, University of Coimbra]. <https://estudogeral.uc.pt/retrieve/276322>
- Ferreira, A. P., Dias, C., & Fernandes, M. (2020). Waste management practices in regional hospitals in the Algarve. *Revista Portuguesa de Saúde Pública*, 38(2), 144–152.
- Fetters, M. D., Curry, L. A., & Creswell, J. W. (2013). Achieving integration in mixed methods designs: Principles and practices. *Health Services Research*, 48(6 Pt 2), 2134–2156. <https://doi.org/10.1111/1475-6773.12117>
- Firmino, J., & Poggi, A. (2024). Eco-design of rehabilitation equipment: The role of 3D printing. *Journal of Sustainable Design*, 10(1), 50–68.
- Glover, J., Champion, D., Daniels, K., & Denny, S. (2024). Healthcare entrepreneurship: An integrative framework. *Journal of Business Research*, 169, 114278. <https://doi.org/10.1016/j.ibusres.2023.114278>
- Granlund, M., Stirbu, D., & Mikkonen, K. (2024). Regulating artificial intelligence medical devices: Circularity, learning systems and accountability. *Health Policy and Technology*, 13(2), 100815. <https://doi.org/10.1016/j.hlpt.2024.100815>
- Health Care Without Harm Europe. (2024). *Reprocessing as a vital component of greener healthcare: EU focus Denmark*.
- Henriques, G. (2022). *Sustainability and the circular economy: Impacts on the healthcare system in Portugal*. ProQuest. <https://search.proquest.com/openview/b2285316f1859aaeca47088173d52136/1>
- Hoveling, T., Nijdam, A. S., Monincx, M., Faludi, J., & Bakker, C. (2024). Design strategies for circular medical devices. *Resources, Conservation & Recycling*, 208, 107719. <https://doi.org/10.1016/j.resconrec.2024.107719>
- Huijben, J., & van Raaij, E. (2025). ESCH R: Study design and methodology for accelerating hospital circular interventions. *PMC*.
- Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualising the circular economy: An analysis of 114 definitions. *Resources, Conservation & Recycling*, 127, 221–232. <https://doi.org/10.1016/j.resconrec.2017.09.005>
- Lemos, M. (2023). *Geoenvironmental study and sustainability in rehabilitation equipment in Brazil* [Master's thesis, University of Minho].
- Mayer, K. (2025). Opportunities and challenges of implementing circular strategies in the German medical device industry. *Journal of Cleaner Production*.
- Meister, J. A., Sharp, J., & Wang, Y. (2022). Assessing long-term medical remanufacturing emissions with life cycle analysis. *arXiv*. <https://arxiv.org/abs/2211.15519>



Moshawih, S. (2025). Transforming healthcare sustainability: Circular economy frameworks and quantification of interventions. *Journal of Sustainable Health Systems*.

NoHarm Global. (2024). *Case study: Aarhus University Hospital — Circular procurement for plastics*.

Omer, R., Lemos, M., & Zhang, X. (2025). Eco-efficiency in rehabilitation devices: A lifecycle approach. *Journal of Circular Health Technologies*, 3(1), 22–44.

Organisation for Economic Co-operation and Development. (2023). *Circular health systems: Aligning healthcare with sustainability goals*.

Quitmann, C., Richter, F., Müller, A., & Schmid, A. (2025). Assessing greenhouse gas emissions in hospitals: Development of an open-access GHG calculator. *Journal of Hospital Carbon Management*, 2(1), 1–14.

Riker, J. (2023). *Circular economy and public management in the healthcare sector* [Master's thesis, Federal University of Amazonas]. [https://tede.ufam.edu.br/bitstream/tede/9800/2/DISS\\_JoabeRiker\\_PPGEF.pdf](https://tede.ufam.edu.br/bitstream/tede/9800/2/DISS_JoabeRiker_PPGEF.pdf)

Saha, S., Dutta, S., & Kharbanda, O. P. (2025). Circular healthcare systems: Pathways to climate-neutral hospitals. *Resources, Conservation & Recycling*, 205, 107843. <https://doi.org/10.1016/j.resconrec.2024.107843>

Sepetis, A., & Parlavantzas, N. (2025). Organisational behaviour and circular economy adoption in healthcare. *Journal of Sustainable Health Management*, 6(1), 33–48.

Tashakkori, A., & Teddlie, C. (2010). *Mixed methodology: Combining qualitative and quantitative approaches*. Sage.

Vanguard. (2025). *Denmark allows reprocessing of single-use medical devices* [Information note].

Velenturf, A. P. M., & Purnell, P. (2021). Principles for a sustainable circular economy. *Sustainable Production and Consumption*, 27, 1437–1457. <https://doi.org/10.1016/j.spc.2021.02.018>

Zocco, F., Sleath, D., & Rahimifard, S. (2024). Towards a thermodynamical deep-learning vision-based robotic cell for circular healthcare. *arXiv*. <https://arxiv.org/abs/>

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