TU Delft

CIRCULAR INNOVATION IN IN-HOSPITAL PATIENT MONITORING

Rethinking the End-to-End Value Chain for Sustainable Healthcare

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MSc Thesis Integrated Product Design
Delft University of Technology | August 2025

Digital Health in the Circular Economy

PHILIPS

CIRCULAR INNOVATION IN IN-HOSPITAL PATIENT MONITORING:
Rethinking the End-to-End Value Chain for Sustainable Healthcare

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Preface

Sustainability has shaped both my academic journey, as well as my activities outside of the classroom from the very beginning of my time in Delft. For my final master's project, it was clear to me that I wanted to integrate this passion into a project with real world impact. When I came across the opportunity at Philips, it immediately felt like the right match. It allowed me to combine my interest in sustainability with the complexity and societal importance of healthcare, a sector for which my interest was sparked by the clinicians in my family growing up.

This project pushed me to grow, not only as a designer but also as a systems thinker. It taught me to approach design through a strategic lens, to think beyond the physical object, and to design for impact that lasts. I leave this journey with a sharpened sustainability toolkit and a deeper understanding of what it means to design for circularity within real world intricacies. Looking ahead, I feel excited and motivated to carry these skills forward and keep exploring how circular design can drive meaningful change.

Conny and Tamara, thank you for guiding me with such clarity and encouragement. You challenged my thinking, helped me raise the bar, and always had the right words and advice to keep me from getting lost in the project, which I appreciate.

Caroline and Margot, thank you for your trust in my capabilities, for always cheering me on, and for being wonderful and warm colleagues. You made me feel part of the team from the very start and gave me the right tools to shape this project into something I am proud of.

Carla and Ankur, thank you for taking the time each week to spar, reflect, and guide. You were always just a Teams call away with in-depth knowledge, helpful feedback, or expert connections, and it made all the difference.

To everyone at the Gelderse Vallei Hospital, the Reinier de Graaf Hospital, and the Princes Maxima Centre, thank you for welcoming me and allowing me to observe across the various departments. These experiences brought the context to life and ensured the project stayed rooted in reality. And to all the other experts from Philips, Karlinska Hospital, MIREC, Binder, Rivertex and University of Ghent, thank you for allowing me to interview you all, and for all the insights you provided.

Mom, thank you for giving me every opportunity in life and for always being there for me. To my friends in Delft, thank you for sharing this student experience and for all the joyful memories. And lastly to my girlfriend, thank you for being by my side as we both navigated our graduation projects, for sharing the highs and the lows, and for the wonderful person you are.

Enjoy reading!

Jamil Badloe

Executive summary

The healthcare sector is under increasing pressure. It must reduce its environmental footprint, while it must also maintain the highest standards of patient care. The use of in-hospital monitoring sensors, which are mostly low-cost, single-use devices, results in a significant amount of medical waste. However, the options for recycling these sensors are limited due to concerns regarding infection risks, logistical challenges, and use of legacy business models. This thesis looks at how circular design can be used strategically to improve in-hospital monitoring sensors' lifecycle impact. This is done through a case study redesign of the Philips Gentle Care NiBP cuff as an example.

Adopting a research-through-design approach, the project integrated insights from environmental lifecycle impact, user research, value proposition and future context to pinpoint critical intervention points at product and system levels throughout the cuff's end-to-end value chain. The findings showed that environmental impact is concentrated in the production and end-of-life phases, while impact during the use phase is minimal. The use of single-patient-use cuffs is done as a measure for infection prevention, but uncertified workflows currently dictate non compliant use and incorrect disposal, which compromises both safety and sustainability goals. The insights led to a system-first approach in which multiple circular scenarios were explored. Of these, local reprocessing was identified as the most viable option, offering a balance between infection prevention, operational feasibility and circular performance. The proposed redesign, called Revo Care, incorporates a smart collect-and-dispense system for non-invasive blood pressure (NiBP) cuffs within high-acuity treatment rooms. This facilitates efficient workflows and encourages circular behaviour. RFID technology enables smart inventory and use tracking, resulting in lean and traceable systems, while a performance-based business model ensures viable implementation.

On a product level, the NiBP cuff was redesigned for full recyclability through a monomaterial polypropylene construction, eliminating fused multi-materials that previously made end-of-life recovery challenging. An new fastener system reduces the cuff's physical footprint, while clearly defined sizing and placement indicators improve usability and measurement accuracy. The use of a detachable hose connector minimises material use over multiple patients and enables the effective separation of materials at the end-of-life. These design interventions resulted in a 76% reduction in manufacturing impact, and a sixteenfold reduction in lifecycle impact when combined with the new local reprocessing system. For hospitals, the system supports growing sustainability targets while ensuring high infection control standards. For nurses, circular practices are reinforced through the seamless integration into existing workflows, improving ease of use. For manufacturers such as Philips, the shift to a performance-based business model creates a viable business case as it aligns the shift in value from volume to circular and safe performance.

This thesis concludes that circular innovation in clinical settings requires more than a sustainable product. It demands system integration, behavioural alignment, and viable economic models. Rather than relying on ideal user behaviour, circular design must be enabled through infrastructure, stakeholder coordination, and system-enforced compliance. Although this project is based on NiBP monitoring in the Dutch healthcare system, the strategic design principles, system enablers and product interventions proposed in this project offer a generalisable foundation for applying circular strategies across a broader range of in-hospital monitoring sensors.

Figure 1: Sneak preview render of the Philips Revo Care NiBP concept

Glossary

Arterial blood pressure - The force of the blood pushing against the walls of the arteries as the heart pumps blood. It is made up of two values: systolic and diastolic.

Circular Economy - A systems solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution. It is based on three principles, driven by design: eliminate waste and pollution, circulate products and materials (at their highest value), and regenerate nature.

Circular Recovery Flows - CRFs are circular strategies with specific steps that illustrate how materials and devices are efficiently collected, processed, and reintroduced into the economy.

Clinical deterioration - The worsening of a patient's condition that precedes serious adverse events such as cardiac arrest, ICU admission, or death.

Consumables - Medical supplies that are used once or have a limited lifespan, requiring frequent replenishment.

Diastolic blood pressure - The pressure in the arteries when the heart is relaxed (diastole).

Disability Adjusted Life Year - One DALY represents the loss of the equivalent of one year of full health.

Disposables - Devices that are intended for one use, or on a single patient during a single procedure.

Hemodynamic monitoring - The monitoring of blood pressure.

Healthcare-Associated Infections - Infections acquired by patients during their stay in a hospital or another healthcare setting.

Acuity Settings (High vs. Low) - Acuity in healthcare refers to the severity and complexity of a patient's condition and the intensity of care they require.

In-hospital monitoring sensors - Medical sensing devices used within hospital settings to collect patient physiological parameters, used for clinical decision making, diagnosis, and treatment support.

ISO 10993 - An international standard for evaluating the biocompatibility of medical devices.

Medical Device Regulation 2017/745 - A legal framework established by the European Union (EU) to govern the design, manufacture, and placing on the market of medical devices within the EU.

Medical device - Products or equipment intended for a medical purpose.

Medical waste - A subset of waste generated at healthcare facilities, which may be contaminated by blood, body fluids, or other potentially infectious, hazardous or radioactive materials.

NiBP cuff - A medical device, usually placed on the upper arm, used to measure a patient's blood pressure non-invasively.

Non critical medical devices - Medical devices that come into contact only with intact skin and not mucous membranes or sterile tissue.

Non-invasive - Relating to any medical test or treatment that does not cut the skin or enter any of the body spaces.

Patient monitoring - The continuous or periodic observation, measurement, and recording of a patient's physiological parameters to assess health status and detect clinical deterioration.

Disinfection - The process of removing micro-organisms, including potentially pathogenic ones, from the surfaces of inanimate objects.

Systolic blood pressure - The pressure in the arteries when the heart contracts (systole).

Abbreviations

- **ABP** Arterial Blood Pressure
- **BoM** Bill of Materials
- **CE** Circular Economy
- **CRFs** Circular Recovery Flows
- **DALY** Disability Adjusted Life Years
- **DiCE** Digital Health in the Circular Economy
- **DMU** Decision making unit
- **ED** Emergency Department
- **GHG** Greenhouse Gas
- **GW** General Ward
- **HAIs** Healthcare-associated infections
- **ICU** Intensive Care Unit
- **MDR** Medical Device Regulation
- **NiPB** Non-invasive Blood Pressure
- **OEM** Original Equipment Manufacture
- **OR** Operating Room
- **PACU** Post-Anesthesia Care Unit
- **RFID** Radio Frequency Identification
- **SUDs** Single-use-devices

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1. Project Outline

Figure 2: Context NiBP monitoring in use (Philips, 2025)

1.1 Introduction

In-hospital monitoring sensors are a critical component of modern-day healthcare, as they enable continuous tracking of vital signs, such as blood pressure, oxygen saturation and pulse rate. Next to that, they improve diagnostics and provide real-time insights into the patient's health. This results in improved conditions for patients, enhanced care accessibility and overall efficiency in healthcare practices (Chan et al., 2012; Eberly et al., 2020; Kang & Exworthy, 2022). In-hospital monitoring sensors in this thesis are scoped as medical sensing devices used within hospital settings to collect patient physiological parameters, used for clinical decision making, diagnosis, and treatment support. However, despite their benefits, the rise of in-hospital monitoring devices also raises questions regarding sustainability, as these sensors are typically designed for a linear make-take-waste approach (DiCE, 2025). As the healthcare sector accounts for 4,6% of global greenhouse gas emissions, redesigning healthcare services for circularity is a critical step towards environmentally sustainable healthcare systems (Hu et al., 2022; MacNeill et al., 2020).

The transition towards more circular healthcare systems, meaning healthcare systems that minimize waste and keep materials in use for as long as possible, requires a fundamental shift in how medical devices are designed, used, and disposed of (Kane et al., 2018). Additionally, challenges exist in balancing circularity with stringent healthcare hygiene and safety requirements, alongside a lack of economic incentive for supply parties, and a perceived ease of use and efficiency of disposable consumables for hospitals (Hoveling et al., 2024; MacNeill et al., 2020). As a result, the majority of these sensors end their lifecycle as incinerated medical waste, which work against goals of the healthcare sector to achieve environmental sustainability goals (European Commission, 2025; Kenny & Priyadarshini, 2021).

This master's thesis addresses the question of how to improve the circularity of in-hospital monitoring sensors, with a particular focus on non-invasive blood pressure (NiBP) monitoring cuffs, as shown in Figure 2. This form of in-hospital patient monitoring remains the most widely used technique for monitoring blood pressure, making it a ubiquitous medical device in hospitals (Sanchez et al., 2020). It functions by placing a NiBP cuff around a patient's arm, which inflates and deflates, to sense a patient's blood pressure. It is a form of blood pressure monitoring that is reliable, easy to use and safe, and because of it, used in almost all departments of the hospital. The market for NiBP monitoring is a large and rapidly growing one, which will grow from a 500-million-dollar market size in 2023 to a projected 850 million dollar by 2031 (Philips, 2023). Its ubiquitous hospital use and large market size, together with the vast amount of waste the disposable NiBP cuffs produce each year, make it a valuable product to research circular redesign solutions.

1.2 Problem definition

The Philips Gentle Care NiBP cuffs are designed as single-patient-use devices intended for in-hospital monitoring of blood pressure, which is one of the core vital signs to monitor for patient stability (Philips, n.d.). These cuffs are commonly used in high acuity settings, like the Intensive Care Unit (ICU), Operating Room (OR), Post-Anesthesia Care Unit (PACU) or Emergency Department (ED). The use of single-use cuffs instead of reusable cuffs is done because single-use disposable cuffs provide a hygienic solution that reduces the risk of cross-contamination between patients. Additionally, single-use NiBP cuffs are an attractive proposition from an operations perspective, as they provide a linear and streamlined workflow, better patient specific sizing and reduced human error in disinfection compared to reusable cuffs (Philips, n.d.).

The flipside of these advantages of single-patient-use NiBP cuffs, is the up to 30 times as high environmental burden compared to reusable alternatives (Keil et al., 2022; Sanchez et al., 2020). High-income nations rely increasingly on linear supply chains composed of single-use disposables, which result in increased healthcare related costs, waste and pollution (MacNeill et al., 2020). These cuffs are a prime example of that. They are disposed, after being used on a single patient, as hazardous medical waste and incinerated, contributing to GHG emissions and material loss. Moreover, the cuffs are manufactured with mixed material components, making them inherently challenging to recycle. From an economic perspective, the business model is centred around an environmentally unsustainable linear one, with the continuous sale of newly produced disposable cuffs.

This situation presents challenges for circular redesign solutions for both the product and system. Designing sustainable alternatives require not only looking at the environmental impact, but also the patient safety, hospital and regulation requirements, as well as the business perspective. As hospitals are increasingly demanding more sustainable practices from manufacturers, circular redesign solutions are needed for the 30+ year old design of the current Philips NiBP Gentle Care cuffs. These solutions should reduce the environmental impact, while maintaining the safety, performance and user needs demanded in clinical care to ensure effective and safe adoption of the product. The findings from this case study could provide insights for similar in-hospital monitoring sensors, shifting the healthcare sector to a more environmentally sustainable future. This thesis addresses the urgent need to redesign single-use NiBP cuffs into a circular product-service system that balances sustainability with clinical safety and operational feasibility, while serving as an inspiration for integrating circularity in in-hospital patient monitoring sensors.

1.3 Parties involved

This master's thesis is part of work package 2, task 2.5 for the larger EU-funded consortium Digital Health in the Circular economy (DiCE). DiCE aims to address the issues of the increasing environmental challenges posed by digital health devices, by guiding the medical sector towards a more circular future (DiCE, 2025).

Among this consortium Philips is a specifically important stakeholder within this project. This thesis revolves around researching circular redesign solutions for a Philips case study product, namely the Gentle Care NiBP cuff. The findings from this case study will be applied to a confidential Philips monitoring sensor, which will be discussed in a confidential Appendix. Philips is a global health technology company which originates from the Netherlands. They are the global market leader within the hospital patient monitoring market with a market share of 40%.

The Delft University of Technology serves as another key stakeholder, since it is a partner within the DiCE consortium, but also as the project is a graduation thesis for the master's program Integrated Product Design from the Industrial Design Engineering (IDE) faculty of the Delft University of Technology (TU Delft).

This thesis serves as the final step towards achieving a Master of Science (MSc) in Integrated Product Design at the Delft University of Technology (TU Delft) in the Netherlands. The TU Delft supervisory team consists of Prof. Dr. Ir. C.A. Bakker as academic chair and Ir. T. Hoveling as academic mentor. The company supervisory team consists of Philips business analyst M. Honkoop and senior consultant C. Allard.

Project goal:

"Developing redesign solutions to improve the circularity of in-hospital NiBP monitoring cuffs, to generate insights and recommendations for circular design in similar in-hospital patient monitoring sensors."

1.4 Goals and deliverables

The goal of this master's thesis is to generate insights and recommendations for circular design in in-hospital patient monitoring sensors. This will be achieved through a redesign case study of NiBP monitoring cuffs, in particular the Philips Gentle Care NiBP cuff range. This focus is chosen, as DiCE work package 2 task 2.5 consists of the redesign of a to be released Philips in-hospital patient monitoring sensor. While insights for this undisclosed sensor will be generated within this thesis, they will be published in a confidential Appendix. As the Philips Gentle Care NiBP cuff range has both functional and contextual similarities with the undisclosed sensor, findings from this case study will be highly transferable and can be made public within this thesis. By focusing on the NiBP cuff, this thesis contributes to the potential valorisation of two currently non-circular products in hospital care.

The thesis will include developing redesign solutions of the NiBP cuff, for the European market on both a product and system level, without fundamentally altering the measurement technology or clinical functionality of the device. In this redesign, the user, meaning hospital staff, hospitals and patients; the future context of 2030; value proposition; and environmental impact along the end-to-end value chain will be considered. Findings will be evaluated in terms of transferability to the broader scope of in-hospital patient monitoring sensors.

DELIVERABLES

The deliverable of this thesis will be threefold:

1. The first deliverable will be product and/or system level circular redesign solutions for the Philips NiBP Gentle Care cuff range, which consider the environmental impact, value proposition, user needs and future context.

2. The second deliverable will be to review the methods for designing for circularity, while extrapolating key insights from the research to apply to similar in hospital monitoring sensors.

3. The third deliverable will be to apply the lessons learned from the first two deliverables onto a confidential Philips monitoring sensor, to propose circular redesign solutions. As this sensor is still highly confidential, this deliverable will not be made publicly available within this thesis report.

1.5 Approach and methods

While it is widely recognized that Circular Economy (CE) principles must be incorporated in medical devices to reduce the healthcare sector's significant environmental footprint, their implementation is challenging. These challenges mainly revolve around sector-specific requirements, like strict safety, performance and regulatory requirements, which are covered more in-depth in chapter 2.3. These are needed because of the high stakes involved in clinical care, as neglecting them could cause harm to patients, and in the worst case, be fatal (Kane et al., 2018). As decision making regarding medical devices will always prioritize patient outcomes, safety and costs, the design approach of environmentally conscious options should integrate these (Sanchez et al., 2020).

SUSTAINABLE NORTH STAR APPROACH

To ensure the safe and effective adoption of the proposed circular redesign, a holistic approach is therefore needed. To gain grip and structure on the complex and different topics which need to be tackled during this project, an adapted version of the Sustainable North Star approach is applied throughout this thesis, as developed by Accenture (2023). This approach provides a structured manner to effectively analyse a product on a system, user and product level over the end-to-end value chain. The findings are converted into relevant design guides, which help in the design phase to create sustainable and innovative solutions (Accenture, 2023). It does so by breaking design for sustainability up in fundamental questions across the categories: environmental impact, user needs, value proposition and future trends, as can be seen in Table 1.

ADJUSTMENTS

While the Sustainable North Star Approach will be used throughout this thesis, some adjustments were made. For example, the approach states that a multidisciplinary team with expertise in LCA's, user research, user experience, engineering, and system design is necessary. However, since this thesis is an individual project, the roles will be fullfilled by myself, with expertise input whenever necessary.

The project will span the course of 20 weeks, starting from March 2025 up until August 2025, totalling 100 workdays.

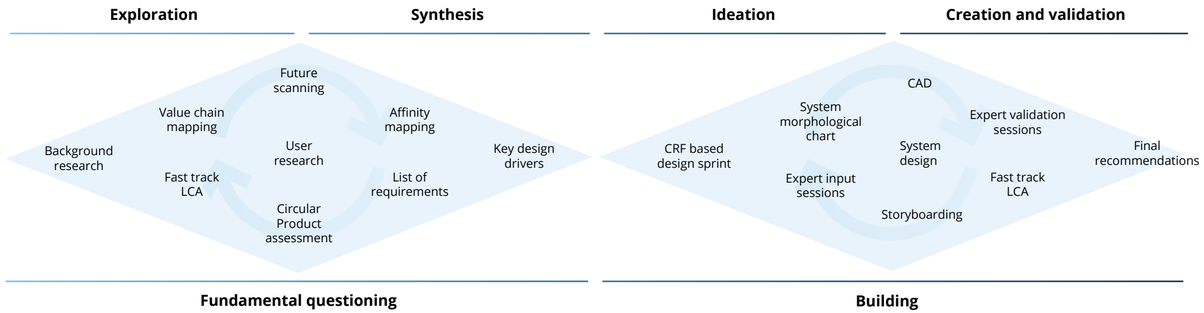


Figure 3: Project approach overview

EXPLORATION

The exploration phase is about researching the fundamental questions, which give insights in the barriers and opportunities hollistically across the categories: environmental impact, user needs, value proposition and future trends, as can be seen in Table 1. This gives an exhaustive insight into the full product and system context.

SYNTHESIS

In the synthesis phase, the large quantity of insights are gathered and focused into managable and actionable key design drivers and requirements to which the final solution must adhere.

IDEATION

After the synthesis phase, there is a clear starting point to diverge into possible solutions, through ideation and expert input on both a product and system level.

CREATION AND VALIDATION

In this final part, the final solution is formed, made tangible and lastly validated with experts and a final comparative fast track LCA for final recommendations.

Table 1: Fundamental questions and methods

Fundamental questions	Method	Explanation of method
What are the product characteristics and how do these shape the opportunities and constraints for circular design in NiBP cuffs?	Value chain mapping	Value chain mapping is the process of identifying the flow of materials throughout a product's lifecycle (Accenture, 2023). This is done through desk research and expert interviews with the Philips NiBP Product Manager and and Philips Global Downstream Product Manager Hemodynamics.
	Fast track LCA	An efficient environmental analysis to estimate the carbon footprint of a product throughout its lifecycle and identify environmental impact contributors. This is done with the Idemat database (2024) . Input data was compiled through internal Philips documentation and expert meetings with the Philips NiBP Product Manager. Results were discussed and validated through expert meetings with a Philips LCA expert.
	Circular Product Assessment	The product's readiness for circularity is assessed through the Circular Product Readiness Tool, developed by Boorsma et al. (2022). It assesses how effective a company is in the transition towards circularity, based on the NiBP cuff, to uncover the product's and Philips' strengths and weaknesses. Input data was provided by two Philips patient monitoring Product Managers.
How do the stakeholder's operations and needs shape the the opportunities and constraints for circular design in NiBP cuffs?	User research	A method to gather knowledge about the context of the product in use. This involves gathering insights from end-users and stakeholders to understand their needs, behaviour and decision-making in a real-world context. Data was gathered through literature research, internal documentation of Philips and expert meetings with the Philips NiBP product manager, Philips Global Downstream Product manager Hemodynamics and Philips Account Manager Medical Consumables. Next to that, staff within three hospitals (De Gelderse Vallei, Reinier de Graaf, and Princess Maxima Center) were interviewed and shadowed across different departments.
How does the future context shape the opportunities and constraints for circular design in NiBP cuffs?	Future scanning	A strategic method to incorporate the future world the proposed design will be part of (TNO, n.d.). This consists of exploring emerging trends, technologies and contextual shift, that may influence the future relevance and viability of a product and/or system. Future scanning will incorporate how the future context of tech, regulation, sustainability and healthcare itself could hinder or drive circularity in NiBP cuffs.

2. Background context

2.1 The impact of modern day healthcare

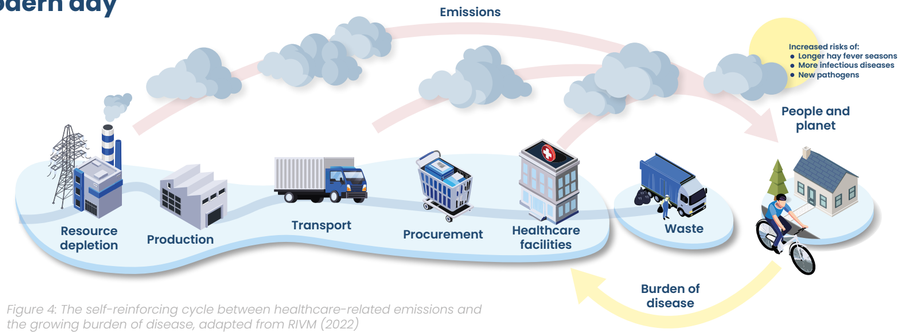


Figure 4: The self-reinforcing cycle between healthcare-related emissions and the growing burden of disease, adapted from RIVM (2022)

While healthcare is fundamentally aimed at improving human health, it paradoxically adversely affects people's health, by being a major emmiter of environmental pollutants (Sherman et al., 2020). Globally, the sector is responsible for approximately 4,6% of greenhouse gas (GHG) emissions, which reach 7,3% in the Netherlands (MacNeill et al., 2020; Steenmeijer et al., 2022). This makes the healthcare sector one of the top contributors to climate change, making it a sector detrimental to limiting global temperature rise to 1,5 °C (The Intergovernmental Panel on Climate Change, 2018). It even exceeds the GHG emissions of all of aviation and shipping combined, sectors that are often prominently criticised for their environmental impact (Karliner et al., 2020). In the US, the pollution the healthcare sector is responsible for, account for up to 614.000 disability-adjusted life-years (DALYs) lost annually (MacNeill et al., 2020). This puts an increasingly higher pressure on healthcare services, leading to a vicious cycle of more climate change, as can be seen in Figure 4.

A driver of this impact is the sector's heavy reliance on linear lifecycle- and single-use consumables (MacNeill et al., 2020; Rijksoverheid, 2022b). Hospitals generate an average of 5.5 kilograms of solid waste per bed per day, increasing to 7.1 kilograms in ICUs due to higher use of disposables (Prasad et al., 2022). As global populations grow and become relatively older, demand for healthcare services is expected to rise, further intensifying resource use and environmental pressure, unless sustainable efforts are adopted (MacNeill et al., 2021; OECD, 2025; United Nations, 2022).

In response, governments and healthcare institutions have begun acknowledging their role in the climate crisis and are taking steps towards action. In the Netherlands, the Green Deal on Sustainable Healthcare 3.0 represents a formal commitment between the national government and healthcare stakeholders to move towards green, climate-neutral healthcare. The agreement emphasizes key themes such as reducing material consumption through the reuse of more materials and a reduction in the use of new materials and resources wherever possible (Rijksoverheid, 2022a).

Sustainability, once a secondary design consideration, is now becoming a procurement priority. As healthcare is shifting towards more sustainable practices, there is a growing demand from hospitals for medical device manufacturers to meet clearly defined sustainability criteria (Personal communication, Philips, 2025). This shift signals that environmental responsibility must extend beyond clinical care to include the entire healthcare value chain, including the design and production of medical devices, to align on the fundamental mission of improving people's health.

2.2 The circular economy

Many of the issues discussed in the previous chapter arise from the healthcare sector's, and much of the global economy's, reliance on a linear model of resource use called the linear economy. This consists of extracting raw materials, manufacturing products, and ultimately discarding them as waste. This make-take-waste approach contributes significantly to the degradation of the environment, for which a solution could be the restorative circular economy (CE) (Ellen MacArthur Foundation, n.d.; European Commission, 2025; Kane et al., 2018). The CE aims to retain the value of materials and products within the economic system for as long as possible. This is done by either lengthening the product's effective lifespan, or by "looping" them back into the system, resulting in zero waste, due to an infinite cycling of the resources (den Hollander et al., 2017). In other words, the CE aims to "design out waste" (Hoveling et al., 2024). By transitioning to this approach, society can move towards a sustainable future, meaning a future where the social, environmental and economic aspects of society and the planet are in equilibrium (D'Alessandro et al., 2024).

Within this thesis, the model of the CE for the healthcare sector is used, developed by Hoveling et al. (2023) for DiCE work package 2.1, as simplified in Figure 5. It builds on established frameworks such as the Butterfly Diagram (Ellen MacArthur Foundation, n.d.) and the 9R-strategies (Potting et al., 2017), by tailoring it towards the healthcare sector. Circular Recovery Flows (CRFs) are organised in a hierarchy, prioritising strategies that retain the highest product value. In general, the more strategies that can be combined, the better. However, their effectiveness depends on the product and context, so each intervention must be carefully evaluated to conclude that the proposed interventions have the intended effect.

The full Circular Recovery Flow Taxonomy and flow descriptions can be found in Appendix A.

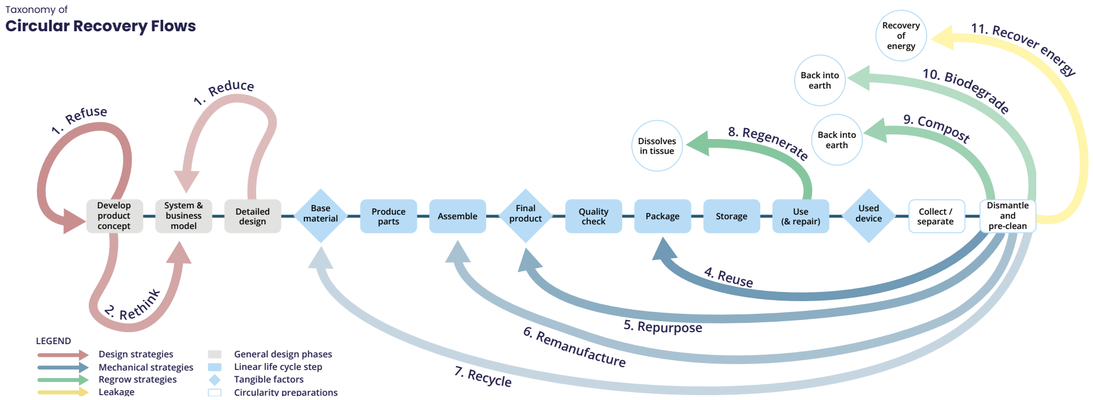


Figure 5: Visual Taxonomy of Circular Recovery Flows, adapted from Hoveling et al. (2023)

Table 2: Priority in Circular Recovery Flows and their definitions

1.	Refuse	Make device redundant by abandoning its function or by offering the same function in a radically different, more sustainable device.
2.	Rethink	Make device use more intensive (e.g. through sharing products, or by putting multi-functional products on the market).
3.	Reduce	Increase efficiency in product manufacturing or use by consuming fewer natural resources and materials.
4.	Reuse	Reuse by another customer (or for another patient in healthcare) of discarded product which is still in good condition and fulfills its original function (in healthcare, often after cleaning processes).
5.	Repurpose	Use discarded product or its parts in a new product with a different function.
6.	Remanufacture	Restore a discarded product and bring it up to date or use parts of a discarded product in a new product with the same function.
7.	Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality.
8.	Regenerate	During or after use, the material is dissolved into nature through tissue regeneration. This applies to regenerative medicine and is currently not applicable to electronic components in itself.
9.	Compost	Materials that can safely be returned to the biosphere are used in the production of the device, to enable processes that together help regenerate natural capital, such as composting and anaerobic digestion.
10.	Biodegrade	Collect the device or parts of the device (=partly biodegrade) after the use cycle to break down materials by naturally occuring micro-organisms. Contrary to composting, for biodegradation no specific rules apply.
11.	Recover energy	Incineration of materials with energy recovery.

2.3 Healthcare specific barriers

Designing for circularity of in-hospital patient monitoring sensors faces several product and healthcare specific barriers. Based on the healthcare-specific circularity barriers defined by Hoveling et al. (2024), the key challenges fall into safety, regulatory, systemic, financial, technological, and social barriers. The full list of applicable barriers for this case study specifically for NiBP cuffs, adapted from Hoveling et al (2024), can be found in Appendix B.

BARRIERS DURING CLINICAL USE

In high acuity settings, like the ICU and OR, infection prevention is a top priority. Single-use-devices (SUDs) are widely perceived as the safest option, as they cannot be subject to inadequate cleaning, and since they reduce time pressure for clinical staff. Within hospitals clinicians and nurses are primarily focused on providing patient care, and are unaware of the environmental impact of SUDs. The ingrained belief that SUDs equals safer use, which does not necessarily have to be the case (this will be discussed in chapter 4.2), further complicates the acceptance of reusable alternatives.

LOGISTICAL BARRIERS

On a logistical level, hospital wastestreams are often set up around linear disposal. Many materials used in the OR or ICU, including often NiBP cuffs, are classified as potentially infectious medical waste and are therefore incinerated, even when not contaminated (Windfeld & Brooks, 2015). This limits the possibilities for circular End-of-Life (EoL) strategies.

MEDICAL DEVICE BARRIERS

Medical devices are subject to strict regulation, where even minor design or material changes can trigger lengthy and costly re-certification processes under Medical Device Regulation (MDR) 2017/745 and ISO 10993. Next to that, NiBP cuffs provide clinicians with vital information about a patient's health status, where there can be no compromises in terms of product performance. Lastly, NiBP cuffs are relatively inexpensive consumables. These regulatory, technological, and financial barriers make reprocessing or redesigning the product economically unattractive.

2.4 NiBP monitoring

Blood pressure is the force with which blood pushes against the walls of the arteries as the heart pumps. This pressure is determined by the volume of blood pumped by the heart into the arteries, the resistance of the artery walls and the blood-flow rate out of the arteries (Magder, 2018). Blood pressure is highest whenever the heart contracts (systolic pressure) and lowest when the heart is at rest (diastolic pressure). Blood pressure, along with pulse, respiratory rate, oxygen saturation and temperature, is one of the core vital signs of a patient's health, offering key insights in the state of a patient before, during and after surgeries (Brekke et al., 2019). Insights in a patient's blood pressure gives clinicians vital information about the patient's cardiovascular status, with the ability to accurately predict clinical deterioration. Through early detection timely measures can be taken, resulting in a decrease in preventable in-hospital cardiac arrests (Churpek et al., 2016).

Because of the vital information blood pressure gives clinicians, the monitoring of blood pressure, named hemodynamic monitoring, is standard practice in all departments of the hospital. The most common method is non-invasive blood pressure (NiBP) monitoring using an upper arm cuff connected to a patient monitor (Lakhal et al., 2018). With this method, in a measurement time of approximately 45 seconds, which can be done automatically and periodically, insights can be given for the systolic arterial pressure, diastolic arterial pressure, mean arterial pressure, pulse rate, heart rate and pulse pressure variation (personal communication, Philips, 2025). In Figure 6, an overview of how NiBP cuffs measure these parameters is shown. An overview of base design requirements for NiBP cuffs can be found in Appendix C.

NiBP monitoring can be performed using either reusable or disposable cuffs. Both are equally accurate, but differ in cost, logistics, infection control, and environmental impact.

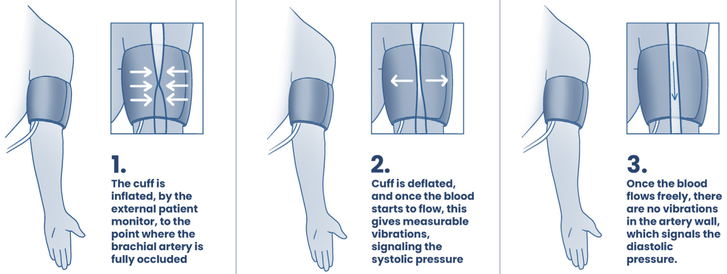


Figure 6: Operational stages of NiBP cuffs

MULTI-PATIENT-USE NIBP CUFFS

Reusable cuffs are designed and rated to withstand repeated cycles of use and disinfection for up to 3,5 years. These types of cuffs are used in approximately 75% of use cases in hospitals (M. Bendon, personal communication, 2025) and are in general the preferred choice for low- to moderate-acuity settings, like the general wards. Though their purchasing cost is approximately a tenfold higher, they offer lower long-term operational expenses. For example, a large US based academic hospital saved approximately 250.000 euros by transitioning from disposable cuffs to reusable cuffs in non-acute areas (Montgomery, 2016). Additionally, reusable cuffs have a significantly smaller environmental footprint during their lifecycle, which is up to 30 times lower than single-patient-use cuffs in ICU settings.

SINGLE-PATIENT-USE NIBP CUFFS

While the use of reusable cuffs seems compelling from a cost and environmental perspective, because of concerns for infection risks, some hospitals choose to use disposable cuffs as a replacement for the traditional reusable cuffs. This trend can also be seen in other medical devices, where disposable versions are superseding reusable alternatives (Sanchez et al., 2020; MacNeill et al., 2020). Disposable single-patient-use NiBP cuffs are assigned for a maximum of 21 days to a single patient during their hospital stay and are discarded after use. Because of this, these cuffs do not need to be cleaned in between different patient uses, decreasing the risk of cross-contamination. In high-acuity settings, like the OR and ICU, these cuffs can therefore be preferred.

2.5 Concluding chapter insights

This chapter gave insights in the need for the implementation of the circulary economy, what the circular economy is, what the specific challenges are for implementing this in a healthcare specific context for NiBP cuffs, and how the fundamentals of NiBP monitoring work. Figure 7, showcases the main opportunities and constraints derived from this chapter.

OPPORTUNITIES	CONSTRAINTS
Sustainability within healthcare is becoming increasingly important	Infection prevention is non-negotiable in high acuity settings
Implementing prioritized and combined CRFs promotes circularity	Compliancy with MDR 2017/745 and ISO 10933 are essential
Raising environmental awareness for effective circularity adoption	NiBP cuffs are and will remain indispensable in healthcare
Rethinking economic models for viable CE implementation in healthcare	

Figure 7: Opportunities and constraints from the background context analysis

3. Product analysis

3.1 Philips Gentle Care cuff

The focus of this thesis is on the case study product of Philips' NiBP Gentle Care adult cuffs, as it has the highest overlap with the confidential sensor that will also be tackled in the confidential Appendix. This NiBP cuff is sold by Philips and is used in hospitals worldwide and is a single-patient-use product. NiBP cuffs, when classified under the EU Medical Device Regulation (MDR) 2017/745, are a Class I medical device under Rule 1 of MDR Annex VIII. This makes cleaning protocols less stringent and sterilization not needed, in contrast to invasive devices. Products within this range are available in three adult sizes, respectively small adult, adult, and large adult.

Due to the increased urgency of the healthcare sector to move towards more sustainable options, Philips wants to update and redesign the current design of the NiBP Gentle Care cuff, so that it is more up to date in terms of user needs and manufacturing, while being future proof in terms of sustainability.

This includes redesigning the cuff for circularity, updating the look and feel of the product, and integrating new materials and technologies. An overview of the components is given in Figure 8. A detailed overview table of the Bill of Materials (BoM) can be found in Appendix D.

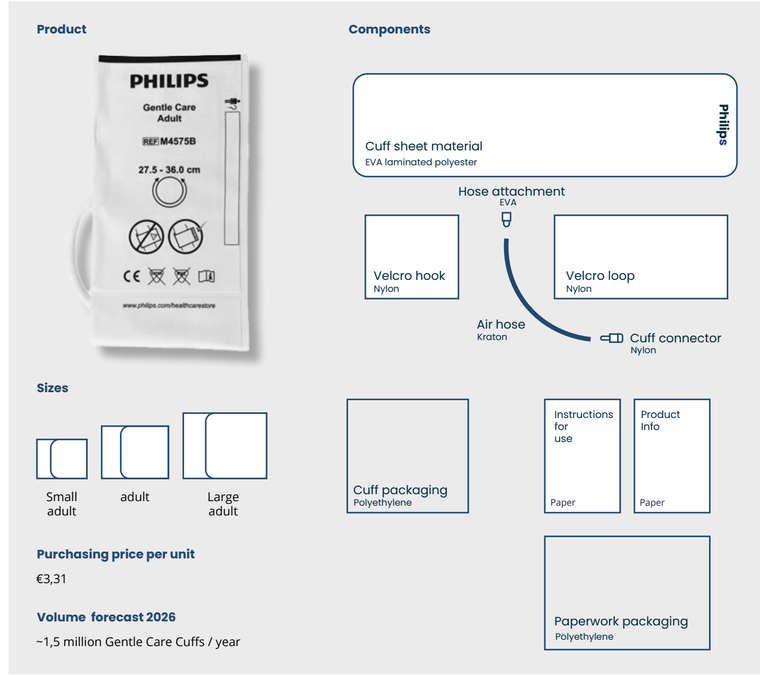


Figure 8: Overview of the Gentle Care NiBP cuff

3.2 Value chain map

To gain a better understanding of the flow of materials and the processes involved over the complete product's lifecycle, an overview of the complete value chain was compiled. This value chain also serves as an important base for the input and scope for the fast track LCA in chapter 3.3.

The scope consisted of mapping all lifecycles of the Philips Gentle Care Adult NiBP cuff, with a focus on the up- and downstream of the value chain. Within chapter 4.3, a more elaborate focus will be lain on the middle-stream in the user research. As starting materials for the cuff are often supplied to Philips through external suppliers, where Philips does not have influence on the extraction and production flows, the value chain often starts with main materials and components. Extraction and production of raw materials is therefore not included. While the Gentle Care cuffs are sold worldwide, the middle- and downstream are focused on the Netherlands.

KEY TAKEAWAYS

- Permanently fused materials and components prevent circular recovery flows during and after use.
- Paper instruction booklets are typically discarded before reaching the actual users, posing unnecessary waste.
- Each cuff includes an unnecessary extension hose, adding avoidable material use.
- Cuffs are often disposed of as medical waste, limiting recovery options after use.
- The current business model is fully linear and based on volume sales.
- The product composition is fairly simple, without any electronics, beneficial for circularity.

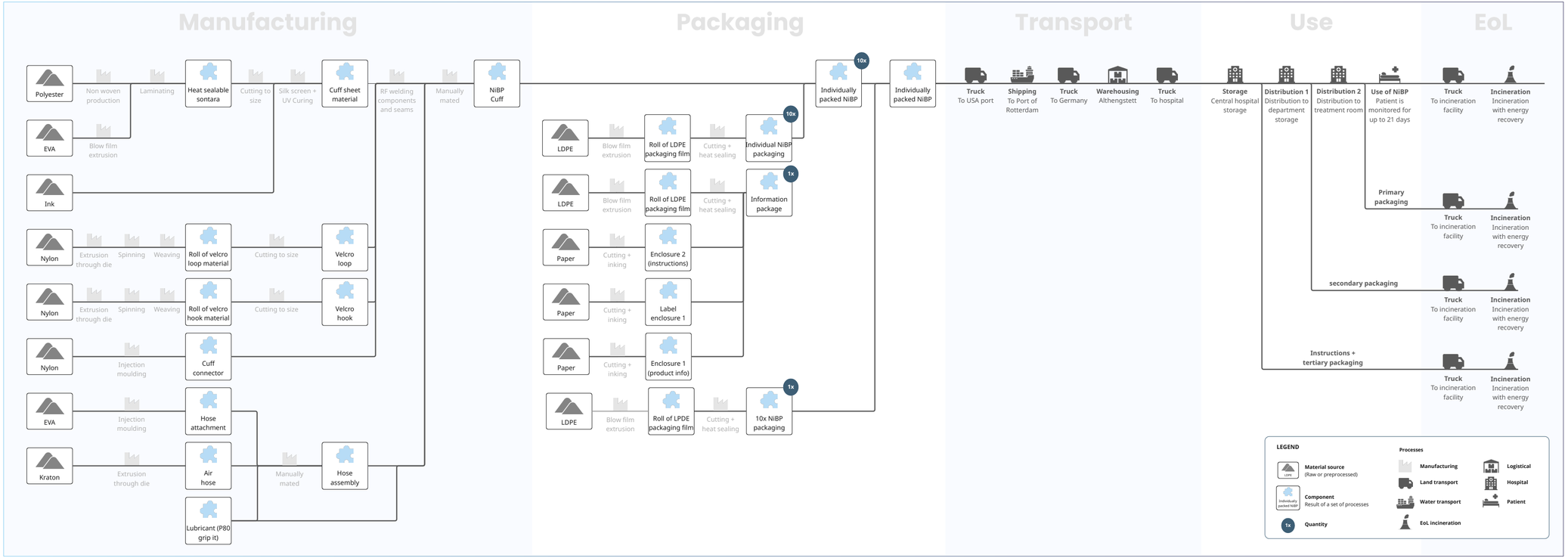


Figure 9: Value chain map of the Philips Gentle Care NiBP cuff

3.3 Product lifecycle impact

A Life Cycle Assessment (LCA) is an internationally standardized (ISO 14,040) modelling tool that was used to evaluate the environmental impact of the gentle care NiBP cuff, along the entire life cycle. This is from the raw materials, up to production and use, to eventually its end-of-life, commonly referred to as Cradle-to-Grave. This thesis makes use of a Fast track LCA method, using the IDEMAT 2024 database (Sustainability Impact Metrics, 2025). This is done because of the limited time available in this project, but also as indepth LCA input data was not available. While more assumptions are made in this method, van de Hoven (2015) argues that it still gives accurate results, as "it is based on formal databases and since it is calculated according to the general rules of LCAs".

RESULTS

For the Gentle Care Adult NiBP cuff, the total Life Cycle Carbon footprint is approximately 0,55kg CO2eq per piece. In Figure 10, the environmental impact over the categories "Materials and Manufacturing", "Transport", "Use" and "End of Life" can be found, as well as the specific environmental impact every specific material and process. The in-depth calculations and assumptions can be found in Appendix E.

Out of the entire lifecycle footprint, the raw materials have the highest contribution to the environmental impact, with 39,6% (of which 92% from the material in the product, and 8% from the packaging), followed by manufacturing processes, which contribute 33,6%. The next highest contribution comes from the EoL, with a 24,7% contribution. Transport contributes to 2% (of which upstream contributes to 99,9% and downstream to 0,1%) and the use phase to an insignificant 0,0%.
These hotspots showcase that to decrease the environmental impact effectively, measures must be taken to reduce the environmental impact produced by the raw materials and the EoL. The EoL has an unexpectedly high contribution to the environmental impact, which can be explained by the product being discarded as medical waste, together with other potentially hazardous materials. This results in the product being processed as hazardous waste and incinerated. This makes collection and separation impossible, negating the possibility to implement circular strategies after the use-phase.

FUNCTIONAL UNIT

lifecycle carbon footprint (kg CO2 equiv.) for a single-patient-use NiBP cuff, doing 6 days of continuous in-hospital measurements on a single patient (approximately the average duration of stay (personal communication, , Philips 2025).

SCOPE

The scope of the LCA is done in accordance with the detailed value chain as described in Figure 9 in chapter 3.2. The BoM used can be found in Appendix D. While a hospital patient monitor is needed to do the actual hemodynamic monitoring, the physical product was left out of scope during the use phase, as redesigning the monitor itself is out of scope for this thesis. Energy consumption from the monitor for the inflation and deflation of the cuff was however included, as this is essential for the cuff to work as a sensor. System boundaries can be defined as the high-level overview of the value chain map in Appendix E.

ASSUMPTIONS

See Appendix E for a full list of assumptions and calculations.

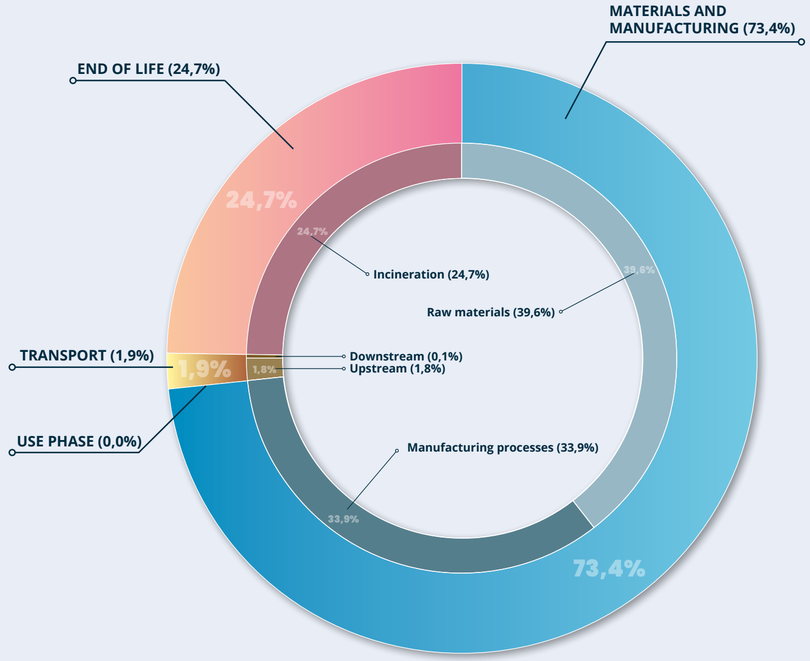
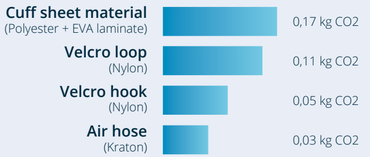


Figure 10: Visual representation of LCA impact for the Gentle Care NiBP cuff

TOTAL LIFECYCLE IMPACT
0,55 kg CO2 equiv. / Gentle Care cuff

HIGHEST IMPACT MATERIALS

Based on the actual mass in the product



KEY TAKEAWAYS

- Medical waste incineration is the single highest impact process at 24,7%.
- Energy use during clinical use for 6 days is insignificant at 0,0%.
- The Materials and manufacturing phase has the highest lifecycle impact contribution at 73,4%.
- Polyester, nylon and kraton are high impact materials within this product due to their relativley high mass and because they are relatively high impact materials.

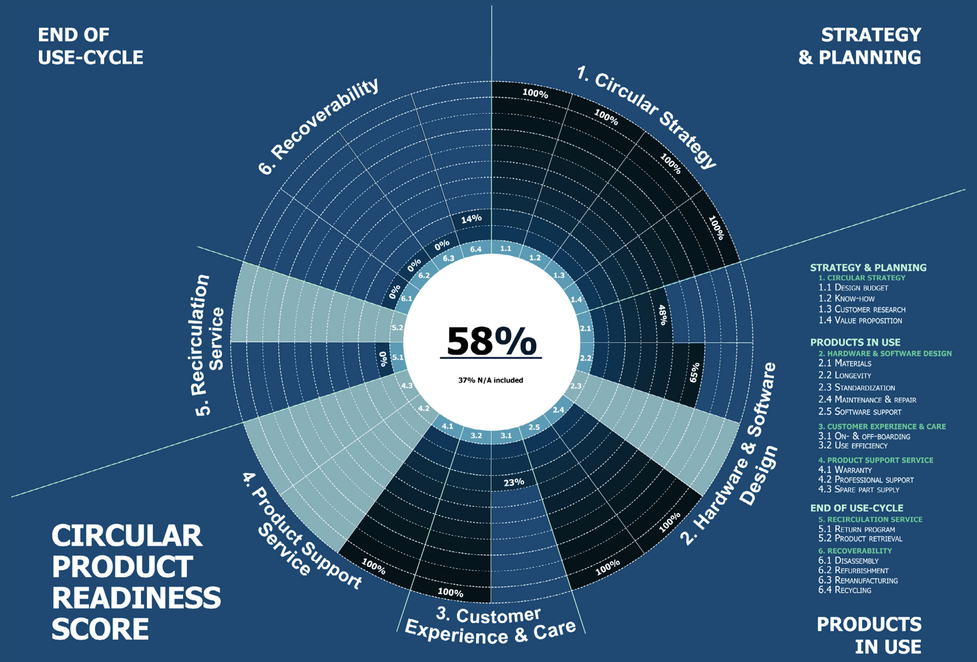


Figure 11: Visual overview of the circular product readiness results for the Genlte Care NiBP cuff

3.4 Circular product assessment

The Circular Product Readiness tool, is a method developed by Boorsma et al. (2022) and was used to gain an understanding about circularity indicators on a product-level in terms of levels of circularity readiness, company strengths and opportunities for improvement over the full life-cycle, while also exposing the circularity barriers Philips still faces. The assessment consists of a questionnaire of 63 questions, which fall under 6 circular design themes. The themes and indicators can be found in Figure 11.

RESULTS

A graph showcasing the results of the Circular Product Readiness assessment for the Philips Gentle Care NiBP cuff can be found in Figure 11. The in-depth answers on the questionnaire can be found in Appendix F. The Gentle Care cuff indicated a circular readiness of 58% or 37,2% when the N/A categories are included.

The product scores particularly high in the circular strategy category, at 100%. This is due to Philips' companywide sustainability targets, giving departments access to sustainability budgets and expertise. This is a driver for sustainable design in Philips products and encourages departments to integrate circularity into its designs.

In terms of hardware and software design, the product scores a 72%. Points are mostly scored, based on the product being a relatively simple product, without any critical or conflict materials. However, it loses points due to the product not having recycled, reused or biodegradable materials, contains hard to separate composites and does not have sustainable packaging. Due to the product being a medical device, there are stringent performance requirements, which could explain why it scores relatively high on longevity and maintenance. However, these scores assume a comparison to the market of single-patient-use cuffs. Next to that, repair is not included, as the product is a disposable product. If reusable cuffs and repair would be included, the overall hardware and software design score would go down from 72% to 41%.

For the customer experience and care, the product scores a 61,5%. This is mainly due to the product being a medical consumable, making communication about effective, reliable and safe use needed. Since it is a medical consumable, the majority of questions do not apply.

Product Support Service scores a 50%. As the product is a disposable product which cannot be serviced, support for maintenance, repair and upgrades does not apply. Additionally, as the product is made by several components which are fused together, the product is sold as a single product. Therefore, spare parts do not exist, and is therefore also not applicable. Were these to be included, the score for this category would fall to 17%.

For the Recirculation Service category, the product scores a 0%. The product is disposable, and Philips does not have its own, or supplier party who handles a return program. Used products are discarded as medical waste and incinerated.

Finally, for Recoverability, the product scores 3,5%. Once again, as the product is a disposable product, disassembly is not considered. Refurbishment and remanufacturing are also not implemented, which could be due to the low economic value of this consumable. Recycling is not done, as the product is discarded (unnecessarily) by clinical staff together with other potentially hazardous medical waste, making recycling impossible.

KEY TAKEAWAYS

- The product's simplicity and lack of conflict and critical materials benefits circularity and should be preserved in future designs.
- The product does not include circularity focused materials in the product or packaging.
- Repairs and maintenance, including product upgrades, are not possible due to the linear disposable design.
- Material recovery is not feasible, as all components are permanently fused.
- Strategically, Philips is well positioned, with the right R&D capabilities to implement circularity.
- There is no existing recirculation service at Philips for low value disposables like NiBP cuffs.

3.5 Concluding chapter insights

This chapter provided insights into the case study product, detailing the material composition and flow of the Gentle Care cuff, its environmental impact, and Philips' readiness to implement circularity in NiBP cuff design. Figure 12, showcases the main opportunities and constraints derived from this chapter.

OPPORTUNITIES	CONSTRAINTS
Redesigning the product to avoid mixed, fused materials enables improved material separation and post-use circular recovery flows.	-
Shifting from disposal as medical waste to alternative end-of-life strategies	
Lowering environmental impact within the manufacturing phase through less and lower impact materials.	
Maintaining product simplicity.	

Figure 12: Opportunities and constraints derived from the product analysis

4. Clinical use analysis

4.1 Stakeholder overview

To understand the use context of NiBP cuffs in hospitals, it is necessary to know which stakeholders come into contact with NiBP cuffs throughout its lifecycle inside of hospitals. A comprehensive stakeholder analysis was conducted to identify who are involved in the full lifecycle of NiBP cuffs, and what their roles and priorities are.

Stakeholders can be divided into two catagories, namely decision making units (DMUs) and users, as showcased in Figure 13. As the main users in hospitals are mainly not the decision makers for procurement, it is important to also adress these DMUs. Table 3 showcases an overview of these stakeholders, their roles, and their priorities regarding NiBP cuffs in hospital settings.

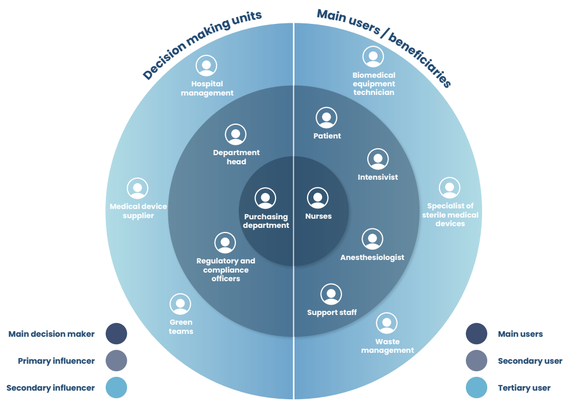


Figure 13: Stakeholder map for NiBP cuffs in clinical use settings

Table 3: Overview of takeholders, their roles, and circularity priorities

Stakeholder	Role description	Priorities
Purchasing department	Selecting and procuring NiBP cuffs from suppliers	Cost-efficiency, regulatory compliance, logistical reliability
Department head	Managing clinical protocols, approving device types for departments	Workflow efficiency, budget alignment
Hospital management	Strategic oversight, budget allocation, sustainability policy enforcement	Balance between cost, effectiveness, strategic alignment and sustainability goals
Medical device supplier	Supplying of NiBP cuffs, as well as technical support	Product performance, competitive advantage, regulatory conformity
Biomedical equipment technician	Managing functionality, maintenance and compatibility of monitoring systems	Reliable performance, technical compatibility with monitor
Nurse	Applying and monitoring NiBP cuffs during patient care, ensuring correct sizing and placement, managing supply and restocking of cuffs in clinical rooms, cleaning and preparing rooms between patients	Ease of use, workflow efficiency, patient safety
Anesthesiologist	Continuous monitoring of patient status during surgery and induction	Accuracy, actionable and timely patient data, patient comfort
Intensivist	Monitoring of patients	Measurement reliability, infection risk minimization, patient safety
Specialist of sterile medical devices	Assessing cleaning protocol compliance, and assessing reprocessing potential	Hygiene assurance, efficient and hygienic workflow
Patient	Undergoing monitoring during treatment without complications	Comfort, safety, non-invasiveness, privacy, hygiene
Support staff	Supplying the centralized ward supplies, and end-of-day logistics and cleaning	Clear handling procedures, infection containment
Waste management staff	Collecting, sorting, and disposing of used equipment	Safety, compliance with hazardous waste protocols
Green teams	Promoting and implementing sustainable practices, evaluating product lifecycle impacts	Reducing waste, increasing reuse/recycling, aligning with green policies
Regulatory and compliance officers	Ensuring that all medical devices and processes comply with legal, safety, and regulatory standards	Legal compliance, proper documentation and certification

An important aspect within the stakeholder analysis is that the end-user of the medical device, such as nurses and intensivists, are not necessarily the decision-makers in terms of what products they use, and how they should handle them after use. These decisions are often dictated by purchasing departments, in consultation with department heads, hospital management and compliance officers, who must account for budgetary, legal and strategic considerations. Although the primary users do influence decision makers, the product preferred by those using it in practice may not be supplied to them by procurement. This adds a layer of complexity for the circular redesign, as the product must not only align with direct user needs and clinical workflows, but also with the interests of a diverse group of decision makers.

KEY TAKEAWAYS

- The procurement and supply stakeholders emphasize the need for cost-effective, compliant and logistically efficient products and workflows.
- Stakeholders within the clinical use phase put a focus on ease of use, hygiene, infection control, accuracy and reliability needs.
- Post-use handling underlines the need for efficient and safe logistical flows at the end of life.

4.2 Perceived safety risks

Before diving into the use cases within hospitals, it is necessary to understand the (perceived) necessity for some hospitals to use single-patient-use cuffs instead of reusable ones.

The choice for disposable NiBP cuffs is often lead by the perception of reduced infection risks compared to reusable NiBP cuffs. However, is this perception in this instance valid? NiBP cuffs are classified as non-critical medical devices, meaning those that come in contact with intact skin, but non mucous membranes (CDC, 2008). This means that only a minimum low-level disinfection is necessary by legislation (Sanchez et al., 2020; Kane et al., 2018). However, NiBP and other non-critical medical devices, have been increasingly linked to healthcare-associated infection (HAI), or nosocomial infection, which are infections acquired during treatment of other conditions within a healthcare setting (Uneke & Ljeoma, 2011; de Gialluly et al., 2016). In multiple studies, reusable blood pressure cuffs were found to have high rates of bacterial colonization (Uneke et al., 2014; De Gialluly et al., 2016; Zimmerman et al., 2018; Walker et al., 2006; Gorrido-Molina et al., 2023). At the skin contact side of the cuff, bacterial growth was higher (Grewal et al., 2013). General Wards (GWs) had the lowest microbial burden, while ICUs cuffs exhibited the greatest growth due to more frequent handling of the cuffs, paired with a proximity to patients who may carry infections. Moreover, the NiBP cuff can act as a source of reinfection when dedicated to a single patient (De Gialluly et at., 2016), making single-patient-use NiBP cuffs also susceptible to HAIs.

However, studies also show that when reusable NiBP cuffs are properly decontaminated through methods intended for non-critical medical devices, that this is adequate in decreasing microbial contamination, thus preventing HAI transmission (Zimmerman et al., 2018; Matsuo et al., 2013). Effective cleaning makes them a safe, cost effective and environmentally friendly alternative to disposable cuffs.

In practice, however, this is currently often not done. NiBP cuffs are listed as the ninth most-touched item in clinical care (Cheng et al., 2015), with cleaning being often not done frequently and thoroughly enough. This has several reasons. First, the item is categorized as a non-critical device, which makes clinical staff also treat it as such, resulting in the neglect of cleaning guidelines (Uneke et al., 2014). Second, due to the high workloads, responsibilities and priorities clinical staff face, disinfection can be rushed or overlooked (Johnson et al,. 2021). While reusable NiBP cuffs could be used throughout the whole hospital as a safe alternative to disposable NiBP cuffs, effective cleaning must thus be ensured, to mitigate HAIs.

As multi-patient-use is a more sustainable method than single-patient-use for NiBP cuffs (Sanchez et al., 2020), and can in theory be done safely in high acuity settings, both scenario's will be analysed.

TAKEAWAYS

- Misconceptions about safety risks make reusable cuffs less desirable in high-acuity settings.
- HAI risks from reusables are primarily caused by inconsistent or improperly followed disinfection protocols.

4.3 Product journey map

To better understand the practical application of NiBP cuffs in hospitals, the flow NiBP cuffs go through in hospitals from procurement to the end-of-life need to be investigated. A product journey mapping was made to visualize this comprehensively, which helps to identify which stakeholders interact with the product at each stage, and what interesting issues and priorities arise. Supporting contextual in-hospital photographs are shown in Appendix G.

Within hospitals, there are two different product flows possible. One where hospitals use single-patient-use cuffs, and one where hospitals use multi-patient-use cuffs. In Figure 14, the product journey map is given for the single-patient-use NiBP cuff.

SINGLE-PATIENT-USE FLOW

Two out of the three hospitals observed used single-patient-use NiBP cuffs in high acuity settings, with the intention of limiting infection risks. However, in practice, both hospitals routinely reused the cuffs beyond their intended purpose on multiple patients. Use ranged from one week in one case, to a month in the other. This extended use, beyond what the product is certified for, had two factors. First, logistically, for a time pressured nurse, retrieving a new cuff at the departments supply room is inefficient. As a result, it is easier for them to quickly wipe down the cuff between patients, though several admitted the cleaning is done often inadequately. Second, while infection prevention staff wanted high acuity departments to use single-patient-use cuffs, departments cut costs in their budgets by extending the use time of these cuffs, even though this compromises both hygiene and product performance. Next to the extended reuse, each package of 10 disposable NiBP cuffs comes with two information booklets, which are discarded immediately. While providing the information is required, doing so in paper form is redundant and ineffective. Lastly, cuffs are often discarded as medical waste, regardless of actual contamination. This default classification, driven by efficiency and staff unawareness, prevents the implementation of CRF strategies at the end-of-life, as medical waste is legally mandated to be incinerated.

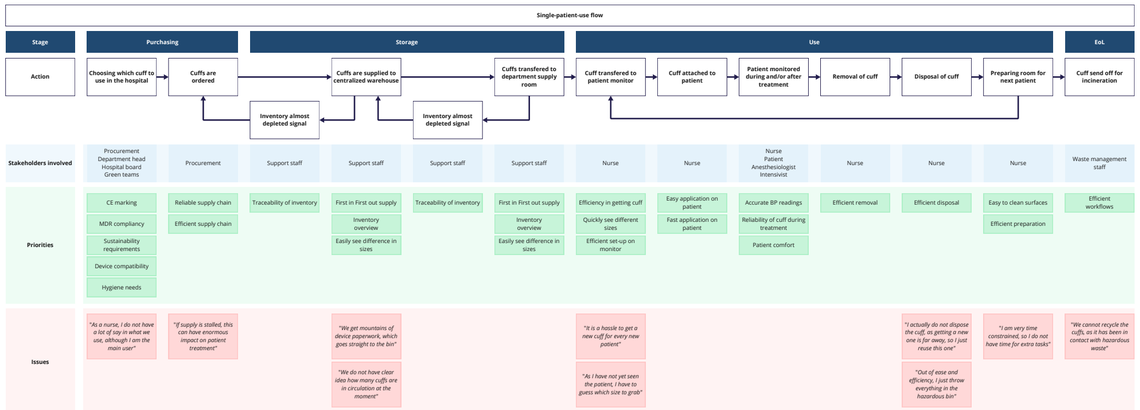


Figure 14: Product Journey Map of single-patient-use NiBP cuffs in clinical settings

MULTI-PATIENT-USE FLOW

While the multi-patient-use flow, used by one of the three observed hospitals, has quite some overlap with the previous flow, it differs slightly in the treatment phase. In Figure 15, an overview of this phase is given.

The main difference that can be seen is that instead of direct disposal of the cuff after use on a patient, is that the cuff is cleaned by nurses and reused. This has several implications, which give different issues compared to the single-patient-use flow. One issue is that although correct sizing is necessary for accurate blood pressure measurements, nurses tend to default to the medium size already attached to the monitor. As long as the cuff closes around the arm and the monitor gives a reading, they do not go through the hassle of interchanging the cuffs to the correct size. Additionally, due to time pressure and high workloads, cleaning done by nurses is often rushed or insufficient, increasing the risk of nosocomial infections. Next to that, the inadequate cleaning, combined with the lint attracting Velcro, hinders the product performance, as the accumulated lint inhibits the Velcro to close reliably. Moreover, there is no system for quality control or traceability. Cuffs are used repeatedly without monitoring their age or condition. This results in cuffs being discarded prematurely or past their certified use time. Often cuffs are used until they are visibly falling apart, or have become too dirty, when a nurse decides to discard of the cuff. The part that most often shows the first sign of wear and tear is the point where the hose connects to the NiBP cuff, resulting in advanced disposal.

KEY TAKEAWAYS

- The hook and loop fasteners complicate effective cleaning and compromise long term product performance.
- As nurses prioritise convenience, ensuring correct sizing, and thus accurate measurements, is an challenge in both current workflows.
- NiBP cuffs lack traceability of inventory and usage, causing non-compliant use.

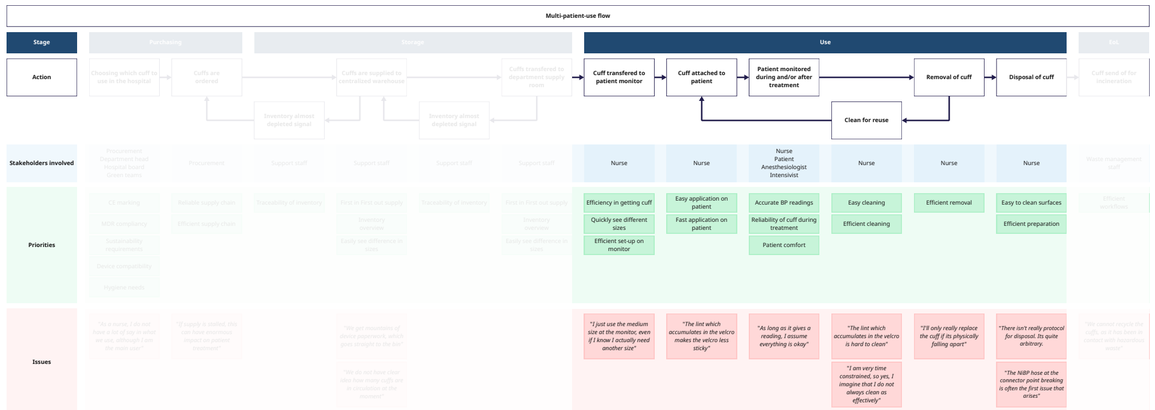


Figure 15: Product Journey Map of multi-patient-use NiBP cuffs in clinical settings

4.4 Future scanning

As a last step, the future context is analysed, to determine if contexts shift in the future, which may influence the redesign of NiBP cuffs and other in-hospital patient monitoring sensors of today. The future scan explored five domains, namely society, economy, regulation, technology, and environment over the short (0 - 5 years) and long term (5 - 10 years). The findings are summarized in Figure 16, while a detailed description of each finding is detailed in Appendix G.

RESULTS

The next decade will see a growing pressure on hospitals and their staff, due to an aging and growing population and increased climate related health threats (Sipos et al., 2024; WHO, 2023, 2024). At the same time, a younger, more climate-conscious generation entering healthcare may help accelerate the adoption of sustainable alternatives (Funk, 2021; Kanste et al., 2025). While SUDs are unlikely to disappear entirely in isolation treatments, rising sustainability targets are expected to reduce the demand for them (Saha et al., 2025). However, concerns about perceived infection risks will continue undermining trust in reusables. This suggests that improved education and transparency will be needed to support the adoption of circular alternatives in practice.

Economically, an increase in economic volatility and supply chain disruptions are pushing healthcare systems and medical device manufacturers to rethink their reliance on globally sourced disposables (Investor's Business Daily, 2025; McKinsey, 2024). Together with raw material costs rising, and new circular business models emerging, such as Healthcare as a Service, it is becoming economically more interesting to embed circular value propositions, both for manufacturers as for hospitals (Asumah, 2025; EY, 2023; Hossain et al., 2025; Rijksoverheid, 2025; Rodriguez & Moulins, 2022).

From a technological perspective, smart inventory systems with detailed traceability of products will emerge to better support lifecycle monitoring, enable smarter reuse, maintenance, and eventually recovery (European Commission, 2024a; WHO, 2024). Advances in biobased and recycled materials, cleaning methods, and smart fabrics will also enhance the performance and cleanability of medical products without compromising safety (EY, 2023; HPRC, 2022; Jarad et al., 2024).

As for the regulatory domain, sustainability is gaining traction as a regulatory priority. Governments, as well as hospitals, are increasingly adopting circularity criteria into tenders and compliance standards (Deloitte, 2023; European Commission, 2024b). Standardization of components and sustainability reporting through digital product passports is expected to play a crucial role in enabling cross compatibility and circularity on a system level (Carvalho et al., 2025; Götz et al., 2022).

As sustainability is becoming increasingly important, healthcare companies who integrate sustainability early on, are set to gain a competitive advantage in the near future (Huang, 2021; Rijksoverheid, 2022).

KEY TAKEAWAYS

- Smart inventory systems enable efficient and traceable inventory management and use.
- Rising pressure on the healthcare workforce will intensify time-related challenges already present in clinical workflows.
- Hospital procurement is increasingly prioritising sustainability, making circular medical devices a strategic necessity for Philips.

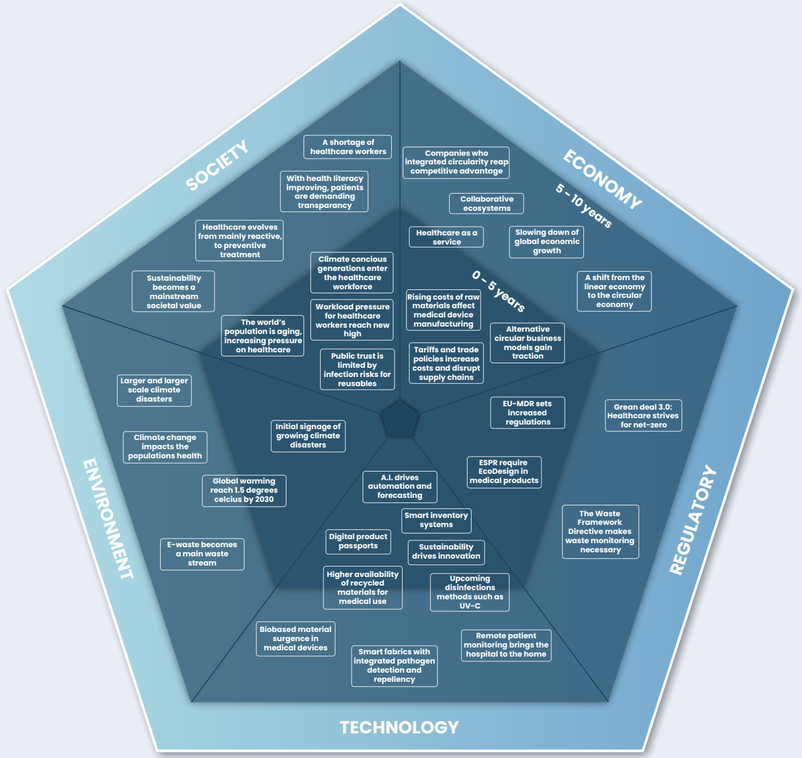


Figure 16: Visual representation of future scanning for the context of NiBP monitoring

4.5 Concluding chapter insights

This chapter provided insights into the case study product, detailing the material composition and flow of the Gentle Care cuff, its environmental impact, and Philips' readiness to implement circularity in NiBP cuff design. Figure 17, showcases the main opportunities and constraints derived from this chapter.

OPPORTUNITIES

Incorporating DMU priorities for procurement.

Addressing misconceptions and improving awareness about the safety of reusable consumables can support adoption.

Implementing infection prevention measures offers an opportunity to reduce (perceived) safety risks.

Adressing premature EoL and non compliant use issues.

Finding alternatives for conventional Velcro to decrease infection risks and increase product performance.

Relieving work pressure for time constrained nurses.

Smart future healthcare enables CE.

Incorporate sizing measures for more accurate measurements

CONSTRAINTS

Efficiency, safety, costs and performance are key priorities for effective implementation and adoption in hospitals

Figure 17: Opportunities and constraints derived from the product analysis

4.6 Fundamental questioning conclusions

To conclude all findings from the past three chapters, key design drivers were derived, which act as a starting point for the ideation phase. The process of extracting these design drivers through affinity mapping can be found in Appendix I.

The design drivers found will serve as the backbone for the redesign solution. Implementing them ensures a product that has a better value proposition than the current offering, both from a business as well as a clinical perspective, while focusing on optimizing circularity.

DESIGN DRIVERS

1. Ensure infection prevention

Without ensuring infection prevention, the solution will not be adopted.

2. Increase physical and system circularity

Product-level circularity is limited by the physical design, as well as systemic issues such as non-compliant use and disposal as medical waste.

3. Maintain product USPs

For effective adoption, the product must match or exceed current solutions in value, with efficiency, safety, cost, and performance as key selling points.

4. Adopt viable new circularity enabling business models

This is necessary to capture the value of the new proposition for a viable product service system. This also incentivizes stakeholders in circular practices.

5. Relief nurse responsibilities

Due to time pressure and workload, nurses may use NiBP cuffs non-compliantly, increasing HAI risks and compromising measurement reliability.

6. Sustain product circularity enablers

The product's simplicity and absence of critical or conflict materials support circularity and should be preserved.

7. Integrate smart systems

Smart systems enable inventory and usage traceability, supporting compliant use and effective implementation of CRFs.

8. Enhance product performance

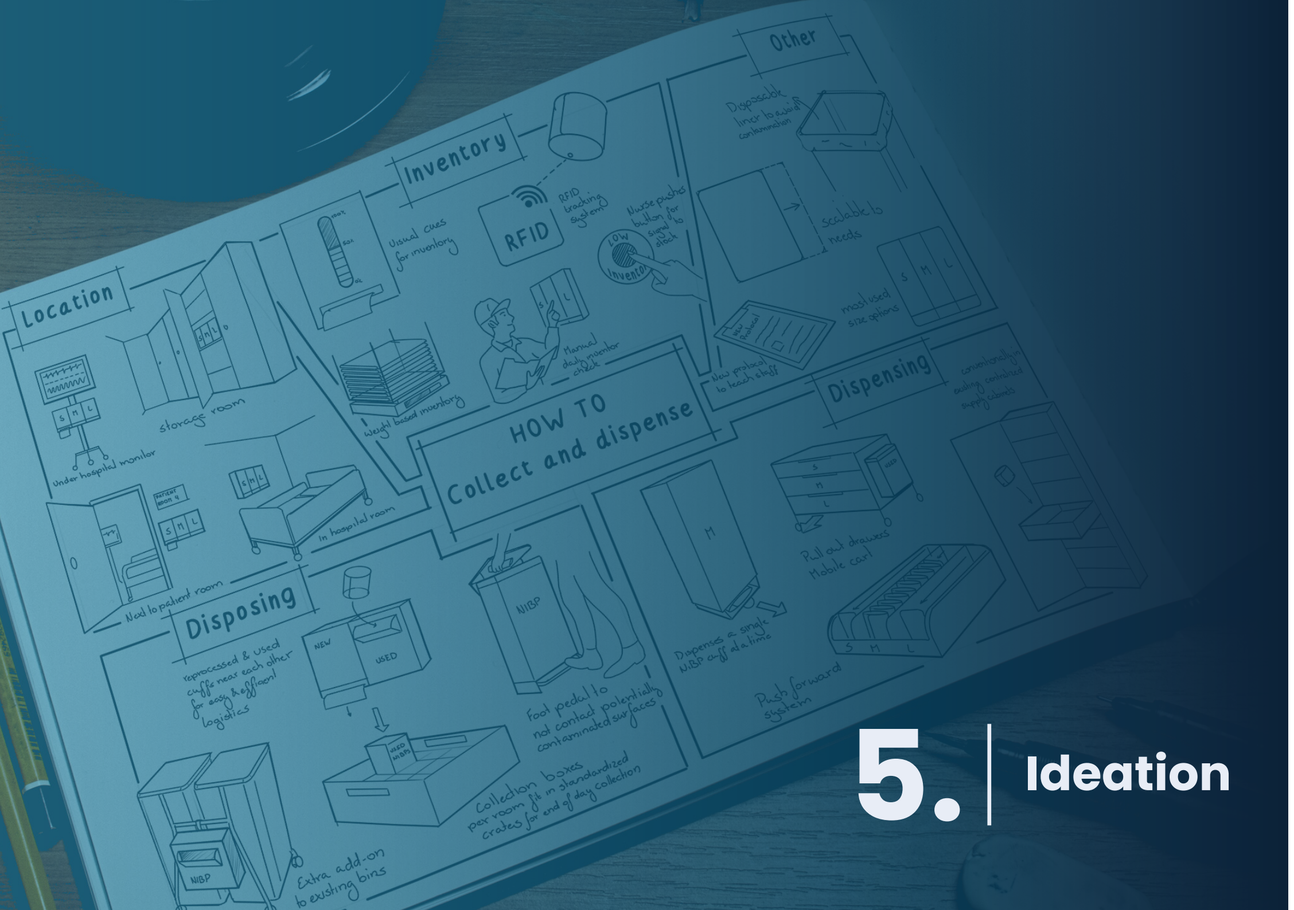
opportunities were found to enhance the user experience and clinical performance, strengthening the overall value proposition.

9. Integrate clear use cues and information for CE

Currently, misconceptions and lack of knowledge hinder the effective implementation of environmentally sustainable alternatives.

10. Leverage the need for sustainable offerings

Sustainability will increasingly be driven by regulation, making it a growing priority in healthcare procurement decisions.



5. Ideation

5.1 Design requirements

To further translate the research done into effective design solutions, a list of requirements is compiled. These requirements combine findings from throughout the first two phases of the design process into verifiable parameters to evaluate both the ideation phase, as well as the final redesigned product.
The requirements can be found in Table 4. They have been divided in product and system level design requirements spanning the following domains: Economic, Product performance, Regulation, Sustainability and User needs.

The full list with referencing and justifications as to why requirements were chosen can be found in Appendix J.

Economic requirements	Product/ system	Requirement/ Wish
The product and or system must incorporate viable business models	Both	R.
Product must be mass producable	Product	R.
Production costs should not exceed current production costs by 50%	Product	W.

Product performance requirements	Product/ system	Requirement/ Wish
The product and system must promote adequate cleaning	Both	R.
Must be an inflatable cuff around the upper arm	Product	R.
Must connect to standard Philips patient monitors	Product	R.
Must be non-invasive in nature	Product	R.
Must include an airtight rectangular bladder measuring 300x140 mm	Product	R.
Must be consistent in performance over its rated lifecycle	Product	R.
Material must be non elastic	Product	R.
Material must be fatigue resistant over its rated lifecycle	Product	R.
Material must conform to the upper arm contour	Product	R.
Cuff must be skin contact safe	Product	R.
Product must be effectively cleanable with low level disinfection	Product	R.
Nurses should be motivated to use correctly sized cuffs	Both	W.
Product should inhibit use beyond the rated use time	Both	W.

Table 4: Program of requirements and wishes for a circularity focused NiBP cuff

User need requirements	Product/ system	Requirement/ Wish
Workflow efficiency must be on par or better during patient treatment	Both	R.
Infection control must be guaranteed	Both	R.
Product performance must be on par or better than current solution	Both	R.
Perception of infection risks should be on par with the current solution	Both	W.
Perception of performance should be on par with the current solution	Both	W.
Should have similar or relieved workload for nurses	Both	W.
Product should include visually easy to discern sizes	Both	W.
Product should be the same or better in terms of patient comfort	Product	W.
Application and operations are as intuitive or better	Product	W.

Regulation requirements	Product/ system	Requirement/ Wish
Product must comply with skin compatability regulation ISO 10993	Product	R.
Product must be compliant with MDR 2017/745	Product	R.

Sustainability requirements	Product/ system	Requirement/ Wish
The lifecycle impact must be lower than the current product	Both	R.
Cuff must not end up as medical waste	System	R.
Must incorporate CE enabling business models	System	R.
Should include traceable inventory and usage data in a digital passport	Both	W.
Packaging waste should be limited	Both	W.
Manufacturing processes should minimize off cuts being incinerated	Both	W.
Should prevent cuff being discarded before it's rated use time	Both	W.
Should minimize the raw material impact	Both	W.
Should maximize product longevity	Both	W.
Should incorporate enabling CE smart technologies	Both	W.
Product should limit permanently fusing multiple different materials	Product	W.
Product should minimize the amount of components needed	Product	W.
Product should maximize the use of low lifecycle impact materials	Product	W.
Product should maintain its simplicity in manufacturing and components	Product	W.
Product should maintain the non use of conflict materials	Product	W.

5.2 System design

Before diving into the product design, it is needed to define in which system the to propose redesign solution will operate, as this determines which Circular Recovery Flows (CRFs) should be prioritised in the redesign. For example, a system where single-patient-use NiBP cuffs are used, a focus will lie on reducing the impact in the manufacturing and EoL stages, as these will be most impactful, as can be seen in chapter 3.3. However, if a multi-patient-use system is chosen, the priorities shift to enabling reuse, which prioritises sustaining product performance over longer times and safely reprocessing the cuff.

Within this chapter, 6 NiBP systems for high acuity settings in hospitals are explored and evaluated to determine the most positively impactful, desirable, feasible and viable solution. The systems consisted of the evaluation of two existing systems and four new systems. The two existing systems consisted of the current single-patient-use and reuse system. The four new systems consist of an alternative single-patient-use system, an alternative direct reuse system, a local reprocessing system, and a specialized reprocessing system. In Figure 18 a simplified version of these scenarios is portrait to explain the differences in these systems. As the name suggests, direct reuse involves directly reusing the product from one patient to the other. In the case of NiBP cuffs, this is done by disinfection at the bedside in between patients. Local reprocessing is done by collecting cuffs after each use, after which they are cleaned in batches in either the hospital itself or at a local service provider. Lastly, specialized reprocessing is the process of collecting cuffs after every use, after which these cuffs are collected at set frequencies by a service provider, who provides reprocessing on a regional level for multitude of hospitals.

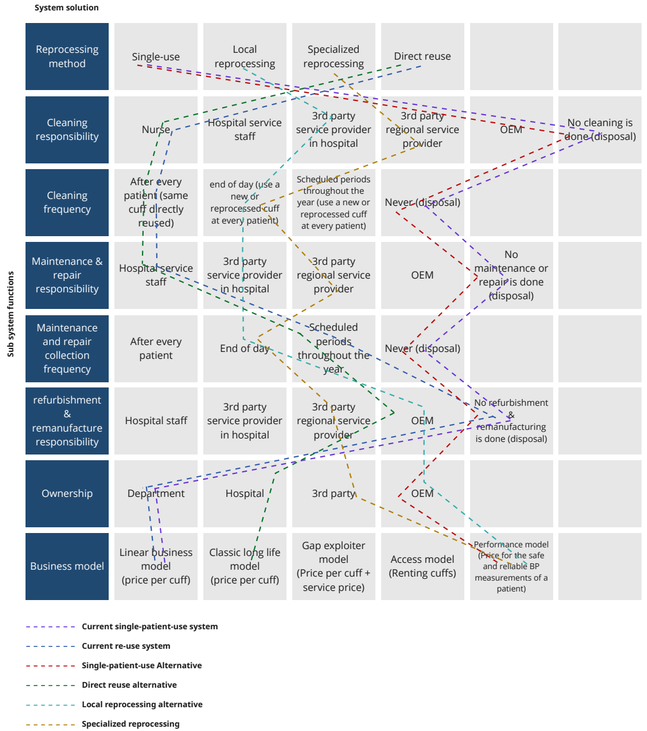


Figure 18: Morphological chart of potential system solutions for a circular NiBP system

Table 5: System design assessment criteria for NiBP system options

	Criteria	Measuring metrics
Sustainability	Amount of CRFs	++ = use 4 or more CRFs + = uses 2 or 3 CRFs - = 1 CRF -- = 0 CRFs
	CRF hierarchy	++ = >12 points + = 9 or 12 points - = 5 to 8 points -- = 0 to 4 points Research, design and development CRFs = 4 points each Performance sustainment CRFS = 3 points each Reprocessing for intended use CRFs = 2 points each End of intended use transformation CRFs = 1 point Recovery of energy CRF = 0 points
	System logistics related additional CO2 impact (compared to current reuse model)	++ = Has less CO2 impact + = Has the same CO2 impact - = has minor additional impact -- = has an extreme additional impact
	System encourages sustainable behaviour	++ = System ensures sustainable behaviour + = Sustainable measures are implemented to encourage sustainable behaviour - = Tries to encourage sustainable behaviour, but lacks incentive -- = Does not have any measures in place to encourage sustainable behaviour
Desirability	Patient infection prevention	++ = 100% infection free guarantee + = n.a. - = System allows for non correct use, making it susceptible to infection risks -- = Infection risks are apparent
	Product performance	++ = Product performances is potentially better than new + = Product performance as new - = Product performance could be maintained, but is reliant on correct use by hospital staff -- = Product performance cannot be guaranteed
	Burden on hospital staff	++ = Relieves hospital staff + = Similar burden on hospital staff - = Additional burden on hospital staff -- = High additional burden on hospital staff
	product/service purchasing + operational costs	++ = Hospital costs are significantly lower than the current single-patient-use system + = Slightly lower costs for the hospital compared to the current single-patient-use system - = Similar costs for the hospital compared to the current single-patient-use system -- = Significantly higher costs for the hospital compared to the current single-patient-use system
	Hospital staff readiness	++ = No changes and/or education necessary for hospital staff + = Slight changes and/or education necessary for hospital staff - = Significant changes and/or education necessary for hospital staff -- = Changes and/or education are needed for hospital staff, but not possible
	Hospital staff trust in safety and performance	++ = Perception of safety and performance of products is similar to using a new cuff on every patient + = Perception of safety and performance is maintained through measures - = Perception of safety and performance is significantly lower -- = Perception of safety and performance is extremely low

The different systems were carefully evaluated on sustainability, desirability, feasibility and viability in the criteria specified in Table 5. In Figure 20, the scores are visualised. The elaborated scoring of the systems can be found in Appendix K.

Feasibility	Infrastructure readiness (new facilities or networks needed)	++ = Fits within the current hospital infrastructure + = Fits within the current hospital infrastructure with minor adjustments - = Does not, but could potentially be feasible in the future with major adjustments -- = Does not, and will probably never be be feasible in the future
	Implementation horizon	++ = Can be implemented right now + = Can be implemented within months to 2 years - = Implementation would take 2 to 5 years -- = Implementation faces many hurdles, and will take 5+ years
	Hospital resources availability (staff, room, etc)	++ = Relieves hospital resources + = Does not use additional hospital resources - = Uses hospital resources, but is manageable -- = Uses significant hospital resources, which are not available
	Systemic change needed	++ = No systemic change needed + = Easy to implement systemic change - = Hard to implement systemic change -- = Reliant on extreme change of the current system, way of working for stakeholders
Viability	Service operating costs	++ = No service operating costs + = Manageable service operating costs - = Significant associated service operating costs -- = Extremely high associated service operating costs
	Regulatory compliance	++ = Complete regulatory compliance as of now + = Changes needed, but easily done - = minor hurdles to overcome -- = Significant hurdles to overcome
	Scalability	++ = Easily scalable to other disposables, as well as other hospitals + = Easily scalable to other disposables, or easily scalable to other hospitals - = Resource intensive scaling towards other disposables, or other hospitals -- = Not scalable
	product/service purchasing costs	++ = Costs are lower than the current reuse system + = Costs are similar to the current reuse system - = Costs are higher to the current reuse system -- = Costs do not justify purchasing costs of the product service system

THE STATUS QUO

The two existing and implemented systems, optimized for convetional linear business models, both perform poorly in terms of sustainability. As they are already in use, require no change, and meet regulatory standards, they score high on feasibility and viability. However, interestingly, they both perform poorly in terms of desirability. In case of the single-patient-use system, this is due to the possibility of non compliant use beyond its intended purpose, which could compromise performance and increase infection risks. As for the current reuse model, it scores poorly due to perceived safety risks of reusables and reliance on time constrained nurses for disinfection, which raises safety concerns.

SINGLE-PATIENT-USE ALTERNATIVE

The alternative single-patient-use system introduces a performance-based business model, where Philips retains ownership of the cuffs and provides the ability to safely, reliably and more sustainably measure a patient's blood pressure. This system is enabled by a dispense and collect system. This allows for integrating pricing for the added logistical value Philips adds, while the system ensures effective collection for recycling. The model is relatively easy to implement, already compliant, and desirable from an infection control standpoint. However, circularity gains are minimal with a product focused around a mainly linear lifecycle.

DIRECT REUSE ALTERNATIVE

This system builds on current practices of direct reuse of NiBP cuffs, where nurses are responsible for cleaning between patients. Through incentives hospitals are however encouraged to send back faulty cuffs, or ones which have reached their EoL, to Philips. While still linear, the model shifts towards a classic long life model, which focuses on providing products wih a long life compared to competition.

This aligns with Philips' positioning as a performance- and reliability-focused supplier instead of a budget supplier. However, although incentives are in place, hospitals will require logistical effort to collect the low value products, and infection risks and perception face the same risks as the existing reuse model.

LOCAL REPROCESSING ALTERNATIVE

The local reprocessing system introduces certified reprocessing staff at or near the hospital. After single patient use, cuffs are collected and reprocessed at the end of the day, including cleaning, inspection, and maintenance. Because of a performance business model, ownership remains at the Original Equipment Manufacturer (OEM), allowing the company to maintain control over logistics, infection control and product performance, while hospitals pay for access to safe to use and effective blood pressure measurements. The model improves performance and safety but requires physical space and systemic change. It also demands a larger cuff stock, compared to direct reuse, to account for reprocessed cuffs for every patient.

SPECIALIZED REPROCESSING ALTERNATIVE

Lastly, the specialized reprocessing system involves regional or national reprocessor handling large-scale reprocessing across hospitals. Ideally this reprocessor is a joint venture betweem OEMs and responsible for all consumables to make use of economies of scale for it to become viable. A joint venture also encourages standardisation, while OEMs will be incentivized to design the products for effective reprocessing. Ownership of the cuffs will be at the reprocessing partner, which hospitals will buy access to through a performance based business model. While theoretically feasible, the system requires major systemic change, new infrastructure, and long transport routes. Environmental gains may thus be offset by the associated resource intensive logistics.

LOCAL REPROCESSING AS THE SOLUTION

Selecting the right system involves balancing circularity, infection control, and the scale of change required. Across the six systems analysed, gains in one area often come with trade-offs in another.For example, the alternative single patient use system is easy to implement and improves infection control, but makes relatively small circularity gains compared to the other reusable alternatives.

Among the alternatives, local reprocessing stands out as the most balanced solution. It removes the disinfection burden from clinical staff and places it with certified personnel, guaranteeing infection control while enabling safe reuse. The model promotes circularity through traceability, maintenance, and extended product life, and while it requires some logistical adaptation within hospitals, it is achievable and scalable to different hospitals.

Sustainability experts at Philips confirmed this system offers the best balance of feasibility, viability, and desirability, with a meaningful reduction in environmental impact.

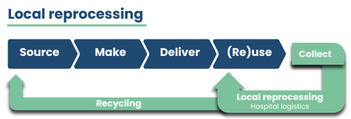


Figure 19: Visual representation of local reprocessing

KEY TAKEAWAYS

- Reprocessing option viability are dependant on product, volume, infection risks and scale of systemic change possible.
- Local reprocessing offers a balanced, yet circularity focused solution for NiBP cuffs.

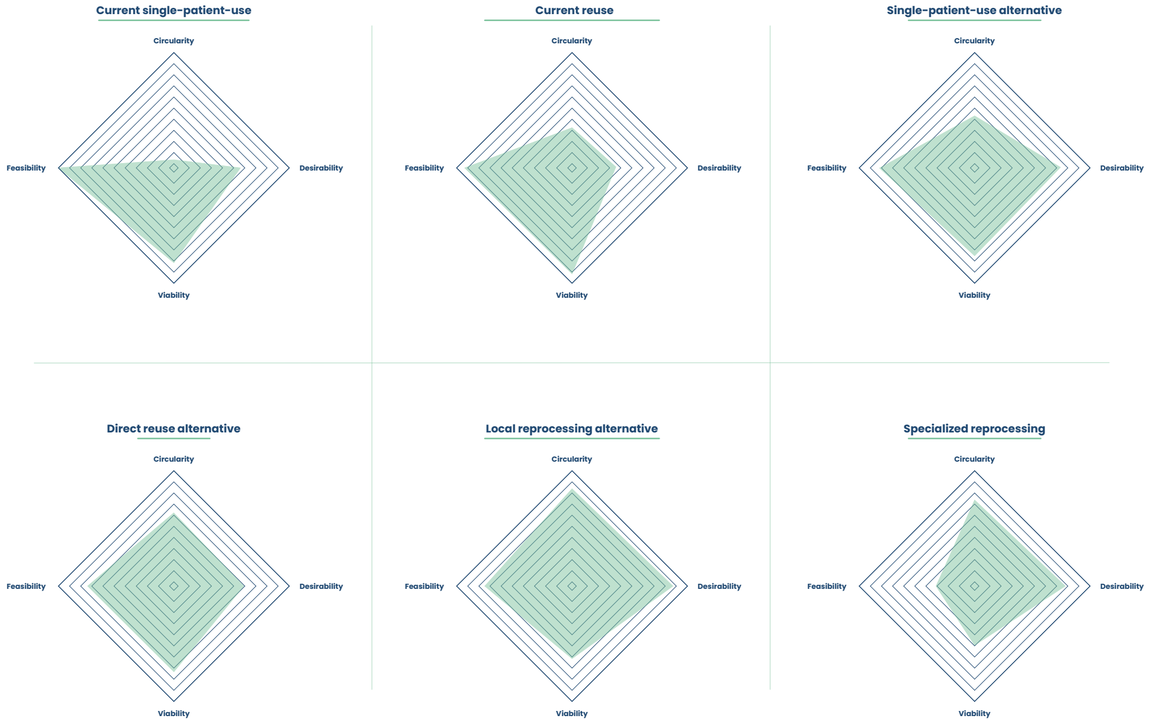


Figure 20: Visual representation of the scoring of the different NiBP system options

5.3 Circular Recovery Flow design sprint

This chapter explores how different Circular Recovery Flows (CRFs), as defined by Hoveling et al. (2024) (Appendix A) can be enabled in the redesign of the Philips Gentle Care NiBP cuff. For each CRF, a design sprint was done specifically for the case study product to investigate solution directions for each specific CRF. Through these explorative design sprints, key design solutions at both the product and system level could be uncovered for NiBP cuffs.

The flows “Refuse”, “Replace”, and “Rethink” are not included, as these do not form applicable flows for NiBP cuffs. These are not applicable, as blood pressure is a universially accepted vital sign, crucial for diagnosing and managing patient conditions within all departments of the hospital. For monitoring this, NiBP cuffs offer an easy, safe, efficient and cost-effective solution, making them clinically essential in healthcare. Due to their low material complexity, specific use case, and limited product value, the “Repurpose” flow is also not considered as a viable option. As the product is non-invasive, the flow “Regenerate” is also not considered, as the product cannot dissolve into the bodies tissue. Lastly, compost and biodegrade are combined within a flow “Renew”, as they provide similar outcomes.

REDUCE

The CRF “Reduce” can be defined as “Increase efficiency in product manufacturing or use by consuming fewer natural resources and materials.” (Hoveling et al., 2024). Possibilities on how to reduce are split up in five key how-to’s derived from the insights from earlier analysis done and are shown in Figure 21.

RESULTS

“Reduce” provides clear opportunities as a CRF for NiBP cuffs, which adress inefficiencies across the product lifecycle. These include eliminating unnecessary components such as the fixed extension hose, using lower impact raw materials, and streamlining manufacturing to reduce production steps and material waste. As paper instructions are often unread, further reductions can be achieved by replacing them with low waste alternatives. Finally, hermetically sealed packaging is by law not required, as it is a non critical item under the Medical Device Regulation. Reductions in packaging are therefore possible to achieve.

MAIN TAKEAWAYS

- “Reduce” provides opportunities for NiBP cuffs.
- A reduction on the number of components is possible.
- Material impact can be reduced through limiting materials and lower impact materials.
- Production processes can be optimized by a reduction of processes and off-cuts.
- Packaging can be reduced, as it is not necessary by law.

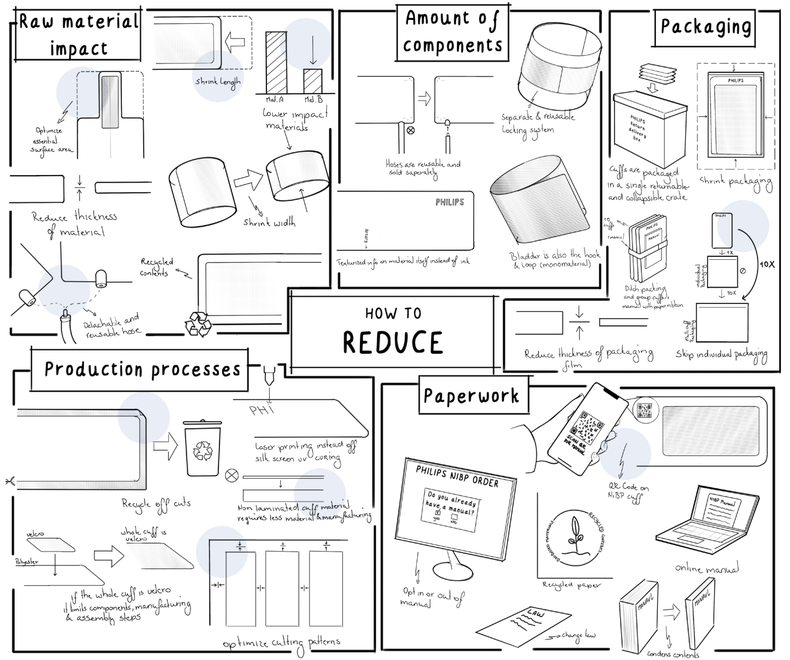


Figure 21: Ideation page for the CRF “Reduce”

REUSE

The CRF "Reuse" can be defined as "Collection of the device or parts of the device (= partly reuse) after the use cycle to reuse it for its original purpose" (Hoveling et al., 2023). In Figure 22 an overview is given for possible design interventions which could enable reuse.

RESULTS

The main objective for "Reuse" is to decrease the infection risks which are associated with the use of reusable cuffs, as this is currently seen as a bottleneck for the implementation of reusable alternatives. Another key point to improve is to prevent premature EoL of the product, to make sure the product is used for its intended use time.

MAIN TAKEAWAYS

- "Reuse" provides opportunities if premature EoL can be prevented, and infection control can be guaranteed.
- Premature EoL can be prevented by:
  - Visual product characteristics
  - Shifting EoL responsibilities away from nurses
  - Easily cleanable materials
  - Education of staff
- Infection control can be done through:
  - Shifting cleaning responsibilities away from nurses
  - Stricter and controlled protocols
  - Automated cleaning
  - Partly disposable cuffs
  - Easier to clean products

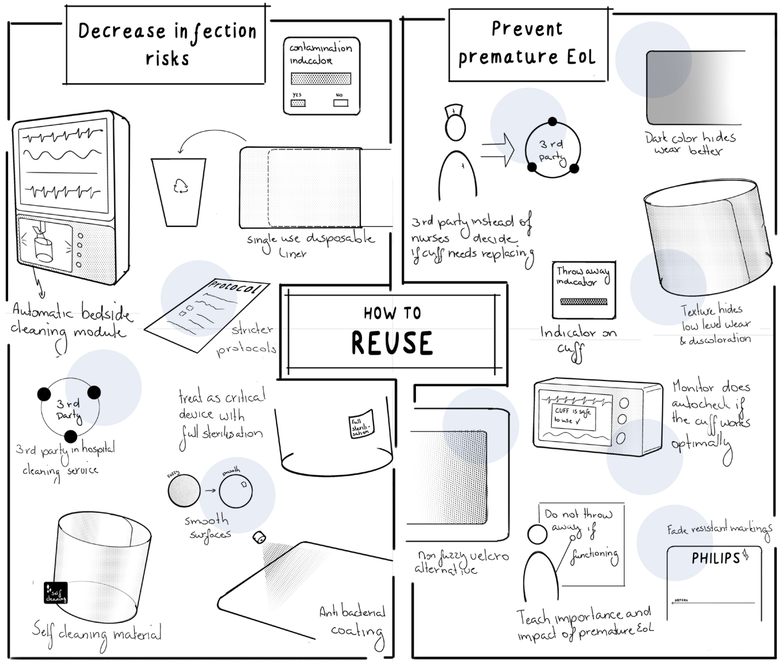


Figure 22: Ideation page for the CRF "Reuse"

MAINTAINCE AND REPAIRS

Maintaince and repairs are part of the CRF "Reuse", but are highlighted in Figure 23 in detail, as they are important factors for enabling extensive reuse.

RESULTS

Paradoxically, to maintain product performance when implementing "Reuse", the product must not be used beyond its rated lifetime. In this case that means discouraging users from using the product beyond their intended purpose, as observed as a problem in chapter 4.3. However, to extend the rated lifetime, the product must be tolerant to the extended use compared to the current rated lifetime. Additionally, introducing traceability and quality control systems enables effective maintenance and repair logistics and control. For repairs it is needed that components within the product are detachable for them to be repairable or replaceable. Currently this is not the case, due to fused materials.

MAIN TAKEAWAYS

- Discourage improper or extended use through indicators, education or product feel.
- Enable product longevity through robust materials and components.
- Enable effective maintenance and repairs through:
  - Traceability in the form of a digital passport
  - Shifting responsibilities of maintenance away from nurses
  - Proactive systems that require quality control checks.
  - Components need to be easily detachable to become repairable or upgradable.
  - Shifting repair responsibilities to the OEM could provide more effective repairs
  - Integrate quality control system to enable repair

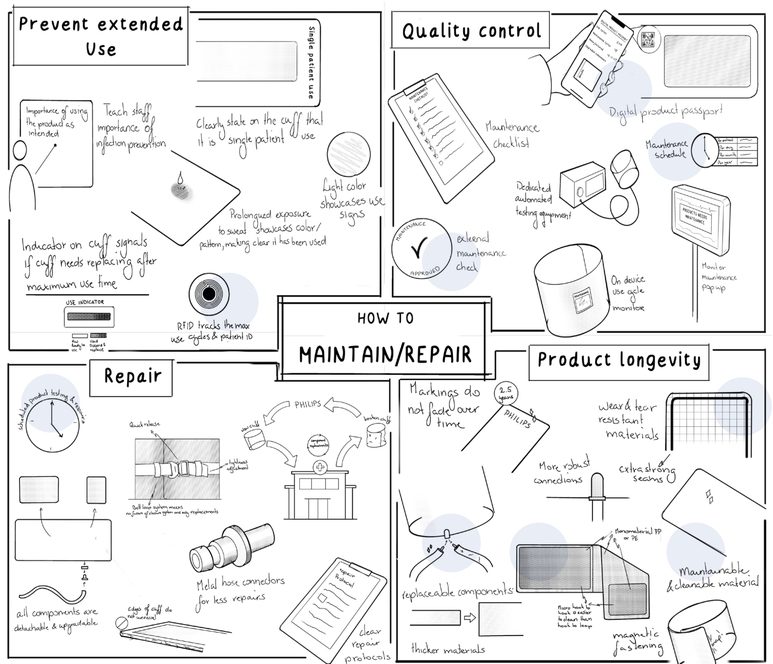


Figure 23: Ideation page for maintenance and repairs

REMANUFACTURE

The CRF "Remanufacture" can be defined as "Collect the device or parts of the device (= partly remanufacture) after the use cycle to test its function, disassemble it into components (if needed) to restore them in a new device (with used and new parts) with the same function. (Hoveling et al., 2023). An overview of interventions to enable remanufacturing can be found in Figure 24.

RESULTS

Effective decontamination and certification are needed to fullfill wishes of users, who might perceive remanufactured items as devices of lesser quality (Hoveling et al., 2023). For remanufacturing to be possible, product compatibility over multiple generations and replaceable components are a must. Due to extensive legal requirements, remanufacturing has to be carried out by certified professionals (personal communication, Philips, 2025). Collection system incentives for hospitals could help to get old cuffs back to the OEM for remanufacturing. Lastly, because of the value of the product, remanufacture might not be a viable solution from a business perspective.

MAIN TAKEAWAYS

- "Remanufacture" provides opportunities but includes sending the cuff to a certified refurbisher (OEM or external partner), who can meet regulation demands.
- "Remanufacture" is enabled through backwards compatibility, standardized components and non-destructive detachable components.
- Perceived quality of remanufactured products might hinder adoption.
- Hospitals incentivization could help to collect cuffs at the EoL.
- Partly remanufacturing components provides opportunities.
- Economic barriers hinder viable remanufacturing.

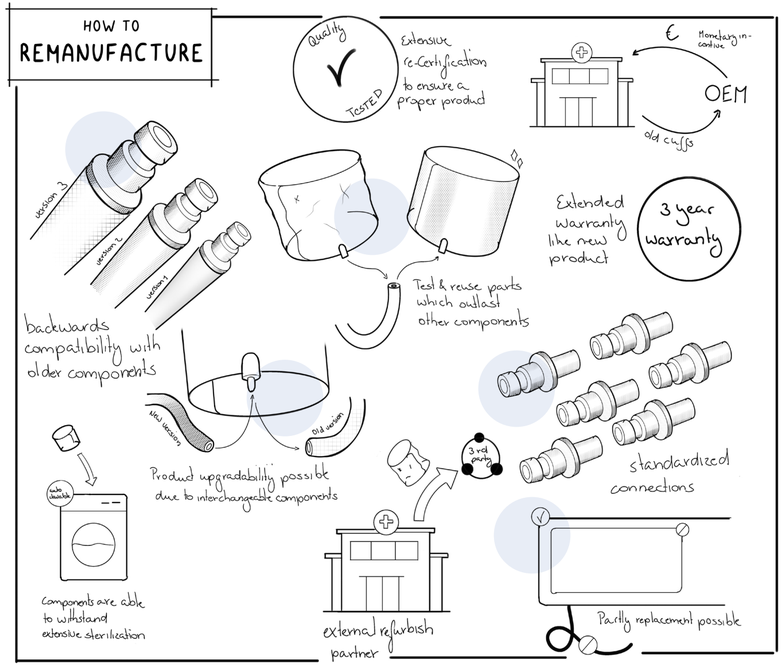


Figure 24: Ideation page for the CRF "Remanufacture"

RECYCLE

The CRF "Recycle" can be defined as "Collect and sort the device or parts of the device after the use cycle to process materials such as paper, glass, plastic, and metal in such a way that they can once again be used as (recycled) base materials in the manufacturing process of the same or a different device or product" (Hoveling et al., 2023). An overview of interventions to enable recycling can be found in Figure 25.

RESULTS

There are several crucial obstacles to overcome for recycling to become possible. The first is to introduce materials which are recyclable, which is currently not possible due to many of the components being laminated or non recyclable materials. Next, the permanent fusion of different components, comprised of different materials inhibits recyclability. Because of this, components have to be either be a mono-material, or should incorporate easy separation. Lastly, waste is often currently not being separated, or even ends up as medical waste, due to convenience and lack of awareness in nurses. Even if the product is physically recyclable, this has to be overcome on a system level, to ensure that the product is eventually recycled.

MAIN TAKEAWAYS

- Recycling provides opportunities for NiBP cuffs if different materials are not permanently fixed together. This can be remedied by:
  - Easily seperable components
  - Using mono-materials
  - Using widely recycled materials
- Nudging nurses to correctly dispose items could help in reducing cuffs ending up in the wrong waste stream.

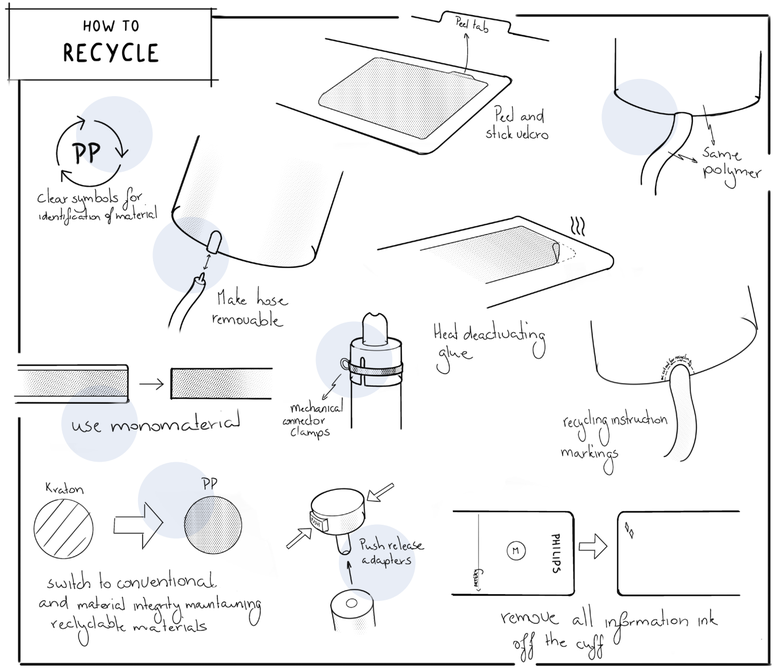


Figure 25: Ideation page for the CRF "Recycle"

RENEW

The final CRF "Renew" can be defined as "Materials that can safely be returned to the biosphere are used in the production of the device, to enable processes that together help regenerate natural capital, such as composting and anaerobic digestion." Possible design interventions can be found in Figure 26.

RESULTS

Implementation of "Renew" is quite straightforward for this product. Biodegradable materials can be implemented for the whole product, for subcomponents, or for single-use items associated with the product, such as for example a disposable infection prevention sleeve. Lastly, packaging can be made biodegradable. For packaging this should be feasible. However, to integrate biomaterials into medical devices, compliance with medical regulations should be ensured. Regulation, such as MDR and ISO 10993, is stringent for safety and performance reasons. As these materials are often relatively new and not yet extensively tested and certified for medical use-cases, combined with the small range of possible materials for specific needs, this could pose compliancy challenges (Jurzak et al., 2024).

MAIN TAKEAWAYS

- "Renew" provides opportunities for the redesign, but mainly in the packaging, due to possible compliancy and product performance hurdles for use in the cuff itself.

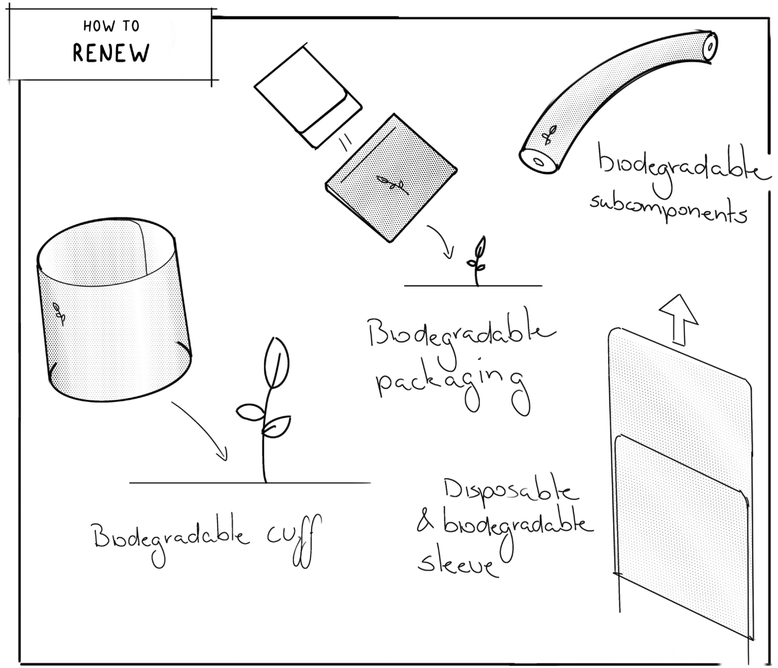


Figure 26: Ideation page for the CRF "Renew"

5.4 Concluding chapter insights

SYSTEM DESIGN

From the ideation phase, it can be concluded that local reprocessing is the best way forward for this case study product to enable reuse, which maximizes circularity potential, while keeping within the constrainsts of the real world context. To implement this effectively, there should be a collect and dispense unit, which tracks inventory and usage, while serving as an efficient and convenient touchpoint for nurses and logistical staff for the safe collection of used cuffs and dispensing of reprocessed cuffs. Such a system makes sures that cuffs are collected effectively, and do not end up as medical waste and guarantees infection risk free cuffs. Below an ideation sketch page is shown which focuses on possible solutions for the implementation of such a system.

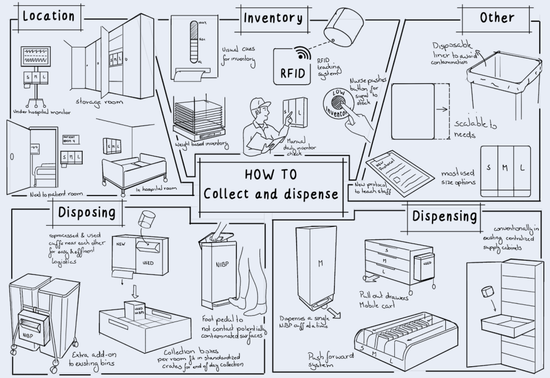


Figure 27: Ideation sketch page on a dispense and collect system

PRODUCT DESIGN

For the product design, measures should be implemented that decrease impact in the manufacturing phase, enable reuse of the product, increase product longevity, and lastly make recycling possible. Because of the low economic value of the product, remanufacture is not considered as an option, while renew measures are also not implemented because of performance and regulation constraints. Within each sketch figure in the CRF design sprint chapter the most impactful measures are highlighted, which will be implemented. A final ideation sketch page is shown below which goes into more technical detail on how to enable an effectively reusable and recyclable product, by introducing a detachable hose system.

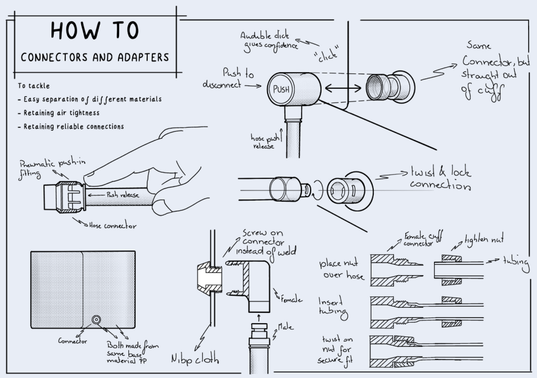


Figure 28: Ideation sketch page on connectors and adapters

6. Philips Revo Care

Figure 29: Philips Revo Care introduction visual

6.1 Philips Revo Care introduction

Philips Revo Care is a circular product service system developed to address the environmental and operational challenges of environmentally sustainable use of NiBP cuffs in high acuity hospital settings. The system integrates two core elements: the redesigned Revo Care cuff, optimised for circularity and safe reuse, and the Revo Care Sensor Station, a smart in-room unit that enables dispensing, collection, and traceability of cuffs throughout their lifecycle.

Together, they form a closed-loop solution that shifts disinfection responsibility from nurses to certified reprocessing personnel, ensures product performance, and supports a circularity enabling performance-based business model. This chapter outlines the design, function, and system integration of Revo Care, showcasing how circularity, infection control, and usability can be effectively combined in a clinical setting. Both are shown in figure 29.

6.2 Revo Care Cuff overview

The final product design consists of a range of three differently sized cuffs built for high acuity settings and optimized for circularity. This is done by minimizing the physical product impact in production, making the product physically able to withstand local reprocessing, which at the end of life can easily be recycled. Within this chapter, the key design changes of the to be introduced Philips Revo Care Cuff and how they enable a safe, reliable, and a for the user optimized product that forms an environmentally attractive value proposition.

The existing product is already a fairly optimized one. It consists of limited components, does not house electronics and is simple in construction. Despite this, it is still possible to introduce significant design interventions to maximize circularity for the high acuity setting it operates in, which will be discussed throughout this chapter. In Figure 30, a simplified overview of the Philips Revo Care Cuff's product lifecycle is portrait, which showcases in which stages of the product's lifecycle design interventions have taken place, to improve the circularity of the product.

PRODUCT ARCHITECTURE

The product consists of 8 components:

- A cuff sheet material used to house an integrated bladder, and forms the mounting base for the other components (components 1 and 7)
- A hook-to-hook system that allows for the fixation of the cuff around the arm (components 4 and 5)
- A cuff connector to allow airflow from the patient monitor into the bladder (component 3)
- A reusable hose, consisting of:
  - A hose connector (component 2)
  - An air tube (component 6)

Product design interventions

Revo Care cuff components

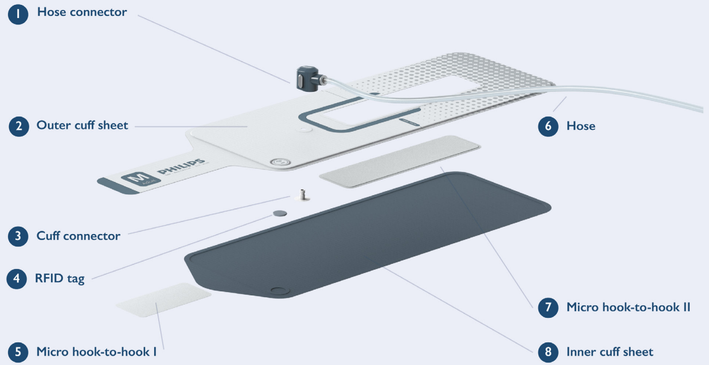


Figure 30: Revo Care Cuff overview with components and design interventions

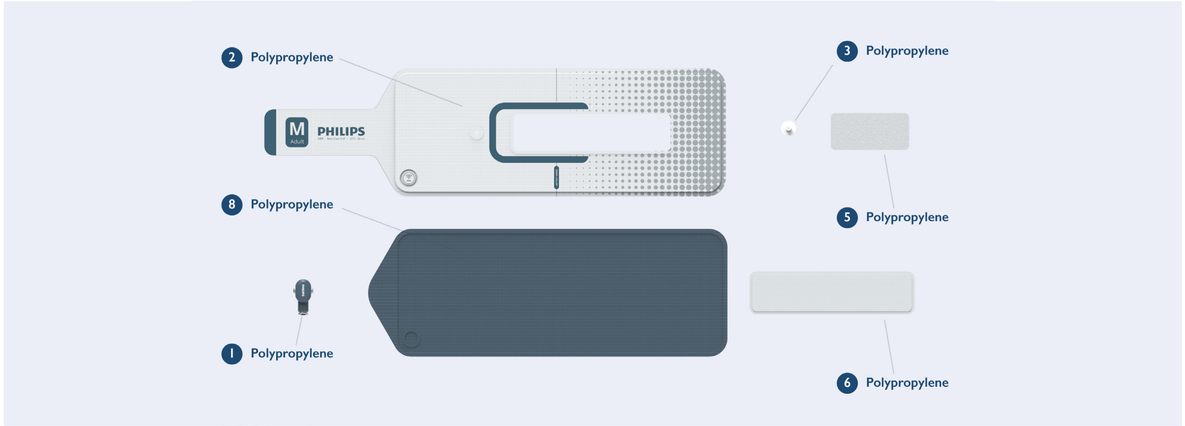


Figure 31: Components of the Revo Care cuff made of PP

MONOMATERIAL CONSTRUCTION

The current NiBP cuff uses multiple laminated and permanently fused materials, making recycling impossible. To address this, a key design change is the switch to a mono-material construction using polypropylene (PP) parts. Through expert interviews with a Philips polymer materials engineer and a Philips sustainable materials product lead, it was confirmed that the switch to a PP mono-material is possible and viable for a reusable NiBP cuff. Due to the many processing techniques possible, the mechanical properties and the skin compatibility, a mono-material cuff could make for a fully recyclable product, while maintaining performance, increasing circularity.

The different components are differently processed PP parts. The cuff material is made from woven PP with a laminate polyolefin PP layer for an air tight bladder. The cuff connector is injection moulded, while the micro hook to hook is extrusion moulded.

Expert interviews with Philips materials specialists and Rivertex confirmed the viability of PP for both the cuff's woven sheet and bladder laminate, offering the necessary flexibility, air tightness, and skin compatibility for safe reuse. Fastening elements, validated with manufacturer Binder, can also be produced in a monomaterial PP. Component fixation is achieved via high-frequency welding, a clean, additive-free process. Only the hose and Radio Frequency Identification (RFID) tag are not made up of PP, but these easily detach through a quick release, or, in case of the RFID tag, get separated through shredding at the recycling facility, which does not affect recyclability, as validated with a MIREC recycling expert.

As PP is a commonly recycled material, if disinfection has taken place to ensure that the product is not hazardous, recycling the cuff becomes as easy as throwing the product in the recycling bin. This contrasts with the conventional incineration that now takes place for this product.

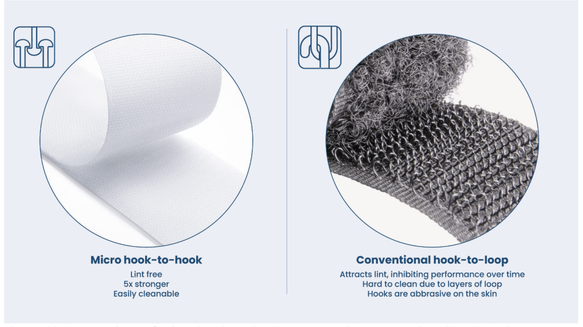


Figure 32: Comparison of micro hook-to-hook compared to conventional hook-to-loop

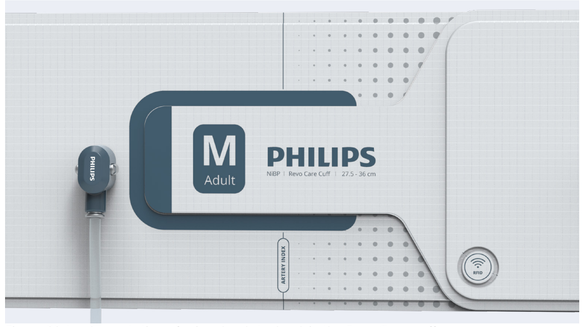


Figure 33: Implementation of micro hook-to-hook in the Revo Care cuff

MICRO HOOK-TO-HOOK FASTENING

To address the limitations of the conventional Velcro used in the NiBP Gentle Care Cuff, various alternative fastening methods were explored. The issues with Velcro primarily include:

- Poor recyclability due to the permanent fusion of different materials onto the main cuff material.
- Accumulation of lint in the "hook" and dirt in the "loop" side of the Velcro, compromising hygiene.
- Reduction in fastening performance over time, due to lint buildup in the "hook".

Throughout the user research, it became apparent that this contributes to premature EoL of the cuffs and drives the preference for single-patient-use products due to the hygiene concerns.

While alternative methods, such as nanotape, as showcased in Figure 23, showed strong functional and hygienic performance, as well as strong durability, they did not meet criteria demands for circularity, or vice versa. A promising solution however is the use of a micro hook-to-hook fastening system, such as Microduotec, developed by component supplier Binder. Through an expert interview with them, the mechanical performance and user needs of Microduotec were evaluated and met the requirements of being fully recyclable, retaining sustained product performance over multiple years and being more hygienic in use than the current Velcro.

Micro hook-to-hook fastens through the use of small and flexible mushroom shaped PP parts, which have the ability to interlock, as shown in Figure 33. This provides a connection which is 5 times as strong in the shearing direction compared to conventional Velcro, which is desirable for the shear forces needed once the cuff is inflated. This also made a physical footprint reduction of 32% possible, as less material is needed for handling the same shearing forces. This gives it is distinctive new look, which simultaneously helps as a "pull tab" for easy an intuitive applications.

Next to the increased strength, it offers a significantly slimmer profile at a 0,57 mm thickness. Because of the less aggressive mushroom shape of the "hooks", together with the low profile, the producer ensures a lint free surface (Binder, 2025). As the material does not have a conventional "loop" dirt and contaminants are easier to clean out, as they do not get stuck in lower levels of the material (personal communication, Binder, 2025).

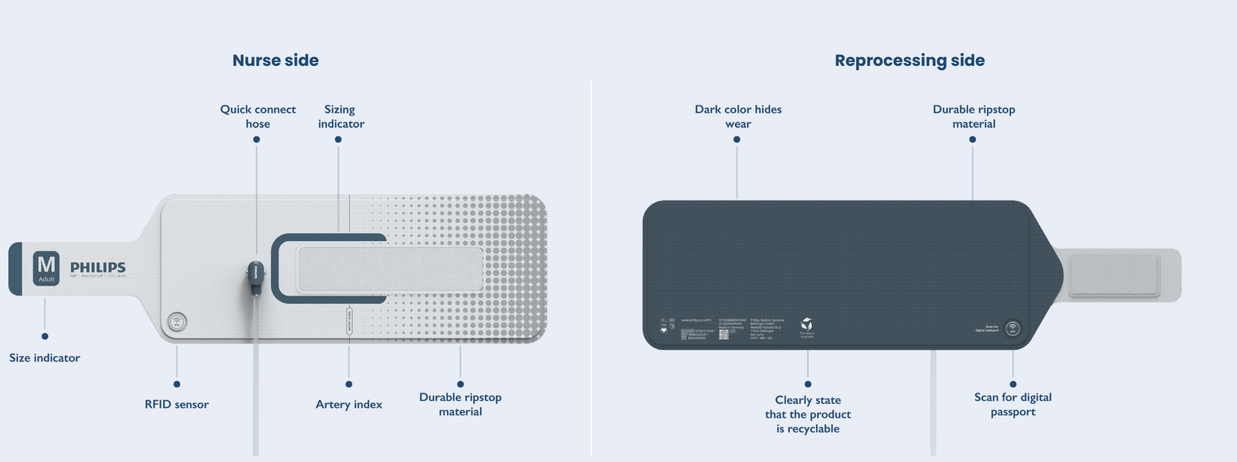


Figure 34: Clinical use–oriented design interventions of the Revo Care cuff

FUNCTIONAL IN USE

The redesign enhances usability by incorporating clear product design and visual cues intended for its main users, namely nurses, logistical staff and reprocessing personnel. The outside of the cuff plays a prominent role in daily workflows for nurses and logistical staff, as it is the side most seen and handled during storage, redistribution, and patient treatment. User research revealed that quickly identifying the correct cuff size is important for both nurses and logistical staff, whether for inventory management or fast size selection during treatment. To address this, the cuff features colour coding and a large, visible size indicator, which remain readable even when folded. To help reduce sizing errors during treatment, visual cues have been added to guide correct placement of the cuff and indicate the optimal range for accurate readings and a secure fit during inflation. Correct sizing is further encouraged, by the cuff connector placement. Since this indicator is positioned where the pull tab ends at the cuff's minimum circumference, using an oversized cuff is discouraged, as it would cover the connector needed to attach the hose.

The perception of the cuff was also addressed. The product is seen and handled currently as a single-patient-use disposable. To change mindsets, the new product should feel more premium to discourage carelessly discarding the product. This is done through an elevated design from a simple rectangle and through High Frequency (HF) welding the micro hook-to-hook from the inside of the bladder, giving a cleaner look, while the outer surface is seamless and provides an extended pull tab for easier handling.

The inner side is designed with reprocessing staff in mind, presenting only the essential and legally required informed, needed for cleaning and traceability. By simplifying the inside, essential data is easy to locate, while the contrast with the outside provides a clear visual cue for nurses, reducing the change of incorrect reversed application, while also hiding prolongued patient contact wear signs.

Figure 35: Hose connection close-up

HOSE CONNECTOR

As opposed to the integrated and permanently fixated extension hose of the Gentle Care Cuff, the redesigned Philips Revo Care Cuff makes use of an easily detachable and directly reusable connector system. This improves both the functionality and circularity of the product.

First, by eliminating the extension hose from the product, which did not provide additional functionality for nurses to the product as discussed at the hospital visits, the cuff has two less components. Instead of a cuff connector, extension hose, and hose connector, the Revo Care Cuff only needs a cuff connector. This simplifies the product architecture, for which less materials and production processes are needed. This reduces the environmental impact of raw materials and production, makes production more efficient and decreases production costs.

Second, the conventional placement of the connector in the old design regularly causes bruising in patients, as the connector digs into the skin during inflation. As also quickly touched upon, by strategically repositioning the hose connector towards the centre of the cuff, it serves a double function, namely enabling air into the cuff, as well as posing as a sizing barrier, while not hindering patient comfort. When a cuff that is too large is used on a patient, the connector will get in the way of the pull tab, effectively blocking the hose attachment. While this makes application more difficult, it does not fully inhibit it if this occurs in acute high stress situations. By encouraging correct sizing, it supports in accurate blood pressure measurements.

As the female hose connector will be a main touchpoint in the current design, it is designed for intuitive and ergonomic use. Through ergonomically placed quick release buttons, the hose can efficiently and easily be detached from the cuff. On the other hand, the connector clicks into place with an audible signal, providing nurses with clear feedback that it is securely attached, to increase the perceived safety. On the bottom, where the hose is fastened to the connector, a push connector which is widely used within the pneumatic industry is used. This provides a secure connection between the hose and connector, is hard to be opened by accident, yet it provides a quick release system when intentionally needed for for example maintenance or replacements.

Lastly, to ensure compatibility with existing systems, the new connector is backwards compatible. By using a Philips standardized male connector, the redesigned cuff can be connected to existing female hose connectors if needed, which helps in not making old equipment be redundant before it's physical end of life.

Figure 36: Side profile of the Revo Care hose connector

AN OPTIMIZED PRODUCTION PROCESS

While incorporating CE principles, it is necessary to keep in mind that the product needs to be mass produceable, as Philips produces over 1,5 million cuffs per year. All components are made with easily available PP and manufacturable through mass scalable production processes, such as injection, blow and extrusion moulding and HF welding. To ensure that minimal waste is generated in the production process, the product is optimized in physical footprint and components. As all materials are recyclable, some inevitable off cuts can be recycled.

RFID ENABLED

Traceability of inventory and usage is crucial to enable efficient reuse systems that can guarantee product performance, without needing excessively redundant stock. To enable this system, all NiBP cuffs are equipped with a passive and chipless RFID tag, which helps in improving patient safety by reducing medical errors (Profetto et al., 2022). These tags require no power supply, as they are energized by radio waves from the RFID reader, and are cost-effective enough for low-cost medical devices (Behera & Karmakar, 2020; Subrahmannian & Behera, 2022). Their simple construction avoids critical materials, limiting environmental impact compared to conventional electronics. On the other hand, the additional impact that is created can be offset by the increase in control over product supply, stock and usage, which can enable more efficient logistics, could require less redundant stock and enables routine maintenance increasing the product's lifespan, as is evaluated in chapter 6.5.

The tag is placed inside the bladder and secured with a perimeter weld. Because it is not bonded to the material, it separates easily during shredding, allowing for efficient recycling of the cuff.

Figure 37: Cuttin pattern of the Revo Care cuff

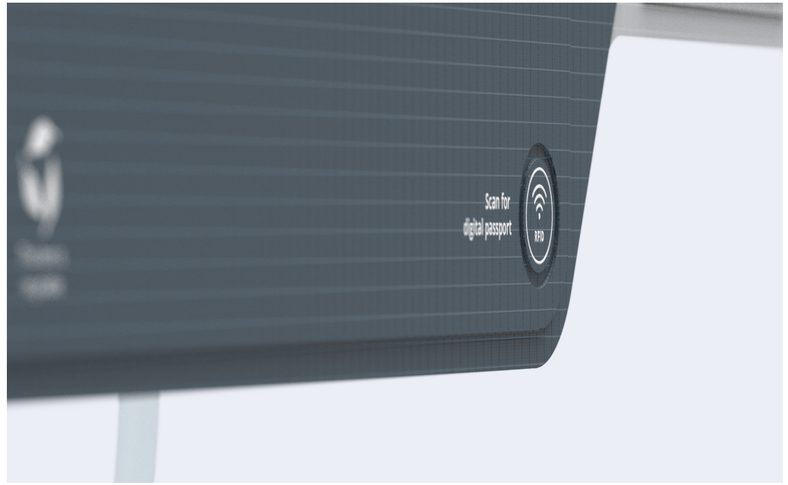


Figure 38: Close-up of the RFID embedded sensor

6.3 Revo Care system overview

To introduce CE strategies, the product itself has to meet the mechanical requirements necessary to make each specific CRF possible. In this specific case, that means for example that the product needs to withstand repeated inflation and deflation cycles over multiple years and that the different materials need to be easily separable for recyclability. However, while these changes in the product design are integrated, this does not yet ensure that the product is not discarded prematurely by staff, or that the product does not end up in a non-recyclabe waste stream, negating the introduced product specific interventions. Because of this, it is needed to zoom out, to ensure that CE principles are enabled on a system level. Within this chapter, the system concept of Philips Revo Care is introduced. A circular pathway to smarter, safer monitoring.

This system is developed to enhance the value proposition of the Revo Care Cuff, ensuring it is perceived as a viable and even preferable alternative to the current single-patient-use solutions. Through a combination of infection prevention, efficient workflows, and product traceability, the system aims to secure adoption in high acuity hospital environments.

SYSTEM ARCHITECTURE

The system revolves around a local reprocessing one. As evaluated in chapter 5.2, local reprocessing offers the most attractive reuse system, as it provides the best value proposition in terms of circularity, while satisfying viability, desirability and feasibility needs. In Figure 39, a simplified overview of local reprocessing is given.

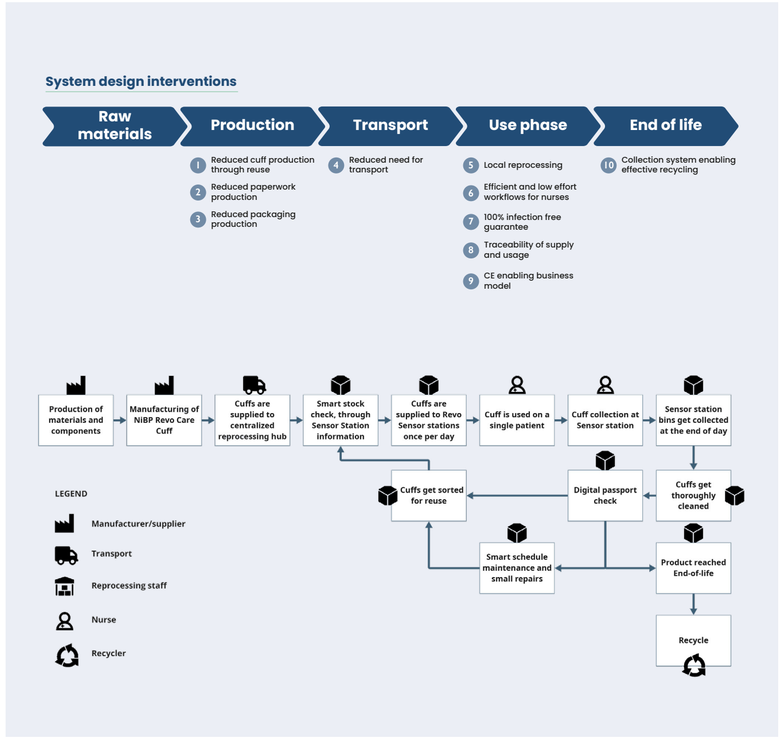


Figure 39: System overview of the Revo Care system

PHILIPS REVO CARE SENSOR STATION

The Philips Revo Care Sensor Station forms a central role in enabling that local reprocessing is done effectively, safely and efficiently. It does so by shifting the responsibility of cleaning from overburdened nurses to certified reprocessing personnel. This enabler acts as a main touchpoint for nurses and logistical staff during distribution in the hospital, use during treatment, and collection afterwards.

User research showed that retrieving NiBP cuffs from central supply rooms was time-consuming, often leading to incorrect reuse or sizing, compromising both infection control and measurement accuracy. To address this, the Revo Care Sensor Station is installed directly in high acuity treatment rooms, combining cuff dispensing and collection in one clearly defined touchpoint for nurses. Clean cuffs are dispensed from the top, and used ones are discarded in a closable bin below. The system is stocked with the three most used sizes, as these account for 95% of treatments. This allows the unit to remain compact, minimising both the physical footprint in the treatment room and the material use associated with overstocking.

A key enabler of circularity is the smart tracking system. Each cuff is equipped with a passive RFID tag, which communicates with readers embedded in monitors, sensor stations, and reprocessing hubs. This enables the tracking of usage, cleaning, and maintenance in digital passports of the cuffs. This provides reprocessing staff tailored reprocessing tasks, such as smartly scheduled maintenance and correctly timed EoL disposal. For logistical staff, inventory traceability supports efficient in-hospital redistribution and automatic restock orders. Together, these features support a safe and extended product life, efficient stock management, and future proof regulatory compliance with the MDR, by ensuring traceability of the products and usage.

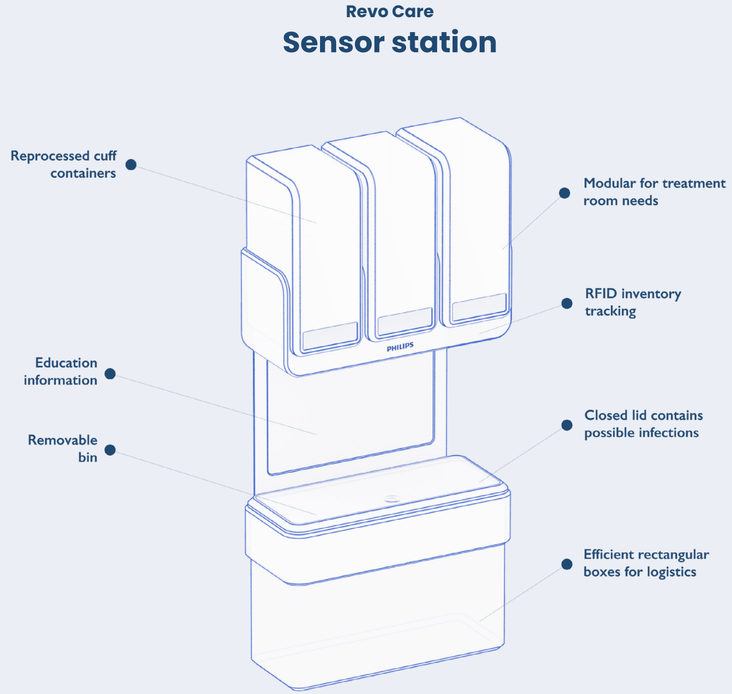


Figure 40: Revo Care sensor station overview

STORYBOARD
To illustrate how the system works in practice, a storyboard is shown in Figure 41.

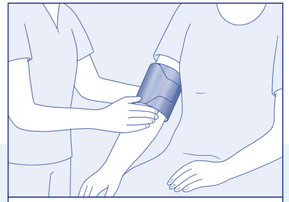
Patient is admitted into the OR

After seeing the patient, the nurse decides the correct size cuff

At present, this is an issue, as sizing is guessed before treatment, affecting correct use

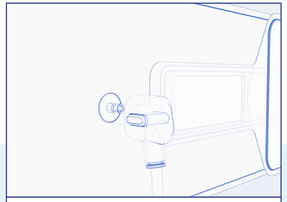
The right size cuff is taken form the sensor station

As this is in the treatment room and sizes are cleary indicated, this is hassle free for nurses



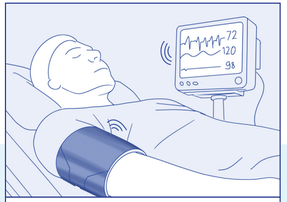
The Revo Care cuff is placed on the patient

This is supported by the intuitive application indicators on the cuff



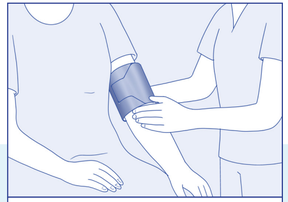
The air hose is attached with the quick connector

The air hose stays stationary at the patient monitor for direct reuse

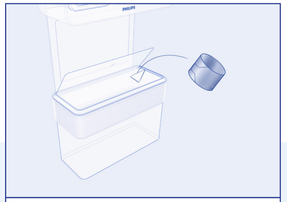


Use on patient is tracked and added to the cuff's digital passport through RFID

This is necessary for predictive maintenance and correct EoL

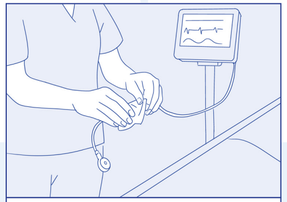


After treatment, the air hose is disconnected and the cuff is removed from the patient



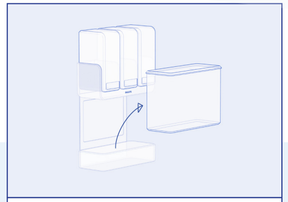
Nurse discards the cuff at the sensor station for reprocessing

This is hassle free, as the station is placed within the treatment room



Equipment, including NiBP hose, get disinfected in for the next patient

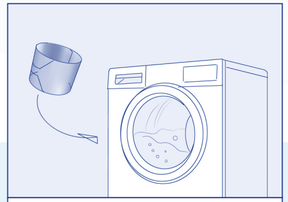
The hose does not make direct skin contact with the patient, so safe direct reuse is possible



At the end of day, all Sensor Station bins are collected

Because of the lid, these remain sealed, safe for handling by logistical staff

Collected bins are transported to a centralized reprocessing area



All cuffs and bins are thoroughly cleaned by certified personnel

This ensures proper cleaning, in contrast to current practices

The cuffs' digital passports are updated

This is enabled through RFID and provides necessary traceability insights

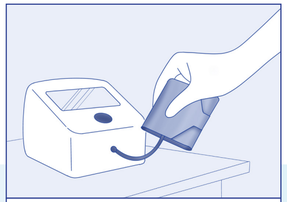
System showcases the cuff is clean and ready for redistribution

Reprocessed cuffs and bins are redistributed to the sensor stations

RFID tracking gives insights in stock levels across different treatment rooms

Figure 41: Revo Care clinical context storyboard

System showcases the cuff needs its smartly scheduled quality check and maintenance



Maintenance is carried out

If the cuff does not show quality issues, it is brought back into the system. If it is faulty it is discarded.

Reprocessed cuffs and bins are redistributed to the sensor stations

RFID tracking gives insights in stock levels across different treatment rooms

The cuff has reached its maximum rated cycles

Through smart tracking, it is known precisely when the cuff reaches its EoL

Cuff is discarded in recycling bin

As the cuff is already cleaned and made of a monomaterial, regular recycling is possible.

A CIRCULAR BUSINESS MODEL

For this Philips Revo Care system to succeed, a fundamental shift in the underlying business model is essential. Within this concept, a shift takes place from a volume based model, built around low cost consumables sold per unit, to a performance based model.

With Philips Revo Care, the cuff itself is built for extensive reuse, and is optimised for recycling at the EoL. Additionally, there is a completely new service which includes inventory managing, infection risk prevention, and certified reprocessing workflows. This shifts the value from the product itself to the ability to deliver safe, traceable, and sustainable blood pressure measurements. This means that the value proposition shifts beyond the physical product, which cannot be captured effectively in a convential volume based model.

The RFID tracking embedded in Revo Care makes this model operable in practice. It enables effective billing through the tracking of use cycles, it lenghtens product lifetime through smart maintenance and usage tracking, and provides automated inventory control. As a result, Philips can run the logistics more economically efficiently.

Next to aligning the business models to better suit the shift in value, it also aligns incentives across the system. As Philips retains ownership, it is motivated to design the cuffs for durability, traceability and safe reprocessability of the cuffs, encouraging effective use of CRFs.

By moving from product sales to performance delivery, Philips can unlock the full potential of Revo Care in terms of circularity, while remaining economically viable for Philips and attractive for hospitals.

6.4 Revo Care evaluation

LIFECYCLE COMPARISON

To evaluate the lifecycle impact of the Revo Care Cuff compared to the current Gentle Care Cuff, another fast track LCA was performed. This LCA showed that over 200 patients, the conventional number of patients for a reusable NiBP cuff before it reaches its EoL (personal communication, Philips, 2025), there is a significant reduction in lifecycle impact between the current and proposed design. The lifecycle impact of the Revo Care Cuff for 200 patients with a 6 day hospital stay and local reprocessing in between each patient (with a reusable microfiber cloth with QAC (Quaternary Ammonium Compound) disinfectant) is 6,4 kg CO2 equivalent. Compared to the same use case for the disposable Gentle Care Cuff, which has a lifecycle impact of 109,4 kg CO2 equivalent, this is approximately 16 times less. Within this change, there is, unsurprisingly, a masive shift in relative impact in their respective lifecycle, as can be seen in Figure 42, with full calculations in the Appendix L.

As "Reuse" was introduced, a lifecycle impact drop was expected. However just considering one use cycle and no reuse, there is still a very significant 68% reduction in environmental impact visible. This is due to the cuff design interventions, such as a reduced phyiscal footprint, less components, lower impact materials and recycling at EoL.

Notably, since each cuff requires local reprocessing between patients, which includes additional inventory, the environmental impact is higher than that of currently implemented direct reuse systems. While some hospitals effectively and safely use direct reuse NiBP cuffs, many still rely on disposable options. For these settings, the Revo Care system offers a potential solution to reduce infection risks while improving sustainability.

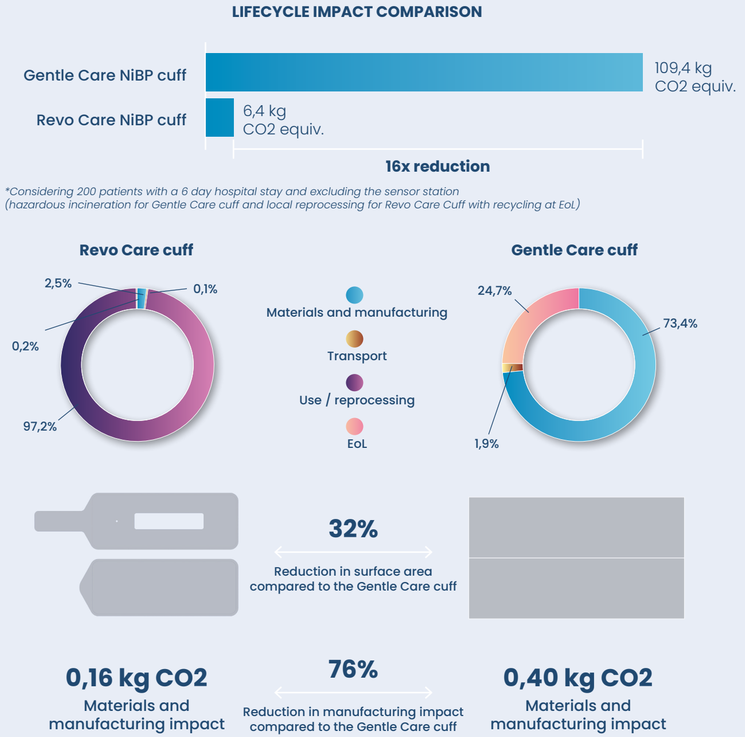


Figure 42: Lifecycle impact comparison between Gentle Care and Revo care cuffs

Figure 43: Physical paper prototype of the Revo Care cuff

PHYSICAL TESTING

To evaluate if the design and dimensions work as intended, a paper prototype was created. This paper prototype featured a 1:1 scale, the actual NiBP air inlet connector, and Binder MicroDuotec for the fastening.

The design works as intended in terms of sizing indicator, connector placement and artery index marker. The new shape also did not provide any problems in terms of ease of handling and application. However, as the paper prototype is quite fragile, the micro hook-to-hook could not be tested extensively in terms of closing and opening. On first impressions, it does however seem to work. While the prototype does not have the actual material, a sample of a woven PP material with a PP laminate from Rivertex however also seemed promising on first sight and feel.

PRODUCTION EVALUATION

Through disucussions with a Philips material and a sustainability expert, the design was deemed feasible in terms of production and materials, although extensive material testing should be considered as new materials will have to be developed, which have not yet been approved for skin compatibility or for performance sustainment in long term use.

CLINICAL USE EVALUATION

Lastly, with the full system and product concept were evaluated with a user from Karlinska University Hospital and secondary input from UCLA Health hospital. From this, it could be concluded that everything from the product design was an improvement compared to the current design, from the connector placement, use cues, design and functionality, to extra rounded corners for patient comfort. The system seems well thought out, and from a user perspective would encourage the intended behaviour. However, while theoretically feasible, the system design has notable challenges. First, while this was done because of the scope of the project, the system would only be feasible if done for most consumables used in hospitals. Next, the costs associated with this system in terms of space, workforce and procurement need to be evaluated, as these will probably be relatively high to the current direct reuse solution. Lastly, it was confirmed that an in-room collect and dispense station, although space could be an issue, and only if done for more consumables, would be a good solution to encourage circular behaviour, as this is currently a bottleneck.

RECYCLING EVALUATION

With a recycling expert from MIREC, discussions were held to evaluate the design in terms of the proposed recycling. These discussions highlighted the effectiveness of a PP monomaterial for recycling. The expert did not foresee any problems with recycling and confirmed that the RFID could likely be seperated through shredding in the current form. However, the expert suggests to make a functioning prototype to validate if issues arise, such as possible interference between the darker color and Infrared sorters at recycling plants. This would also help establish if the RFID tag can get effectively separated.

DESIGN REQUIREMENT EVALUATION

While the design requirements were consulted throughout the design phase, a final check is performed to see if all requirements are satisfied, and which wishes could be implemented.

When evaluating the design requirements, as can be found in chapter 5.1, all are satisfied by the Revo Care concept. However, for some of these, assumptions were made. The assumptions are that production costs are will be lower, as less components and production processes are used and a smaller surface area in materials. However, this assumes that costs for the new materials and RFID will not put an significant additional strain on the costs. Next, while experts confirmed that a PP cuff material could be safe to use, and be up to par in terms of performance, this material could not been tested for its mechanical properties and skin safety. The same goes for regulation compliancy. Last, the clinical user requirements will have to be tested in practice, but for now have been assumed as satisfied through user evaluation sessions. Apart from these assumptions, all requirements and wishes are justifiably satisfied.

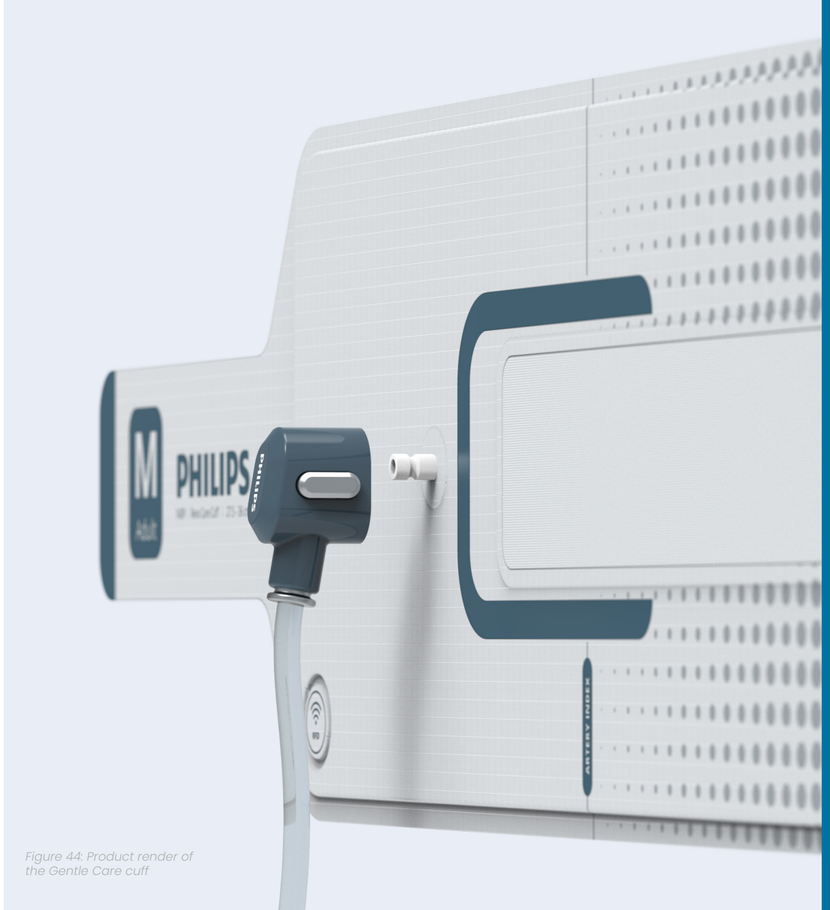


Figure 44: Product render of the Gentle Care cuff

7. Discussion

7.1 Project discussion

REVO CARE

Philips Revo Care is a circular product service system developed to address the environmental impact of current NiBP cuff use in high acuity hospital care. It combines the infection control benefits of single-patient-use with the sustainability advantages of reuse. By shifting reprocessing responsibilities from overburdened nurses to certified personnel, the system enables safe and compliant reuse through local reprocessing. At the core of the system is the Revo Care Sensor Station, which serves as the central touchpoint for clinical, logistical, and reprocessing staff. Located in high-acuity treatment rooms, the station supports hygienic cuff dispensing and collection, while its RFID-enabled tracking system facilitates usage traceability, efficient inventory management, predictive maintenance, and responsible end-of-life handling. Together, these elements significantly reduce the environmental impact compared to the case study product, being 16 times less impactfull over its full lifecycle.

From a product design perspective, environmental impact is reduced by 68% through a smaller physical footprint, fewer components, full recyclability, and lower impact materials. This is achieved through having a monomaterial polypropylene (PP) construction, a detachable hose connector, and a compact micro hook-to-hook fastener. Next to environmental gains, it introduces user experience upgrades through a quick connect hose, removing and overwhelming cuff markings, and introducing intuitive sizing and placement indicators, enabling more accurate and reliable measurements.

Despite its potential, several barriers to implementation exist. The success of Revo Care is heavily relient on the willingness of hospitals to disruptively change their way of working. This includes a shift in procurement practices, from purchasing products to procuring a service, as well as adjustments to clinical protocols. While the system is designed to be intuitive for nurses, it introduces new roles requiring dedicated, certified personnel for reprocessing.

Additionally, there could potentially be significant costs involved with the need for personnel who have to dedicate time to reprocessing, and the physical space needed to do this. Current direct reuse practices in high acuity settings are often more cost effective and faster, as cuffs can be reused at the bedside without the need for extensive logistical networks. However, due to the associated infection risks, this approach remains flawed and not widely adopted.

Another barrier is that valuable real estate has to be sacrificed both within the treatment rooms for the sensor stations, as well as in or near the hospital for the reprocessing. While users confirmed that a sensor station within a treatment room would be appreciated and needed to enable effective reuse of conventional disposables, finding sufficient space for it may prove challenging.

Lastly, barriers exist in inventory and usage management. The Revo Care system operates independently from existing in-house inventory management systems, which may create challenges in integration. Aligning with hospital IT infrastructure could prove complex and, in some cases, incompatible, limiting adoption.

Revo Care recommendations

To address these issues and to validate assumptions, several recommendations are done.

First, it is recommended to scale the Revo Care system to most reprocessable consumables within hospitals. By including other consumables, such as, for example, ECG leadset, multiple reusables can benefit from the same infrastructure. This helps hospitals to avoid fragmented logistics, while making use of economies of scale, justifying the space required for a consumables station in the treatment room, as well as space for reprocessing. As the scope of this project was NiBP specific, this was however left out of scope for this thesis.

Second, to support the first recommendation, efforts should be made to standardise the system across multiple OEMs. Hospitals often use different suppliers for different consumables, for which effective interoperability in terms of reprocessing and digital passport management is necessary for Revo Care to work effectively.

Third, as the Revo Care is still very much a concept, a clinical pilot is recommended to validate real-world effectiveness of the system. This would test if system integration is possible, if reprocessing logistics are feasible, and if the clinical use experience is actually improved as expected.

Lastly, for the physical NiBP Revo Care cuff, further investments in R&D are necessary to validate the mechanical properties of the fastening system and monomaterial PP components for user experience, long term durability, infection control and regulation compliancy.

THE BROADER SCOPE OF IN-HOSPITAL MONITORING SENSORS

This thesis has thus far focused on the case study of the circular redesign of NiBP cuffs. However, many of these methods, design decisions and systemic interventions explored throughout the case project have a relevance for the broader scope of in-hospital monitoring sensors in high acuity settings.

Before diving into recommendations for circular design in in-hospital patient monitoring sensors, it is valuable to discuss where in the realm of these sensors NiBP cuffs fall, and for which sensors findings could apply.

The NiBP cuff can be classified as a low-value non-critical item in the design framework for circular medical products, developed by Kane et al. (2017). This means that findings will typically relate to other sensors in this quadrant. However, as this thesis focused on high acuity settings, where infection risks are a priority topic, findings could be relatable to higher criticality devices. Due to the lower economic value, refurbishment and remanufacturing were left out of the final design. For higher value sensors, these CRFs could provide opportunities. Additionally, reuse strategies will also become more viable for higher value items, as procuring less sensors could offset the additional logistical costs associated with them.

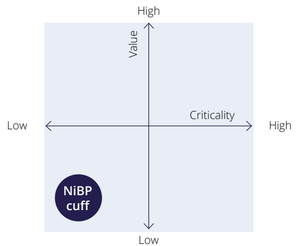


Figure 40: Positioning of NiBP cuffs on the desing framework for circular medical products

Circularity challenges in high acuity settings

When designing for circularity in high acuity settings in in-hospital sensors, such as SPo2 sensors or ECG leadsets, there is a high change that other designers face similar obstacles as the case study product. The foremost challenge exists in infection control, which drives the use of disposable consumables. To enable reuse, system interventions will need to take place to ensure that reuse can be done safely. Current HAI risks are caused by inadequate disinfection during direct reuse reprocessing, and should thus be either resolved or avoided by for example shifting responsibilities to less time constrained personnel. Further challenges exist in the perception of clinical staff that reusables are unsafe, and a lack of awareness in environmental impact of disposables limits the correct adoption of reuse systems. These can be adressed by issueing “new” reprocessed cuffs at every patient and by implementing behaviour encouraging measures, such as a in-treatment room collect and dispense system.

Circularity challenges in traceability

In-hospital monitoring sensors are often consumable sensors, with little to no visibility into their usage or lifecycle stage. Most hospitals lack reliable systems to track product age or condition, which poses a significant barrier to implementing circular strategies. Without this data, ensuring compliant use, timely maintenance, or tracking of repairs becomes difficult. Introducing digital product passports, enabled by low cost and low impact passive RFID tags,is a solution to this problem. This tracks actual usage and enables data driven lifecycle and inventory management. Unlike estimations based on worst case scenarios currently used for compliant use, usage can be determined by actual cycles, prolonging the use time. Next to that, predictive maintenance can ensure proper functioning of the product before issues arise.

Circularity challenges beyond the user

While it is important to adress challenges regarding implementing circularity for users for effective adoption, it is important to recognise that end users are not typically responsible for procurement decisions. Purchasing is often handled by decision-making units with priorities that differ from those of clinical staff. Cost, compatibility, compliancy and procurement strategies often dictate decision making. To ensure a circular product or service enters the hospital system at all, it must align with these procurement priorities alongside focusing on circularity.

Circularity challenges from a business perspective

Introducing circular in-hospital monitoring sensors, without challenging the linear volume based business currently often used, risks making the new product unviable. Adopting CE enabling business models makes sure to capture the newly added circularity value. Additionally, traditional revenue models tied to unit sales disincentivise design for longevity, traceability, and reuse. Circular business models, such as service-based or performance-based offerings, enable OEMs to retain ownership, which promotes designing for longevity.

Reprocessing strategy considerations
Reuse has the potential to be highly impactful for a high number of single-use in-hospital monitoring sensors. However, the viability is highly dependent on context. There are three different processing methods: direct reuse, local reprocessing, and centralised reprocessing. Each of these reprocessing methods has distinct trade-offs in terms of risk, infrastructure, scalability and costs.

Table 6: Reprocessing strategy consideration overview

STRATEGY	INFECTION CONTROL	SYSTEMIC CHANGE	SCALABILITY NEED	SUITABLE FOR
DIRECT REUSE	Low	Minimal	None	Low-risk, low-cost items
LOCAL REPROCESSING	High	Moderate	Hospital scale	Medium-value sensors
CENTRALISED REPROCESSING	High	Extensive	Regional/national	all sensors combined

While direct reuse requires little resources and change, it is only feasible for low-risk reusable sensors, as disinfection cannot be guaranteed. Local reprocessing does guarantee infection prevention, but already requires extensive change within the hospital workflows and is most viable if done for more in-hospital sensors. Centralized processing is the most extensive measure and is only viable if done in large quantities across many hospitals for most to all in-hospital monitoring sensors. This is not only needed to offset the logistical associated costs, but also to offset the environmental impact this brings along. Ultimately, choosing a reprocessing strategy is not a one size fits all decision. It requires evaluating infection control requirements, product specifications and scale at which it is required to operate.

PROJECT LIMITATIONS
This thesis offers practical insights and strategic design guidance for circular innovation in in-hospital monitoring sensors across the end-to-end value chain. However, several limitations must be acknowledged regarding the scope, generalisability and depth of validation.

Case-specific scope
Reaching the objective of generating insights and recommendations for circular design in in-hospital patient monitoring sensors was done through a case study. However, this case study focuses on a relatively simple in-hospital monitoring sensor, which is non-invasive, has low economic value, and is used in high-acuity settings. This enabled depth in the study, but limits the level of certainty of applicability of findings onto other in-hospital monitoring sensors with different product characteristics or context.

Confidentiality constraints
The scope includes the redesign of a yet-to-be-released Philips monitoring product. Due to confidentiality, the Philips Gentle Care NiBP cuff served as a proxy, selected for its functional overlap and relevance. While the approach allowed for meaningful insights, certain design details and trade-offs specific to the confidential product could because of this not be explored in depth.

Regional context
The case study was focused on the dutch Dutch healthcare system and regulations. Clinical protocols, regulatory structures, and available logistics may differ internationally, which may affect certain system level recommendations.

Environmental assessment accuracy
Fast-track LCAs were conducted throughout this thesis. This works with accurate standardized data, but also includes assumptions. While this is sufficient to map hotspots of the lifecycle impact of the product, it is not ISO compliant for auditing. Therefore, resulting claims are comparative rather dan definitive.

Assumptions in adoption behaviour
Within the case study, user research was conducted to guide usability and workflow integrations. However, apart from a user validation interview, no physical user testing was done with the final redesign through simulations or physical prototypes with users. Future behaviour-related risks such as non-compliant use, logistical hurdles or informal workarounds remain untested.

Regulation compliancy assumptions
While assumptions are made about compliancy with MDR 2017/745 and ISO 10993 through expert interviews, extensive regulatory testing and biocompatibility testing should be done to ensure that this is the case.

Mechanical performance assumptions
The redesigned product makes carefully considered assumptions in mechanical performance of materials. However, repeated long term material and product testing should ensure if the mechanical properties behave as required throughout repeated inflation and reprocessing cycles.

7.2 Personal reflection

This graduation project grew out of a desire to finish my master's with something meaningful, a project where I could unite my interest and expertise in sustainability with my growing fascination for medical design. I feel very fortunate to have found that opportunity at Philips, as it offered the perfect context to explore a challenging sustainability problem in the field of patient monitoring, but also gave me a front row seat to see how professionals work. It allowed me to work alongside experts from across the world, from the Netherlands to Germany and the US, where I was able to test both my design skills and my ability to operate within a large corporate setting, a valuable experience as I prepare for the next chapter of my career.

This project truly was a good final showcase of my skills as a designer, as it allowed me to work across the full spectrum of design. From analysing a problem to its roots, to product development, strategic systems thinking and convincingly communicate my creations to stakeholders. It was also a good moment to put my professional soft skills to the test, working independently, coordinating with stakeholders, and planning and adapting the project effectively. It allowed me to take full ownership of every phase of the project. What I am most proud of is not just the final result, but the way I navigated the project towards the final outcome.

That said, the journey was not always without difficulty. At times I felt lost, and did not see how the vast amount of insights I gathered over the multiple domains could be focused into something tangible in the short amount of time I had. The shear volume of the analyses done in the end inhibited me to move efficiently to next phases. I learned the hard way that more is not always better. Combined with a pressure to deliver in a condensed timeline, as the project started three weeks later than originally planned planned, it led to some intense weekends and late nights of work. It tested me, but I am happy that I leaned into this challenge and it showed me what I am capable of. However, for the future, I now know that clarity and focus are not just beneficial to the final outcome, but are also essential for your peace of mind.

This project also taught me that circular design is not something you master in a single assignment. It is a field that continues to evolve, and while I feel I have built a strong foundation, I am aware there is still much more to uncover. I leave this project with a deeper understanding, but also with a clear desire to keep expanding my skills and knowledge in circularity.

At the start of the project I set three personal goals. First I wanted to immerse myself in circular design. Today I feel confident and excited to put these skill to use beyond academics in my future career. Second, I hoped to sharpen my strategic lens. The hollistic approach I took, blending product and system design, proved the perfect challenge where I have grown in this area. Lastly, as design projects are usually group projects, I wanted to test myself to see if I could independently lead and execute a large scale, end-to-end project, of which I am very proud of how I handled that.

Zooming out, this project marks the closing of a very special time of my life. During my years at the IDE faculty I got to develop myself and my design toolkit and got to meet people who I will call friends for life. I now look forward to some well deserved time off in Indonesia and am curious to see how my skills as a designer will contribute to my desire to impact people and planet positively.

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Appendices

A. Taxonomy of Circular Recovery Flows (Hoveling et al., 2023)

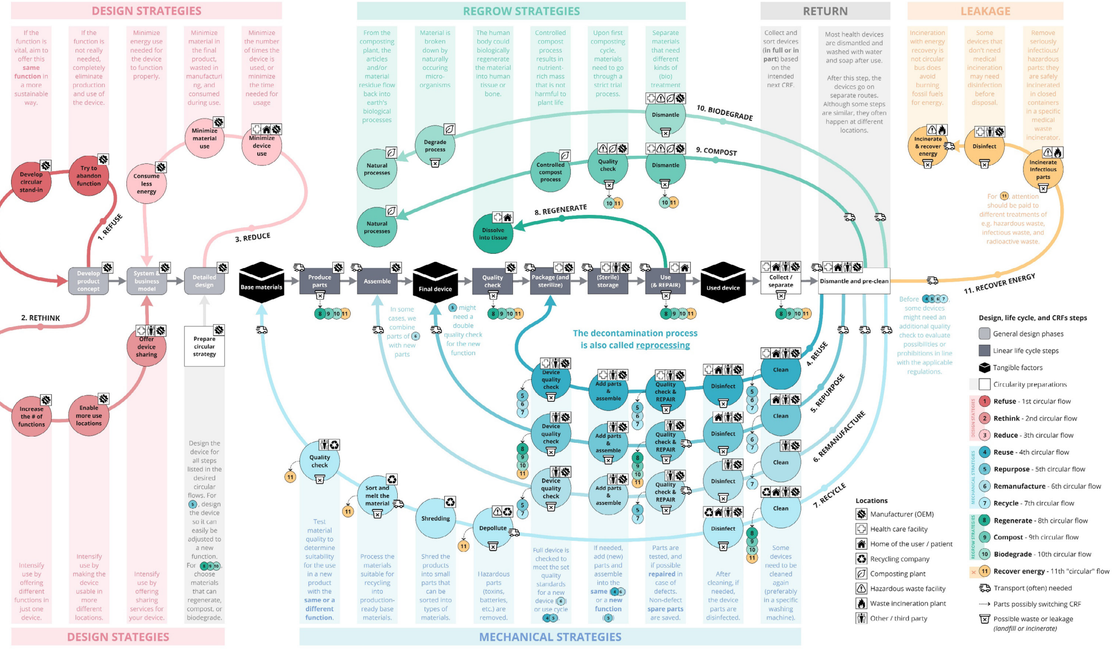


Figure 2 - Circular Recovery Flows (CRFs)

Hoveling et al. (2023)

B. Healthcare specific circularity barriers for NiBP cuffs (adapted from Hoveling et al., 2023)

Barrier	Category	Applicability notes for NiBP cuffs
Safety, infection, and contamination risks	safety	Used in high acuity settings
Focus on use and clinical outcomes, opposing circularity	Safety	Because of high infection risks (see barrier 1.1), they opt for single use for patient safety.
Careless adherence to decontamination method (human factor)	Safety	Due to hospital staff workloads, there is less time for decontamination, making single use in times favourable.
Practical difficulties related to collection and separation logistics	Systemic	Low economic value and medical waste, make collection difficult
Difficulty to move away from linear norms	Systemic	Thrown away together with medical waste
Time constraints of all stakeholders	Systemic	The product has been the same for 30+ years, due to regulatory barriers
Regulations that complicate the process	Regulatory	New projects must undergo a long and expensive procedures, before coming onto the market
Differences in device value (high value gets circular priority)	Financial	Relatively inexpensive consumable, making reprocessing economically challenging
Focus on and need for high quality and function of the device	Technological	Reliability is key for this type of product, for accuracy and dependencies.
(Outdated) designs not intended for circular strategies (+ forced obsolescence)	Technological	This product is specifically made to be single-use with a 30+ year old design
Unawareness about and complexity of the circular economy	Social	Hospital staff that handles NiBP cuffs are unaware of the environmental impact of everything they use
Lack of trust/social acceptance that leads to favourable behaviours (partly due to greenwashing)	Social	Hospital staff prefer single use, as they are then sure it is safe to use in high acuity situations
Attitudes, preferences (or differences between), and lack of support	Social	Costs are seen as more important in this product range than environmental impact

Adapted from Hoveling et al. (2023)

C. Base NiBP design requirements

Correct use:

- **Correct cuff sizing** — undersized cuffs give to high readings, oversized cuffs do the opposite
- **Correct bladder positioning** — Artery has to be in the middle of the bladder for correct use
- **Correct tightness** — 1 to 2 fingers should be able to fit in between
- **Correct positioning in accordance to the heart** — Should approx. be level with the heart

Mechanical requirements:

- **Bladder size** — 130 x 400 mm
- **Bladder shape** — Rectangular as is
- **Air tight bladder** — Necessary to determine correct inflation pressure
- **Resistant to tearing** — Due to high air pressure
- **Fatigue resistant** — Due to repeated inflation
- **Non elastic** — For accuracte measurements
- **Comformable to upper arm contours** — Must comfortably fit the patient

Comfort and biocompatibility:

- **Skin contact safe** — ISO 10993
- **Non abrasive surface**
- **Avoid sharp corners** — Digs into the skin during inflation
- **Non-toxic additives in production**
- **Latex and PVC free**

Cleanability:

- **Tolerant to disinfection agents** — Needed for both single- and multi-use
- **Easy to clean surface** — Non-porous, smooth and non absorbant

D. Bill of Materials (BoM)

Part description	Part photo	# / parts	Material	Length (mm)	Width (mm)	Height (mm)	Volume (cm3)	Density (g/cm3)	Net weight (g)	Net surface (m2)	Net lenght (m1)	UoM	Net Weight (g) / m2
Cuff sheet material		1	RF Heat Sealable EVA polyolefin laminated to 2oz Sontara 100%polyester	525	278	0,35	51,1	0,62	31,7	0,146		m2	218
Ink prints		1	Ink (for disposable cuff)	40	40	0,04	0,1	1,05	0,1			kg	
Hook closure		1	White Hook 100% nylon with weldable adhesive system	125	100	0,4	5,0	1,83	9,1	0,013	0,125	m2	
Loop closure		1	White Suede Olefin Alloy (3oz Nylon Loop)	210	100	0,51	10,7	1,03	11,0	0,021	0,21	m2	
Air hose		1	Material: Kraton Color: White	205	7,6	diam. (inner 4.5mm)	6,0	1,09	6,6		0,205	m1	
Lubricant for hose - connector		2							0,2			kg	
Hose Attachment		1	Plastic EVA Tapered Nipple	13	15	diam.	0,3	1,15	0,36			kg	
Cuff connector		1	White nylon male connector	23	11	diam.	0,6	0,77	0,47			kg	
Plastic bag		1	PE	310	250	0,050	7,8	0,96	4,34			piece	
Enclosure 1 (product info)		0,1	Paper	215	139	0,08	2,4	0,80	2,17	0,030		kg	73
label on enclosure 1		0,1	Paper	38	26	0,07	0,1	1,14	0,08	0,001		kg	80
Enclosure 2 (Instructions for use): BW, 11 sheets + 2 staples		0,1	Paper	210	150	0,07	25,8	0,77	19,84	0,347		kg	57
Plastic bag		0,1	PE	610	300	0,038	14,0	0,96	10,83			piece	
Total									63,9				

E. LCA input Gentle Care Cuff

Purpose: Estimate biggest impacts to set design priorities
Boundaries: See value map
Functional unit: Environmental impact per patient being NiBP monitored
Impact unit: kg CO2 eq.
Uncertainty rubric: 10% for database perfect match, 30% for plausible substitution, 100% for wild guess

Design option:
NiBP cuff Dutch hospital flow

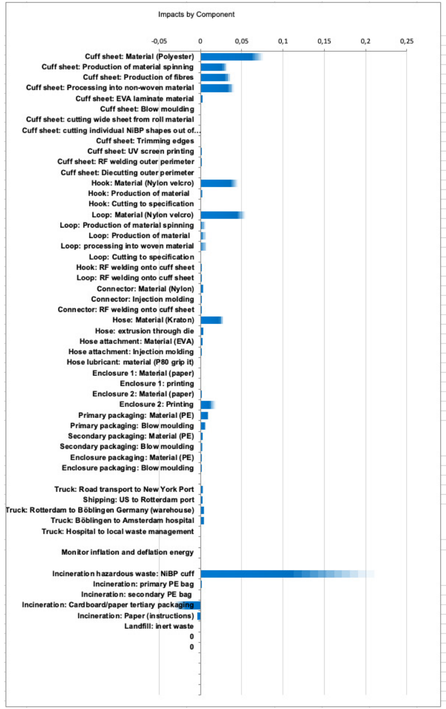
Manufacturing	Eco-intensity (impacts/kg)	Mass per item (kg)	Items per func.unit (#)	Uncertainty (%)	Index	Notes	Calculated impact
Cuff sheet: Material (Polyester)	2,190	0,0317	1	10%	A.130.07.118.230701 PET (Polyethylene terephthalate) bottle grade		0,069423
Cuff sheet: Production of material spinning	0,918	0,0317	1	10%	A.140.03.116.230701 spinning extruder polymer filaments (80 - 500 dtex)		0,029096
Cuff sheet: Production of fibres	1,046	0,0317	1	10%	A.140.03.103.230701 heat setting and washing synthetic fabrics		0,033149
Cuff sheet: Processing into non-woven material	1,167	0,0317	1	10%	D.120.01.106.230701 injection moulding, production site		0,036994
Cuff sheet: EVA laminate material	3,619	0,00036	1	10%	A.130.05.103.230701 EVA (ethylene vinyl acetate rubber)		0,001303
Cuff sheet: Blow moulding	0,012	0,00036	1	10%	D.120.01.102.230701 blow moulding, production site		4,43E-06
Cuff sheet: cutting wide sheet from roll material			1			negl.	0
Cuff sheet: cutting individual NiBP shapes out of material			1			negl.	0
Cuff sheet: Trimming edges			1			negl.	0
Cuff sheet: UV screen printing	0,492	0,0016	1	10%	D.110.01.103.230701 Printing per m2, 100%, UV, inkjet		0,000788
Cuff sheet: RF welding outer perimeter	0,052	0,015	1	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,000774
Cuff sheet: Diecutting outer perimeter			1			negl.	0
Hook: Material (Nylon velcro)	4,520	0,0091	1	10%	A.130.07.104.230803 PA 6 (Nylon 6, Polyamide 6)		0,041132
Hook: Production of material	1,167	0,0091	1	10%	D.120.01.106.230701 injection moulding, production site		0,01062
Hook: Cutting to specification			1			negl.	0
Loop: Material (Nylon velcro)	4,520	0,011	1	10%	A.130.07.104.230803 PA 6 (Nylon 6, Polyamide 6)		0,04972
Loop: Production of material spinning	0,918	0,011	1	30%	A.140.03.116.230701 spinning extruder polymer filaments (80 - 500 dtex)		0,010096
Loop: Production of material	1,046	0,011	1	30%	A.140.03.103.230701 heat setting and washing synthetic fabrics		0,011503
Loop: processing into woven material	3,644	0,011	1	10%	A.140.03.125.230701 weaving 200 dtex		0,040082
Loop: Cutting to specification			1			negl.	0
Hook: RF welding onto cuff sheet	0,052	0,015	1	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,000774
Loop: RF welding onto cuff sheet	0,052	0,015	1	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,000774
Connector: Material (Nylon)	4,520	0,00047	1	10%	A.130.07.104.230803 PA 6 (Nylon 6, Polyamide 6)		0,002124
Connector: Injection molding	1,167	0,00047	1	10%	D.120.01.106.230701 injection moulding, production site		0,000548
Connector: RF welding onto cuff sheet	0,052	0,015	1	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,000774
Hose: Material (Kraton)	3,785	0,0066	1	10%	A.130.05.101.230701 BR and IIR (butadiene rubber and butyl rubber) in tires	Kraton has similar properties like rubber	0,024981
Hose: extrusion through die	0,335	0,0066	1	10%	D.120.01.104.230701 extrusion, production site		0,00221
Hose attachment: Material (EVA)	3,619	0,00036	1	10%	A.130.05.103.230701 EVA (ethylene vinyl acetate rubber)		0,001303
Hose attachment: Injection molding	1,167	0,00036	1	10%	D.120.01.106.230701 injection moulding, production site		0,00042
Hose lubricant: material (P80 grip it)			1			negl.	0
Enclosure 1: Material (paper)	0,405	0,00217	0,1	10%	A.120.01.106.230701 Paper, woodfree uncoated, bleached		8,79E-05
Enclosure 1: printing	0,012	0,09	0,1	30%	D.110.01.102.230701 Printing per m2, 100%, offset, conventional		0,000111
Enclosure 2: Material (paper)	0,405	0,01984	0,1	10%	A.120.01.106.230701 Paper, woodfree uncoated, bleached		0,000803
Enclosure 2: Printing	1,622	0,09	0,1	30%	A.030.26.101.230701 Printing Ink, Black, conventional		0,014595
Primary packaging: Material (PE)	1,870	0,00434	1	10%	A.130.07.112.230701 PE (LDPE, Low density Polyethylene)		0,008116
Primary packaging: Blow moulding	1,098	0,00434	1	30%	D.120.01.102.230701 blow moulding, production site		0,004766
Secondary packaging: Material (PE)	1,870	0,01083	0,1	10%	A.130.07.112.230701 PE (LDPE, Low density Polyethylene)		0,002025
Secondary packaging: Blow moulding	1,098	0,01083	0,1	30%	D.120.01.102.230701 blow moulding, production site		0,001189
Enclosure packaging: Material (PE)	1,870	0,00434	0,1	10%	A.130.07.112.230701 PE (LDPE, Low density Polyethylene)		0,000812
Enclosure packaging: Blow moulding	1,098	0,00434	0,1	30%	D.120.01.102.230701 blow moulding, production site		0,00047

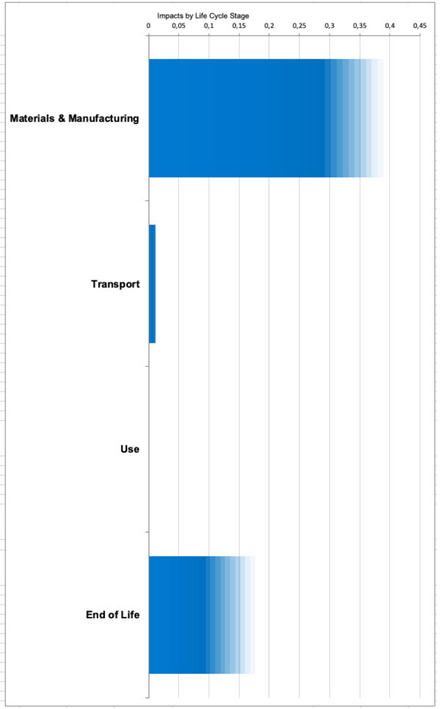
Transport	Eco-intensity (impacts/ ton-km)	Mass per item (ton)	Distance per item (km)	Items per func.unit (#)	Uncertainty (%)	Index	Calculated impact
Truck: Road transport to New York Port	0,076	6E-05	425	1	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	0,002064
Shipping: US to Rotterdam port	0,005	6E-05	5850	1	10%	C.070.01.106.230701 Container ship (min weight/volume ratio 0,41 ton/m3)	0,001785
Truck: Rotterdam to Böblingen Germany (warehouse)	0,076	6E-05	640	1	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	0,003108
Truck: Böblingen to Amsterdam hospital	0,076	6E-05	640	1	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	0,003108
Truck: Hospital to local waste management	0,076	6E-05	20	1	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	9,12E-05

Use	Eco-intensity (impacts/MJ or other)	Amount per item (MJ or other)	Items per func.unit (#)	Uncertainty (%)	Index	Calculated impact
Monitor inflation and deflation energy	0,052	0,00001333	1	30%	B.046.08.130.231201 Electricity New Hampshire production	6,88E-07

End of Life	Eco-intensity (impacts/kg)	Mass per item (kg)	Items per func.unit (#)	Uncertainty (%)	Index	Calculated impact
Incineration hazardous waste: NiBP cuff	2,532	0,064	1	30%	Figure by Philips LCA expert	0,161815
Incineration: primary PE bag	0,054	0,004	2	10%	F.108.01.102.230701 film LDPE 50 mu in mun waste inc	0,000469
Incineration: secondary PE bag	0,054	0,011	0,1	10%	F.108.01.102.230701 film LDPE 50 mu in mun waste inc	5,85E-05
Incineration: Cardboard/paper tertiary packaging	-1,222	0,200	0,1	30%	F.020.01.108.230701 Paper, Cardboard, Leather, Cotton (12% MC) co-firing in electrical power plant	-0,024442
Incineration: Paper (instructions)	-1,222	0,022	0,1	10%	F.020.01.108.230701 Paper, Cardboard, Leather, Cotton (12% MC) co-firing in electrical power plant	-0,00269
Landfill: inert waste	0,00	0,060216	1	10%	F.130.01.106.230701 landfill (inert waste)	0
						0
						0
						0
						0
						0
						0

Raw material contribution	0,216425012	39,6%			
Packaging impact	0,017911156	3,3%			
total supplier materials contribution	0,349361044	63,9%	Materials and mfg	0,4016	73,42%
Manufacturing	0,185148381	33,9%	Transport	0,0102	1,86%
Upstream transport	0,010065351	1,8%	Use	0,0000	0,00%
Downstream transport	0,0000912	0,0%	EoL	0,1352	24,72%
Incineration	0,162	29,6%	**Total**	0,5469	





Goal
The goal of the LCA is to get a better understanding, of where within the value chain, from manufacturing to EoL, does the product have the biggest carbon footprint.

Functional unit
lifecycle carbon footprint (kg CO2 equiv.) for a single use NiBP cuff, doing 10 days of measurement

Carbon footprint (kg CO2 equiv.) per monitor per year with 36 different patients

Assumptions
- A patient is monitored on average 6 days
- Within this period, a single NiBP cuff is used
- Cutting is negligible in carbon footprint
- Raw materials: IDEMAT datasets due to unavailability of actual supplier data.
- Manufacturing operations which are excluded due to low impact:
  - Processes like cutting, press fitting, alligning, quality control and manual labour.
- Production processes for plastics have been (educately) assumed.
- Cuff material is 100% Polyester (laminated EVA is negligible)
- RF welding takes 3 seconds per operation
- Truck: New Hamsphire to port of NY (425 km)
- Shipping: NY port to Rotterdam Port 5850 km
- Truck: Rotterdam to Althengstett warehouse (620 km)
- Truck: Rotterdam to Althengstett warehouse (640 km)
- Truck: hospital to local incineration (20 km)
- A patient is measured 60 times per day (normally dependant on the needs of the situation)
- Energy consumption from a single measurement for inflation/deflation is

Calculation RF welding

Parameters:
Welding time (cycle time): 5 seconds
Machine power rating: 10 kW
Cycle time: 5 seconds

Energy (kWh) = (Power (kW) * cycle time (s) / 3600 = 0,004166 kWh
Energy (kWh) * 3,6 = 0,015 MJ

RF takes seconds:

Power rating RF

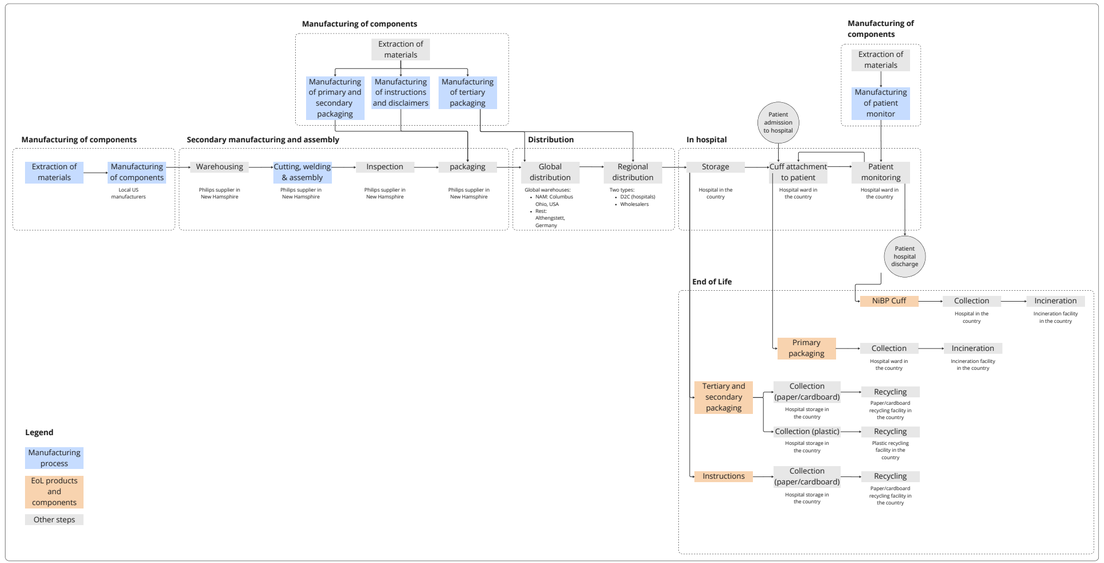
Calculation inflation

Parameters:
Pressure needed: 32.000 Pa (240 mmHg (Very high blood pressure measurement)
Cuff volume: 500 ml (.0005 m3)
Mechanical efficiency: 40%

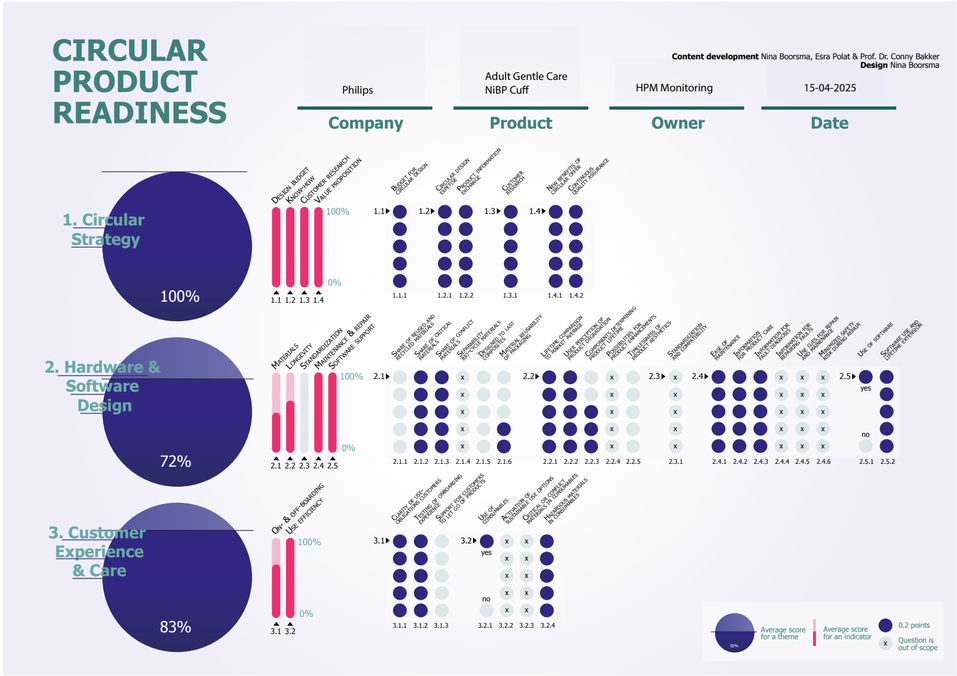
Full cycle energy (J) = inflation energy + deflation energy
Inflation energy = deflation energy
Energy (J) = 2* Pressure increase (in Pascals) * Volume (in m3) * Efficiency
Energy (J) = 2* 32000 * 0,0005 / 0,4 = 80 J
Energy (kWh) = Energy (J) / 3600000 = 0,0000222222

Energy for 10 days measurements = 0,0000222222 * 60 (m/day) * 10 (days) = 0,01333 kWh

High level scope of Gentle Care LCA



F. Circular Product Readiness input



G. Hospital visit context photographs

Hospital visited

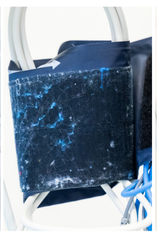
At the Gelderse Vallei, a full day of shadowing and interviews with nurses and doctors were done across the ER, Coronary care unit, Neonatology and OR. Next to that, interviews were conducted with the medical physicist and specialists of Sterile Medical Devices.

At the Prinses Maxima Centre, interviews were conducted with several nurses, as well as the Lead of Medical Devices. Next to that, observations were done across the complete flow from where supply of the NiBP cuffs come in, to use, to how they end their life.

At the Reinier de Graaff, an interview was conducted with the Supervisor Medical Instrumentation.

Reusable context

Cuffs hang at the patient bedside, with one or two differnt sizes in a drawer below. However, these are almost never switched out



Reusable cuffs are kept being used if they give readings. With the lint built-up however, performance cannot be guaranteed

Markings visibly fade and edges fray

Supply rooms on every department hold consumables

NiBP cuffs are somewhere in a corner in a miscelaneous crate

Emergency care

Floor space seems limited, but there is wall space left

Gentle Care cuff is taken from storage before patient sizing is determined

Every ED room has movable bins for normal trash and dirty linens

The department storage room is not closeby enough for quickly getting new supplies

Philips single-patient-use cuffs are used non compliantly for weeks on multiple patients

Pre-induction room

Pre-induction rooms are open and shared

"Broodjes" are prepared before use, when sizing is not determinable

Before entering the pre-induction room, there is a change room to prevent bringing in infections

Items in storage are unclear in terms of different sizing

This area holds many patients with a high turnover

Operating room

Wrongly sized NiBP cuffs usually already hang at the monitors and are reused non compliantly for up to a week

Only the very essential are present near the patient

Storage carts are nearby with single use consumables

Floor space is limited

PACU

After operations, patients are held in the post anesthesia care unit

Every patient has their own monitoring station

Many patients in the same room

Of to the side, bins are placed, which are used to discard items used in PACU

Author

H. Future scanning

SOCIETY
(0 - 5 years)

Reusable medical products' public trust is limited by infection risk perception
"There is a profound lack of awareness of SUD reprocessing and reuse among all relevant stakeholders. ... Despite research and history having shown the practice to be safe, apprehension and misconceptions remain. Survey results suggest that education may be able to subdue such patient concerns." - Grantcharov et al., 2019

Climate concious generations are emerging and entering the healthcare workforce
"Understanding the needs and wishes of Generation Z is crucial to attracting and retaining them in the health-care profession and to helping organizations make working life in the sector more sustainable." - Kanste et al., 2025 https://www.sciencedirect.com/science/article/pii/S0260691725001133
"Younger generations in the U.S. are especially likely to express an interest in addressing climate change – and to say they have personally taken some kind of action to do so." Funk, 2021

The world population is aging, increasing pressure on healthcare
"People worldwide are living longer. Today most people can expect to live into their sixties and beyond. Every country in the world is experiencing growth in both the size and the proportion of older persons in the population." - WHO, 2024

Climate change means more pressure on the healthcare system
"Climate change is directly contributing to humanitarian emergencies from heatwaves, wildfires, floods, tropical storms and hurricanes and they are increasing in scale, frequency and intensity." - WHO, 2023

Workload pressure for healthcare workers reach new high
"Healthcare workers face rising pressures from increasing patient demands, complex health conditions, workforce shortages, administrative burdens, and emotional stress, intensified by evolving technologies" - Sipos, 2024

Increased population size means an increase in patients
"Every country in the world is experiencing growth in both the size and the proportion of older persons in the population." - WHO, 2024

(5 - 10 years)

Sustainability becomes a mainstream societal value, including in healthcare.
"Healthcare ... reflects the growing interest in integrating CE principles into this critical sector" - Saha, et al., 2025
"The increasing interest in CE practices within the healthcare sector reflects a growing focus on sustainability" - D'Alessandro et al., 2024

With health literacy increasing, patients are demanding transparency in healthcare
"By improving people's access to understandable and trustworthy health information and their capacity to use it effectively, health literacy is critical to both empowering people to make decisions about personal health, and in enabling their engagement in collective health promotion action to address the determinants of health." - WHO 2024

Healthcare evolves from reactive, to preventive treatment
"The shift from break–fix to predict–prevent for disease is not only essential for improving patient outcomes, but is also a crucial component for the sustainability of the Australian healthcare system." - Sullivan, 2024
" Linking discovery science and its translatable innovations beyond reactive disease intervention to proactive prevention will maximize society's returns, creating the greatest benefit for the greatest number of people globally." - Waldman & Terzic, 2018

A shortage of healthcare workers
"The WHO expects a shortage of 4.1 million healthcare workers in the EU by 2030, despite having more health and care workers than ever." - European Parlement, 2025

TECHNOLOGY
(0 - 5 years)

Standardization
"Different monitors and diagnostic devices often need different connections and ports. Over the last few years, we've seen a move toward greater standardization.." GE Healthcare, 2022

Easy-to-clean devices reducing HAIs
"One monitoring trend has nothing to do with data and everything to do with patient safety: easy-to-clean devices that reduce healthcare-acquired infections (HCAI). Up to one-third of HCAIs can be prevented by proper cleaning of medical equipment.4." GE Healthcare, 2022

Single use items in healthcare remain
"Given the inherently stringent hygiene standards, it is still often most advisable to design certain advanced devices as single-use items. Otherwise, significant safety and economic compromises must be accepted. By incorporating modular components, materials that are easier to disassemble, and implementing take-back programs, MedTech companies can enhance the recyclability and resource efficiency of such devices." EY, 2023

Higher availability of recycled materials for medical use
"recent investments in domestic recycling infrastructure and new advanced recycling technologies are poised to deliver recycled plastic resins on par with their virgin counterparts. " HPRC, 2022

Smart Surfaces
"Given the inherently stringent hygiene standards, it is still often most advisable to design certain advanced devices as single-use items. Otherwise, significant safety and economic compromises must be accepted. By incorporating modular components, materials that are easier to disassemble, and implementing take-back programs, MedTech companies can enhance the recyclability and resource efficiency of such devices." EY, 2023

Sustainability drives innovation to gain competitive advantages
"It is more widely recognized that sustainability is a key driver of innovation, and only those companies that make sustainability as a goal will achieve competitive advantage" - Huang, 2021

Digital Product Passports
"DPPs are expected to play a key role in facilitating innovative approaches by enabling the exchange of information on the sustainability parameters of products, such as their carbon footprint and recyclability, across value chains. More broadly, DPPs could be key to enabling circular economy and carbon reduction strategies, including those for new markets and business models, and also to social compliance reporting." - WHO, 2024

AI drives automation and forecasting
"AI is emerging not just as a tool but as a transformative force reshaping healthcare delivery." - European Commision, 2024

(5 - 10 years)

One patient monitor follows the patient
"Some hospital systems have begun using a single monitor platform: one monitor that accommodates patients across multiple care areas. Patient data continues to be collected during transport and at the bedside, ensuring continuity." GE Healthcare, 2022

Biobased material surgence in medical devices
"The global bio-based medical materials market is experiencing robust growth, driven by increasing demand for biodegradable implants and devices, rising awareness of environmentally friendly healthcare solutions, and the inherent advantages of biocompatibility and reduced adverse reactions offered by these materials." DiMarket, 2025

Smart fabrics with integrated pathogen detection, repellency and antimicrobial properties
"The multifaceted attributes of the SF coating provide profound implications for public health, particularly in the mitigation of pandemic risk and nosocomial infections. The integration of antimicrobial properties and a chromatic transition mechanism represents a promising strategy in the ongoing battle against infectious diseases." - Abu Jarad et al., 2024

Upcoming disinfection methods (UV-C, disinfection fogging, steam vapor
Environmental cleaning with steam technology was found to be as effective against MDR microorganisms as a two-step cleaning process (water/detergent and disinfecting with 1,000 resp. 5,000 ppm hypochlorite) in ICUs." Oztoprak et al., 2019
Hydrogen peroxide fogging is a feasible form of disinfection and reduces SSI rates when applied in the OR of a Children's Hospital with a moderate to large surgical volume. Davis et al., 2023
In conclusion, the UVSC equipment is a promising alternative for implementing disinfection protocols in hospitals and other health care settings to inanimate objects that can be used both inside and outside these settings, thus reducing risk of infection transmission. - Guridi et al., 2019

ENVIRONMENT
(0 - 5 years)

Initial signage of growing climate disasters, increasing people's awareness
"We show that not only do hurricanes influence the proportion of people who believe climate change is happening and is caused by human activity, but that they also change the proportion that supports regulating CO2 emissions." Sloggy et al., 2021

Climate change impacts health
"Climate change affects our health. We suffer more from UV radiation, heat stress, allergies and air pollution. Climate change also affects our drinking and bathing water, our food and the prevalence of infectious diseases." RIVM, 2025

(5 - 10 years)

Larger and larger scale climate disasters
"(IPCC) predicts further increases in the twenty-first century, including a growing frequency of heat waves, rising wind speed of tropical cyclones, and increasing intensity of droughts. A one-in-20-years "hottest day" event is likely to occur every other year by the end of the twenty-first century." Banholzer et al., 2014

Global warming reach 1.5 degrees Celsius by 2030
"If the 30-year warming trend leading up to then continued, global warming would reach 1.5°C by June 2030" Copernicus, 2025

E-waste becomes a main waste stream
"Economic growth seen in the past 25 years with changes in Information Technology and the concurrent rapid electronic product obsolescence has generated massive amounts of electronic waste (or e-waste), creating a general waste management issue" Subhaprada & Kalyani, 2017
"A record 62 million tonnes (Mt) of e-waste was produced in 2024, Up 82% from 2010; On track to rise another 32%, to 82 million tonnes, in 2030," Unitar, 2024

REGULATORY
(0 - 5 years)

Increased regulations due to EU-MDR
"While for high-risk legacy devices (class III and class IIb implantable devices) the transition deadline has been set on 31 December 2027, the transition deadline for medium and low risk legacy devices (class I(m, s, r), class IIa and class IIb) is 31 December 2028. " Deloitte, 2023

ESPR (Ecodesign for sustainable product regulation) require EcoDesign in medical products
- "The ESPR enables the setting of performance and information rules – known as 'ecodesign requirements' – for almost all categories of physical goods, including:-
- Improving product durability, reusability, upgradability and reparability
- Enhancing the possibility of product maintenance and refurbishment
- Making products more energy and resource-efficient
- Addressing the presence of substances that inhibit circularity
- Increasing recycled content
- Making products easier to remanufacture and recycle
- Setting rules on carbon and environmental footprints
- Limiting the generation of waste
- Improving the availability of information on product sustainability" European Commission, 2024

(5 - 10 years)

Healthcare becomes net-zero
"The new Green Deal on Sustainable Healthcare sets out agreements to make the sector more sustainable, for instance by using fewer materials and reducing carbon emissions." Rijskoverheid, 2024

EU waste framework directive makes waste monitoring necessary
"The Waste Framework Directive provides additional labelling, record keeping, monitoring and control obligations from the "cradle to the grave", in other words from the waste production to the final disposal or recovery. It also bans the mixing of hazardous waste with other categories of hazardous waste, and with non-hazardous waste." European commission, 2023

ECONOMY
(0 - 5 years)

Tariffs and trade policies increase costs and disrupt supply chains
"Supply chains were not a major manufacturing issue in the medical devices industry before 2020. Now, it's a concern in the C-suite, Evans told Investor's Business Daily." Business Daily 2025

Rising costs of raw materials affect medical device manufacturing
"Continuous Cost Pressures Affecting Medical Technology Manufacturing" MedTech Europe, 2022

Medical costs keep rising
"Medical cost growth will rise to highest level in 13 years; a renewed call to action to address affordability" PwC, 2025

Uncertainties in supply chains
"Supply chain disruptions keep on coming. From missile attacks on commercial shipping in the Red Sea to automotive production delays following floods in Europe, global supply chains continue to experience instability." McKinsey, 2024

Deglobalisation
"Supply chain disruptions keep on coming. From missile attacks on commercial shipping in the Red Sea to automotive production delays following floods in Europe, global supply chains continue to experience instability." McKinsey, 2024

Alternative business models
“Besides focusing on physical products, companies are also offering services such as equipment leasing, maintenance, and upgrades. This shift not only enables MedTech companies to retain ownership and responsibility for the products throughout their lifecycle, but also encourages innovation and drives resource efficiency, allowing for the successful implementation of circular business models.” EY, 2023
“A performance-based business model can be implemented in the medical industry which helps monetize the take-back principle of the EPR. Also commonly known as the servicization model, where the functionality of the products is sold instead of the products itself, ensuring uninterrupted functionality of the product by the providers through continuous maintenance, and product support” Hossain et al., 2025

(5 - 10 years)

A shift from the linear economy to the circular economy
“De Nederlandse economie moet in 2050 volledig draaien op herbruikbare grondstoffen. Voor de overgang naar een circulaire economie werkt de overheid samen met bedrijven en maatschappelijke organisaties.” Rijksoverheid 2025

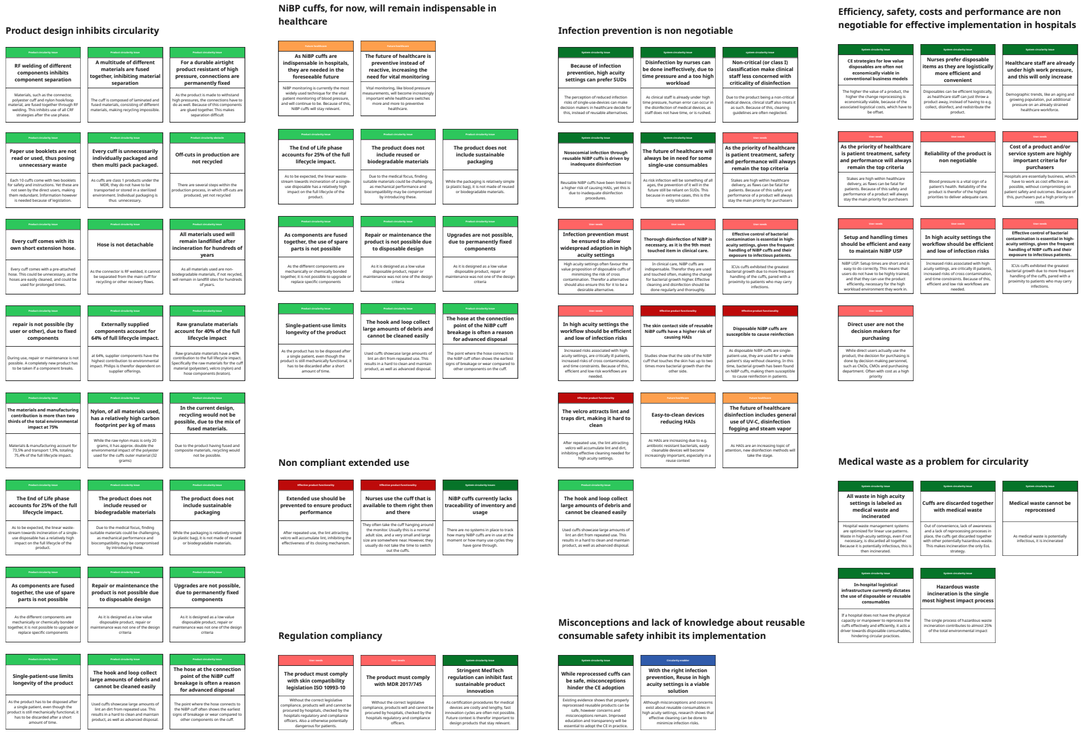
Slowing down of global economic growth
“GDP growth in the United States is projected at 2.2% in 2025 before slowing to 1.6% in 2026. In the euro area, growth is projected to be 1.0% in 2025 and 1.2% in 2026.” OECD, 2025

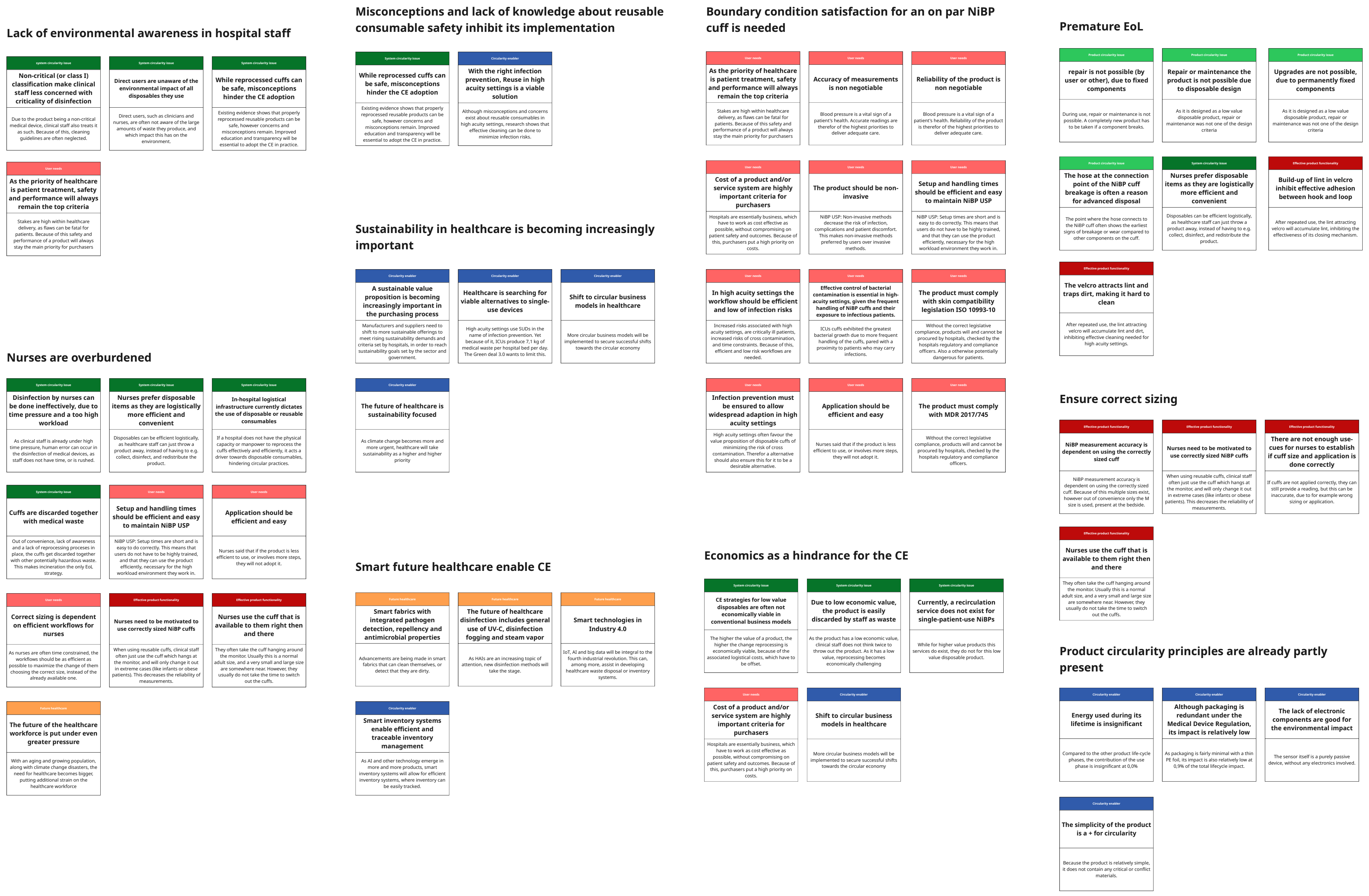
Healthcare as a Service
“However, a new trend is emerging in the healthcare industry: Healthcare as a Service (HaaS), driven by subscription-based models that aim to make healthcare more accessible, efficient, and affordable. “ Asumah, 2025

Collaborative ecosystems
“One of the key trends in advancing sustainability in MedTech is the emergence of collaborative ecosystems. By forging partnerships across the value chain, MedTech companies can optimize the use of resources, facilitate the recovery and recycling of materials, and reduce waste generation. “ EY, 2023

Companies who integrated sustainability gain an competitive advantage
“It is more widely recognized that sustainability is a key driver of innovation, and only those companies that make sustainability as a goal will achieve competitive advantage” - Huang, 2021

I. Affinity mapping (clustering of insights)





I. Affinity mapping (From clusters to design drivers)

Ensure infection prevention
- Infection prevention is non-negotiable
- Misconceptions and lack of knowledge about reusable consumable safety inhibits its implementation

Increase physical product and system circularity
- Product design inhibits circularity
- Medical waste as a problem for circularity
- Premature EoL
- Non compliant extended use
- NiBP cuffs, for now, will remain indispensable in healthcare
- Regulation compliancy

Maintain product USPs for effective adoption
- Boundary conditions satisfaction for an on par NiBP cuff is needed
- Efficiency, safety, costs and performance are non-negotiable for effective implementation in hospitals
- Regulation compliancy
- Infection prevention is non-negotiable

Adopt viable new circularity enabling Business models
- Economics as a hindrance for implementing CE principles.
- Efficiency, safety, costs and performance are non-negotiable for effective implementation in hospitals

Relief nurse responsibilities
- Nurses are overburdened

Sustain product circularity enablers
- Product circularity principles are already partly present

Integrate smart systems
- Smart future healthcare enables CE

Enhance product performance
- Ensure correct sizing
- Premature EoL
- Boundary conditions for an on par NiBP cuff
- Non compliant extended use

Integrate clear use cues and information for CE
- Misconceptions and lack of knowledge about reusable consumable safety inhibit its implementation
- Medical waste as a problem for circularity

Leverage the need for sustainable offerings
- Regulation compliancy
- Sustainability in healthcare is becoming increasingly important

J. Design Requirements elaborated

Requirement	Description	Product/system	From	Category	Mandatory/desirable
Product performance must be on par or better than the current product	One of the top priorities for users for effective adoption	Both	2.3 Healthcare specific barriers	User needs	Mandatory
Infection control must be guaranteed	One of the most important criteria for the use of this product is infection risk prevention	Both	2.3 NiBP monitoring, 4.3 Product Journey Map	User needs	Mandatory
The workflow must be similar in efficiency during patient treatment	High acuity settings are time constrained and need efficient workflows	Both	2.3 NiBP monitoring, 4.3 Product Journey Map	User needs	Mandatory
Application and operations are as intuitive or better	Ease of use is one of the USPs of the current NiBP cuffs	Product	2.3 NiBP monitoring	User needs	Mandatory
Product infection risk perception should be on par with the current product	Perception of infection risks could influence adoption	Both	4.4 Future scanning	User needs	Desirable
Product performance perception should be on par with the current product	Perception of performance could influence adoption	Both	4. Clinical Use Analysis	User needs	Desirable
Should have similar or relieved workload for nurses	Nurses are time constrained, making extra tasks not favourable	Both	4. Clinical Use Analysis	User needs	Desirable
Product should include visually easy to discern sizes	Helps in oversight in stock and convenience for staff	Both	4. Clinical Use Analysis	User needs	Desirable
Product should be the same or better in terms of patient comfort	One of the USPs of the Gentle Care NiBP cuff is increased comfort over the competition	Product	3.1 Philips NiBP Gentle Care cuff	User needs	Desirable
Must incorporate CE enabling business models	Linear business models are often not viable for CE	System	4.4 Future scanning	Sustainability	Mandatory
The lifecycle impact must be lower than the current product	The goal of implementing circularity is to become more environmentally sustainable	Both	3.3 Product Lifecycle Impact	Sustainability	Mandatory
Cuffs must not end up as medical waste	This inhibits EoL CHF strategies	System	2.3 Healthcare specific barriers 4. Clinical use analysis	Sustainability	Mandatory
Should incorporate enabling CE smart technologies	Could help in traceability and inventory optimization or even EoL optimization	Both	4.4 Future scanning	Sustainability	Desirable
Should maximize product longevity	The longer a product can be used, usually the better	Both	3.4 Circular product assessment	Sustainability	Desirable
Product should maintain the non use of conflict materials	This is a + in the current design for circularity	Product	3.4 Circular product assessment	Sustainability	Desirable
Should minimize the raw material impact	Raw material impact has the highest contribution to the LCA	Both	3.3 Product Lifecycle Impact	Sustainability	Desirable
Product should maximize the use of low lifecycle impact materials	Multiple relatively high impact materials are used such as nylon	Product	3.2 Value chain map, 3.3 Product Lifecycle Impact	Sustainability	Desirable
Packaging waste should be limited	Under MDR, it is a non critical item, meaning packaging is not necessary	Both	3.2 Value chain map	Sustainability	Desirable
Manufacturing processes should minimize off cut being incinerated	Currently, off cuts are not recycled and occurr in multiple steps in the production	Both	3.2 Value chain map	Sustainability	Desirable
Should prevent being discarded before it's rated use time	Currently, since it is a low value product, it is easily discarded prematurely	Both	3.2 Value chain map	Sustainability	Desirable
Product should limit permanently fusing multiple different materials	Currently, multiple different materials are welded, making CHF strategies impossible	product	3.2 Value chain map	Sustainability	Desirable
Product should minimize the amount of components needed	The product currently has components which are not needed such as the air hose	Product	3.2 Value chain map	Sustainability	Desirable
Product should maintain its simplicity in manufacturing and components	This is a + in the current design for circularity	Product	3.2 Value chain map	Sustainability	Desirable
Should include traceable inventory and usage data in a digital passport	This is currently done ineffectively, inhibiting correct use time	Both	4. Clinical Use Analysis	Sustainability	Desirable
Product must be compliant with MDR 2017/745	Needed for medical devices	Product	3.1 Philips NiBP Gentle Care cuff, 4. Clinical Use Analysis	Regulation	Mandatory
Product must comply with skin compatibility regulation ISO 10993	Needed for medical devices	Product	2.3 NiBP monitoring	Regulation	Mandatory
Product must be effectively cleanable with low level disinfection	Currently, this is not always the case due to velcro	Product	4. Clinical Use Analysis	Product performance	Mandatory
Cuff must be skin contact safe	Regulation requirement and needed for product performance.	Product	2.3 NiBP monitoring, 4. Clinical Use Analysis	Product performance	Mandatory
The product and system must promote adequate cleaning	One reason for disposables is the risk of infection of reusables because of inadequate cleaning	Both	2.3 NiBP monitoring	Product performance	Mandatory
Must be an inflatable cuff around the upper arm	Case restriction	Product	2.3 NiBP monitoring	Product performance	Mandatory
Must connect to standard Philips patient monitors	Case restriction	Product	2.3 NiBP monitoring	Product performance	Mandatory
Must be non invasive in nature	One of the main USPs of NiBP cuffs	Product	2.3 NiBP monitoring	Product performance	Mandatory
Must include an air tight rectangular bladder measuring 300 mm x 140 mm	Case restriction	Product	2.3 NiBP monitoring	Product performance	Mandatory
Must be consistent in performance over its rated lifecycle	Needed reliable performance for repeated use cycles	Product	2.3 NiBP monitoring	Product performance	Mandatory
Material must be non elastic	Needed for the functionality of the product to occlude the artery.	Product	2.3 NiBP monitoring	Product performance	Mandatory
Material must be fatigue resistant over its rated lifecycle	Material is repeatedly inflated and deflated, putting a toll on the material properties.	Product	2.3 NiBP monitoring	Product performance	Mandatory
Material must conform to the upper arms contour	To effectively and with comfort measure, it needs to conform to the upper arm.	Product	2.3 NiBP monitoring	Product performance	Mandatory
Product should inhibit use beyond the rated use time	Use beyond the intended purpose, potentially affects performance and infection risks	Both	4. Clinical Use Analysis	Product performance	Desirable
Nurses should be motivated to use correctly sized cuffs	Correct sizing gives more accurate readings, and nurses often disregard this	Both	2.3 NiBP monitoring, 4. Clinical Use Analysis	Product performance	Desirable
Product must be mass producable	As Philips is a large player within the market, efficient mass producability is necessary	Product	3.1 Philips NiBP Gentle Care cuff	Economic	Mandatory
The product and or system must incorporates viable business models	CE strategies are often not viable in conventional business models for low value consumables	Both	2.3 Healthcare specific barriers	Economic	Mandatory
Production costs should not exceed current production costs by 50%	While some price increases can be justified by the increased USP, costs should stay competitive	Product	3.1 Philips NiBP Gentle Care cuff	Economic	Desirable

K. Scoring of system design

- -	-	+	+ +
= 0 points	= 2,5 points	= 7,5 points	= 10 points

Current Single-Patient-Use

Current SPU system			Score	Comments	Measuring metrics
Average score: 0,625	Sustainability	Amount of CRFs	- -	The device does not utilize any CRF methods	++ = use 4 or more CRFs + = uses 2 or 3 CRFs - = 1 CRF -- = 0 CRFs
		CRF hierarchy	- -	Currently, zero CRFs are implemented, thus no points are awarded	++ = >12 points + = 9 or 12 points - = 5 to 8 points -- = 0 to 4 points Research, design and development CRFs = 4 points each Performance sustainment CRFS = 3 points each Reprocessing for intended use CRFs = 2 points each End of intended use transformation CRFs = 1 point Recovery of energy CRF = 0 points
		System logistics related additional CO2 impact (compared to current reuse model)	-	Every cuff needs to be shipped, increasing CO2 logistical impact of the system compared to the current reuse model. However, this can be done quite efficiently in bulk, as demonstrated in the LCA.	++ = Has less CO2 impact + = Has the same CO2 impact - = has minor additional impact -- = has an extreme additional impact
		System encourages sustainable behaviour	- -	Every cuff is thrown away, and often so as medical waste out of convenience by nurses. This makes recycling impossible. The current system does not have any measures in place to encourage sustainable behaviour.	++ = System ensures sustainable behaviour + = Sustainable measures are implemented to encourage sustainable behaviour - = Tries to encourage sustainable behaviour, but lacks incentive -- = Does not have any measures in place to encourage sustainable behaviour
Average score: 10	Feasbility	Infrastructure readiness (new facilities or networks needed)	+ +	Currently already implemented, showcasing that it fits within the current infrastructure of hospitals.	++ = Fits within the current hospital infrastructure + = Fits within the current hospital infrastructure with minor adjustments - = Does not, but could potentially be feasible in the future with major adjustments -- = Does not, and will probably never be be feasible in the future
		Implementation horizon	+ +	Is already implemented right now	++ = Can be implemented right now + = Can be implemented within months to 2 years - = Implementation would take 2 to 5 years -- = Implementation faces many hurdles, and will take 5+ years
		Hospital resources availability (staff, room, etc)	+ +	Direct device to disposal relieves hospital resources, as cleaning or quality checks or maintenance are not needed.	++ = Relieves hospital resources + = Does not use additional hospital resources - = Uses hospital resources, but is manageable -- = Uses significant hospital resources, which are not available
		Systemic change needed	+ +	Is an already existing and widely used system.	++ = No systemic change needed + = Easy to implement systemic change - = Hard to implement systemic change -- = Reliant on extreme change of the current system, way of working for stakeholders
Average score: 5,8	Desirability	Patient infection prevention	-	While the value proposition is infection risk free use of cuffs, 2 out of 2 hospitals who used SPU cuffs , which were interviewed, used the disposable cuffs in the current system as a reusable cuff for up to a month. Next to that, cleaning was reliant on overworked nurses who potentially clean the cuffs insufficiently. There are also same patient reinfection risks in the current system.	++ = 100% infection free guarantee + = n.a. - = System allows for non correct use, making it susceptible to infection risks -- = Infection risks are apparent
		Product performance	-	Product performance could be maintained, if used correctly. However, hospitals are using the cuff incorrectly by reusing them on different patients, for which they are not rated, making product performance not guaranteed in those instances.	++ = Product performances is potentially better than new + = Product performance as new - = Product performance could be maintained, but is reliant on correct use by hospital staff -- = Product performance cannot be guaranteed
		Burden on hospital staff	+	Relieves burden on hospital staff in terms of cleaning, but does mean that additional preparation needs to be done to connect a new cuff, making the burden similar.	++ = Relieves hospital staff + = Similar burden on hospital staff - = Additional burden on hospital staff -- = High additional burden on hospital staff
		product/service purchasing costs	-	While the price of SPU cuffs are significantly lower than reusable ones, the costs add up to significantly more than reusable alternatives, due to needing more cuffs due to the disposable nature.	++ = Hospital costs are significantly lower than the current single-patient-use system + = Slightly lower costs for the hospital compared to the current single-patient-use system - = Similar costs for the hospital compared to the current single-patient-use system -- = Significantly higher costs for the hospital compared to the current single-patient-use system
		Hospital staff readiness	++	Existing system, so hospital staff is ready to use this system	++ = No changes and/or education necessary for hospital staff + = Slight changes and/or education necessary for hospital staff - = Significant changes and/or education necessary for hospital staff -- = Changes and/or education are needed for hospital staff, but not possible
		Hospital staff trust in safety and performance	++	If used correctly, thus using it the product on a single patient, trust in safety and performance should be guaranteed, as the product is new at every patient.	++ = Perception of safety and performance of products is similar to using a new cuff on every patient + = Perception of safety and performance is maintained through measures - = Perception of safety and performance is significantly lower -- = Perception of safety and performance is extremely low
Average score: 8,1	Viability	Service operating costs	++	There are no costs involved, as after buying the cuff, it is used on a single patient, and then thrown away.	++ = No service operating costs + = Manageable service operating costs - = Significant associated service operating costs -- = Extremely high associated service operating costs
		Regulatory compliance	++	Existing functioning system, thus regulatory compliance.	++ = Complete regulatory compliance as of now + = Changes needed, but easily done - = minor hurdles to overcome -- = Significant hurdles to overcome
		Scalability	++	As long as product production can be scaled, the system is easily scalable	++ = Easily scalable to other disposables, as well as other hospitals + = Easily scalable to other disposables, or easily scalable to other hospitals - = Resource intensive scaling towards other disposables, or other hospitals -- = Not scalable
		product/service purchasing costs	-	Per cuff, the costs are lower, but as every patient needs a new cuff, within 10 patients, the current reusable system is more cost effective.	++ = Costs are lower than the current reuse system + = Costs are similar to the current reuse system - = Costs are higher to the current reuse system -- = Costs do not justify purchasing costs of the product service system

Current Reuse

Current reuse system			Score	Comments	Measuring metrics
Average score: 3,125	Sustainability	Amount of CRFs	-	Uses CRF reuse	++ = use 4 or more CRFs + = uses 2 or 3 CRFs - = 1 CRF -- = 0 CRFs
		CRF hierarchy	- -	Reuse CRF is 2 points	++ = >12 points + = 9 or 12 points - = 5 to 8 points -- = 0 to 4 points Research, design and development CRFs = 4 points each Performance sustainment CRFS = 3 points each Reprocessing for intended use CRFs = 2 points each End of intended use transformation CRFs = 1 point Recovery of energy CRF = 0 points
		System logistics related additional CO2 impact (compared to current reuse model)	+	Is the system which it is compared to, so no additional impact	++ = Has less CO2 impact + = Has the same CO2 impact - = has minor additional impact -- = has an extreme additional impact
		System encourages sustainable behaviour	-	Sustainable behaviour is encouraged, by making the product reusable. However, the system itself does not have measures or incentives in place to ensure sustainable behaviour by users.	++ = System ensures sustainable behaviour + = Sustainable measures are implemented to encourage sustainable behaviour - = Tries to encourage sustainable behaviour, but lacks incentive -- = Does not have any measures in place to encourage sustainable behaviour
Average score: 9,375	Feasbility	Infrastructure readiness (new facilities or networks needed)	+ +	Currently already implemented, showcasing that it fits within the current infrastructure of hospitals.	++ = Fits within the current hospital infrastructure + = Fits within the current hospital infrastructure with minor adjustments - = Does not, but could potentially be feasible in the future with major adjustments -- = Does not, and will probably never be be feasible in the future
		Implementation horizon	+ +	Is already implemented right now	++ = Can be implemented right now + = Can be implemented within months to 2 years - = Implementation would take 2 to 5 years -- = Implementation faces many hurdles, and will take 5+ years
		Hospital resources availability (staff, room, etc)	+	Is the system which it is compared to, so no additional resources needed	++ = Relieves hospital resources + = Does not use additional hospital resources - = Uses hospital resources, but is manageable -- = Uses significant hospital resources, which are not available
		Systemic change needed	+ +	Is an already existing and widely used system.	++ = No systemic change needed + = Easy to implement systemic change - = Hard to implement systemic change -- = Reliant on extreme change of the current system, way of working for stakeholders
Average score: 4,583	Desirability	Patient infection prevention	- -	While with adequate cleaning safe reuse is possible with limited infection risks, the reliance on overworked staff for this makes infection risks apparent.	++ = 100% infection free guarantee + = n.a. - = System allows for non correct use, making it susceptible to infection risks -- = Infection risks are apparent
		Product performance	-	The product is rated for an X amount of cycles of good product performance. However, nurses keep on using the product, even if it is filthy, or apparent wear is visible, as long as it gives a reading on the monitor.	++ = Product performances is potentially better than new + = Product performance as new - = Product performance could be maintained, but is reliant on correct use by hospital staff -- = Product performance cannot be guaranteed
		Burden on hospital staff	+	Is the system which it is compared to, so no additional burden	++ = Relieves hospital staff + = Similar burden on hospital staff - = Additional burden on hospital staff -- = High additional burden on hospital staff
		product/service purchasing costs	++	Reusable cuffs are much lower in costs, due to being reusable, instead of being thrown out after every patient.	++ = Hospital costs are significantly lower than the current single-patient-use system + = Slightly lower costs for the hospital compared to the current single-patient-use system - = Similar costs for the hospital compared to the current single-patient-use system -- = Significantly higher costs for the hospital compared to the current single-patient-use system
		Hospital staff readiness	++	Existing system, so hospital staff is ready to use this system	++ = No changes and/or education necessary for hospital staff + = Slight changes and/or education necessary for hospital staff - = Significant changes and/or education necessary for hospital staff -- = Changes and/or education are needed for hospital staff, but not possible
		Hospital staff trust in safety and performance	--	As hospitals do not trust it to be safe for use in high acuity settings, this is not the case, even if it is possible with adequate cleaning.	++ = Perception of safety and performance of products is similar to using a new cuff on every patient + = Perception of safety and performance is maintained through measures - = Perception of safety and performance is significantly lower -- = Perception of safety and performance is extremely low
Average score: 9,375	Viability	Service operating costs	++	Apart from cleaning wipes and a quick cleaning action of the nurse, there are no additional costs. After buying the cuff, it is used for a maximum of 3,5 years, and then thrown away.	++ = No service operating costs + = Manageable service operating costs - = Significant associated service operating costs -- = Extremely high associated service operating costs
		Regulatory compliance	++	Existing functioning system, thus regulatory compliance.	++ = Complete regulatory compliance as of now + = Changes needed, but easily done - = minor hurdles to overcome -- = Significant hurdles to overcome
		Scalability	++	As long as product production can be scaled, the system is easily scalable	++ = Easily scalable to other disposables, as well as other hospitals + = Easily scalable to other disposables, or easily scalable to other hospitals - = Resource intensive scaling towards other disposables, or other hospitals -- = Not scalable
		product/service purchasing costs	+	Is the system which it is compared to, so the same purchasing costs	++ = Costs are lower than the current reuse system + = Costs are similar to the current reuse system - = Costs are higher to the current reuse system -- = Costs do not justify purchasing costs of the product service system

Single-Patient-Use alternative

SPU alternative			Score	Comments	Measuring metrics
Average score: 4.375	Sustainability	Amount of CRFs	+	The system utilizes the CRFs reduce, recycle and renew	++ = use 4 or more CRFs + = uses 2 or 3 CRFs - = 1 CRF -- = 0 CRFs
		CRF hierarchy	-	Reduce (4 points) + recycle (1 point) + renew (1 point) = 6 points	++ =12 points + = 9 or 12 points - = 5 to 8 points -- = 0 to 4 points Research, design and development CRFs = 4 points each Performance sustainment CRFs = 3 points each Reprocessing for intended use CRFs = 2 points each End of intended use transformation CRFs = 1 point Recovery of energy CRF = 0 points
		System logistics related additional CO2 impact (compared to current reuse model)	-	Every cuff needs to be shipped, increasing CO2 logistical impact of the system compared to the current reuse model. However, this can be done quite efficiently in bulk, as demonstrated in the LCA.	++ = has less CO2 impact + = has the same CO2 impact - = has minor additional impact -- = has an extreme additional impact
		System encourages sustainable behaviour	-	Through measures such as an collection system, hospitals are incentivized to make sure correct disposal is done, so that recycling is possible. However, the incentives may be lacking, due to the low economic value of the product, compared to the effort and extra space it takes up in or near the high acuity patient room.	++ = System ensures sustainable behaviour + = Sustainable measures are implemented to encourage sustainable behaviour - = Tries to encourage sustainable behaviour, but lacks incentive -- = Does not have any measures in place to encourage sustainable behaviour
Average score: 4.285	Feasibility	Infrastructure readiness (new facilities or networks needed)	+	With minor adjustments, such as a collection system, it fits within current hospital infrastructure.	++ = Fits within the current hospital infrastructure + = Fits within the current hospital infrastructure with minor adjustments - = Does not, but could potentially be feasible in the future with major adjustments -- = Does not, and will probably never be feasible in the future
		Implementation horizon	+	Can be implemented quickly, but takes some time to organize new logistics and protocols.	++ = Can be implemented right now + = Can be implemented within months to 2 years - = Implementation would take 2 to 5 years -- = Implementation faces many hurdles, and will take 5+ years
		Hospital resources availability (staff, room, etc)	+ +	Direct device to disposal relieves hospital resources, as cleaning or quality checks or maintenance are not needed.	++ = Relieves hospital resources + = Does not use additional hospital resources - = Uses hospital resources, but is manageable -- = Uses significant hospital resources, which are not available
		Systemic change needed	+	Some changes are needed in the business model and logistics, but other than that, it should be fairly easy to implement the systemic change.	++ = No systemic change needed + = Easy to implement systemic change - = Hard to implement systemic change -- = Reliant on extreme change of the current system, way of working for stakeholders
Average score: 3.5	Desirability	Patient infection prevention	+ +	Dispense and collect system, combined with the SUP cuff, ensures 100% infection free guarantee.	++ = 100% infection free guarantee + = n.a. - = System allows for non-correct use, making it susceptible to infection risks -- = Infection risks are apparent
		Product performance	+	Every patient will get a new cuff. Product performance will thus be as new for every patient.	++ = Product performance is potentially better than new + = Product performance as new - = Product performance could be maintained, but is reliant on correct use by hospital staff -- = Product performance cannot be guaranteed
		Burden on hospital staff	+	Relieves burden on hospital staff in terms of cleaning, but does mean that additional preparation needs to be done to connect a new cuff, making the burden similar.	++ = Relieves hospital staff + = Similar burden on hospital staff - = Additional burden on hospital staff -- = High additional burden on hospital staff
		product/service purchasing costs	-	While the price of SPU cuffs are significantly lower than reusable ones, the costs add up to significantly more, due to needing more cuffs due to the disposable nature. The collection and dispense system will probably also provide some little additional costs for hospitals.	++ = Hospital costs are significantly lower than the current single-patient-use system + = Slightly lower costs for the hospital compared to the current single-patient-use system - = Similar costs for the hospital compared to the current single-patient-use system -- = Significantly higher costs for the hospital compared to the current single-patient-use system
		Hospital staff readiness	+	Some small changes and education necessary for the correct use of the dispense and collect system.	++ = No changes and/or education necessary for hospital staff + = Slight changes and/or education necessary for hospital staff - = Significant changes and/or education necessary for hospital staff -- = Changes and/or education are needed for hospital staff, but not possible
		Hospital staff trust in safety and performance	+ +	If used correctly, thus using it the product on a single patient, trust in safety and performance should be guaranteed, as the product is new at every patient.	++ = Perception of safety and performance of products is similar to using a new cuff on every patient + = Perception of safety and performance is maintained through measures - = Perception of safety and performance is significantly lower -- = Perception of safety and performance is extremely low
Average score: 2.5	Viability	Service operating costs	+	There will be some additional costs for the additional logistics of collecting the cuffs. However, these should not be extreme, and can be send to a local recycler.	++ = No service operating costs + = Manageable service operating costs - = Significant associated service operating costs -- = Extremely high associated service operating costs
		Regulatory compliance	+ +	Existing functioning system, thus regulatory compliance.	++ = Complete regulatory compliance as of now + = Changes needed, but easily done - = minor hurdles to overcome -- = Significant hurdles to overcome
		Scalability	+ +	As long as product production and collect and dispense product can be scaled and adapted for other SUDs, the system is easily scalable.	++ = Easily scalable to other disposables, as well as other hospitals + = Easily scalable to other disposables, or easily scalable to other hospitals - = Resource intensive scaling towards other disposables, or other hospitals -- = Not scalable
		product/service purchasing costs	-	Per cuff, the costs are lower, but as every patient needs a new cuff, within 10 patients, the current reusable system is more cost effective. There are also more recurring costs, due to the collection and dispense costs for hospitals.	++ = Costs are lower than the current reuse system + = Costs are similar to the current reuse system - = Costs are higher to the current reuse system -- = Costs do not justify purchasing costs of the product service system

Direct Reuse alternative

Alternative re-use model 1			Score	Comments	Measuring metrics
Average score: 4.25	Sustainability	Amount of CRFs	+ +	CRFs: maintain, repair, reuse, refurbish, remanufacture and recycle	++ = use 4 or more CRFs + = uses 2 or 3 CRFs - = 1 CRF -- = 0 CRFs
		CRF hierarchy	+ +	14 points	++ =12 points + = 9 or 12 points - = 5 to 8 points -- = 0 to 4 points Research, design and development CRFs = 4 points each Performance sustainment CRFs = 3 points each Reprocessing for intended use CRFs = 2 points each End of intended use transformation CRFs = 1 point Recovery of energy CRF = 0 points
		System logistics related additional CO2 impact (compared to current reuse model)	-	The cuffs need to be send back to the OEM for refurbishing or remanufacturing whenever a product is past it's prescribed usage or if is broken. This low volume shipment of cuffs has additional logistical CO2 impact, but can be reduced by collection a certain amount of cuffs before shipping the cuffs to the OEM.	++ = Has less CO2 impact + = Has the same CO2 impact - = has minor additional impact -- = has an extreme additional impact
		System encourages sustainable behaviour	-	The system tries to encourage sustainable behaviour through a buy back system for recycling. However, incentive may be lacking for such a low economic value consumable, compared to the effort and space necessary.	++ = System ensures sustainable behaviour + = Sustainable measures are implemented to encourage sustainable behaviour - = Tries to encourage sustainable behaviour, but lacks incentive -- = Does not have any measures in place to encourage sustainable behaviour
Average score: 3.5	Feasibility	Infrastructure readiness (new facilities or networks needed)	+	Only difference is that cuffs need to be collected when broken. For this there should be a small centralized area for collection to send the cuffs back. Other than that the OEM needs logistics for take back, quality checking and refurbishment and/or remanufacturing.	++ = Fits within the current hospital infrastructure + = Fits within the current hospital infrastructure with minor adjustments - = Does not, but could potentially be feasible in the future with major adjustments -- = Does not, and will probably never be feasible in the future
		Implementation horizon	+	From a hospital perspective, this is easily implementable, apart from some small protocol changes and education of staff. From a OEM perspective, the refurbishment and remanufacturing facilities need to be put in place, but should not be to difficult.	++ = Can be implemented right now + = Can be implemented within months to 2 years - = Implementation would take 2 to 5 years -- = Implementation faces many hurdles, and will take 5+ years
		Hospital resources availability (staff, room, etc)	+	Compared to the current setup of reusables, there are no additional resources necessary, except for a small designated area/box for faulty cuffs.	++ = Relieves hospital resources + = Does not use additional hospital resources - = Uses hospital resources, but is manageable -- = Uses significant hospital resources, which are not available
		Systemic change needed	+	Change consists of a difference in business models, as well in a minor change in logistics for the take back and remanufacturing/refurbishing facilities. These are fairly easy to implement and tried and tested on other products.	++ = No systemic change needed + = Easy to implement systemic change - = Hard to implement systemic change -- = Reliant on extreme change of the current system, way of working for stakeholders
Average score: 5	Desirability	Patient infection prevention	- -	This is not reduced, compared to the existing reuse model. There infection risks are apparent.	++ = 100% infection free guarantee + = n.a. - = System allows for non-correct use, making it susceptible to infection risks -- = Infection risks are apparent
		Product performance	-	The product is rated for an X amount of cycles of good product performance. However, this system is still reliant on hospital staff and nurses. These keep on using the product, even if it is filthy, or apparent wear is visible, as long as it gives a reading on the monitor.	++ = Product performance is potentially better than new + = Product performance as new - = Product performance could be maintained, but is reliant on correct use by hospital staff -- = Product performance cannot be guaranteed
		Burden on hospital staff	+	This is similar to the current reuse system.	++ = Relieves hospital staff + = Similar burden on hospital staff - = Additional burden on hospital staff -- = High additional burden on hospital staff
		product/service purchasing costs	+ +	This should be fairly similar to the current reusable system. There could be slight costs associated with the increased value proposition of sustainability and the logistics for buy back.	++ = Hospital costs are significantly lower than the current single-patient-use system + = Slightly lower costs for the hospital compared to the current single-patient-use system - = Similar costs for the hospital compared to the current single-patient-use system -- = Significantly higher costs for the hospital compared to the current single-patient-use system
		Hospital staff readiness	+ +	Very similar to the current system, so apart from insignificant change in protocols for collection, there are no changes needed.	++ = No changes and/or education necessary for hospital staff + = Slight changes and/or education necessary for hospital staff - = Significant changes and/or education necessary for hospital staff -- = Changes and/or education are needed for hospital staff, but not possible
		Hospital staff trust in safety and performance	- -	Hospitals do not trust it to be safe for use in high acuity settings, even if it is possible with adequate cleaning.	++ = Perception of safety and performance of products is similar to using a new cuff on every patient + = Perception of safety and performance is maintained through measures - = Perception of safety and performance is significantly lower -- = Perception of safety and performance is extremely low
Average score: 3.5	Viability	Service operating costs	+	There are some slight manageable costs involved with the buy back logistics, quality control and remanufacturing/refurbishing	++ = No service operating costs + = Manageable service operating costs - = Significant associated service operating costs -- = Extremely high associated service operating costs
		Regulatory compliance	+	Existing functioning system for reuse, so compliant. Remanufacturing/refurbishing might need some extra certification.	++ = Complete regulatory compliance as of now + = Changes needed, but easily done - = minor hurdles to overcome -- = Significant hurdles to overcome
		Scalability	+ +	As long as product production and the take back facilities can be scaled, the system is easily scalable	++ = Easily scalable to other disposables, as well as other hospitals + = Easily scalable to other disposables, or easily scalable to other hospitals - = Resource intensive scaling towards other disposables, or other hospitals -- = Not scalable
		product/service purchasing costs	-	Product costs should be similar, with slight costs associated with the buy back program and its logistics. Quality control, and remanufacturing/refurbishing may be relatively expensive for the low value products.	++ = Costs are lower than the current reuse system + = Costs are similar to the current reuse system - = Costs are higher to the current reuse system -- = Costs do not justify purchasing costs of the product service system

Local Reprocessing alternative

Alternative re-use model 2			Score	Comments	Measuring metrics
Average score: 4.125	Sustainability	Amount of CRFs	+ +	CRFs: maintain, repair, reuse, refurbish, remanufacture and recycle	++ = use 4 or more CRFs + = uses 2 or 3 CRFs - = 1 CRF -- = 0 CRFs
		CRF hierarchy	+ +	14 points	++ =12 points + = 9 or 12 points - = 5 to 8 points -- = 0 to 4 points Research, design and development CRFs = 4 points each Performance sustainment CRFs = 3 points each Reprocessing for intended use CRFs = 2 points each End of intended use transformation CRFs = 1 point Recovery of energy CRF = 0 points
		System logistics related additional CO2 impact (compared to current reuse model)	-	Logistically, the cuffs stay within the hospital, meaning that there is minimal additional logistics related CO2 impact. However, as a new reprocessed cuff is needed at every patient, meaning that additional cuffs are needed in the system.	++ = Has less CO2 impact + = Has the same CO2 impact - = has minor additional impact -- = has an extreme additional impact
		System encourages sustainable behaviour	+ +	Due to how the system is set up, responsibility for sustainability is shifted towards specialised people. Next to that the system ensures that the cuffs are used as intended.	++ = System ensures sustainable behaviour + = Sustainable measures are implemented to encourage sustainable behaviour - = Tries to encourage sustainable behaviour, but lacks incentive -- = Does not have any measures in place to encourage sustainable behaviour
Average score: 3.5	Feasibility	Infrastructure readiness (new facilities or networks needed)	+	There are minor adjustments needed, such as the introduction of a third party, and a small area within or near the hospital to reprocess the cuffs.	++ = Fits within the current hospital infrastructure + = Fits within the current hospital infrastructure with minor adjustments - = Does not, but could potentially be feasible in the future with major adjustments -- = Does not, and will probably never be feasible in the future
		Implementation horizon	+	It could be implemented fairly easily, with some small changes within the hospital.	++ = Can be implemented right now + = Can be implemented within months to 2 years - = Implementation would take 2 to 5 years -- = Implementation faces many hurdles, and will take 5+ years
		Hospital resources availability (staff, room, etc)	+	Some space within or near the hospital is needed, but this can be managed. It simultaneously relieves hospital resources in terms of cleaning responsibilities for hospital staff. Net zero change.	++ = Relieves hospital resources + = Does not use additional hospital resources - = Uses hospital resources, but is manageable -- = Uses significant hospital resources, which are not available
		Systemic change needed	+	Easy to implement systemic change.	++ = No systemic change needed + = Easy to implement systemic change - = Hard to implement systemic change -- = Reliant on extreme change of the current system, way of working for stakeholders
Average score: 4.75	Desirability	Patient infection prevention	+ +	Reprocessing is done by a specialized party, making a 100% infection risk free guarantee possible.	++ = 100% infection free guarantee + = n.a. - = System allows for non-correct use, making it susceptible to infection risks -- = Infection risks are apparent
		Product performance	+ +	As the specialized reprocessing service can upgrade components such as tubing, it can not only restore products to its original performance, but to potentially better than new performance.	++ = Product performance is potentially better than new + = Product performance as new - = Product performance could be maintained, but is reliant on correct use by hospital staff -- = Product performance cannot be guaranteed
		Burden on hospital staff	+ +	Responsibilities shift from busy nurses to specialized personnel, relieving hospital staff.	++ = Relieves hospital staff + = Similar burden on hospital staff - = Additional burden on hospital staff -- = High additional burden on hospital staff
		product/service purchasing costs	+	There will probably be some costs involved with this extra service. Also, hospitals will need to have less cuffs in inventory than single-patient-use, but more than direct reusable cuffs, due to reprocessing after every patient.	++ = Hospital costs are significantly lower than the current single-patient-use system + = Slightly lower costs for the hospital compared to the current single-patient-use system - = Similar costs for the hospital compared to the current single-patient-use system -- = Significantly higher costs for the hospital compared to the current single-patient-use system
		Hospital staff readiness	+	There will be a slight change in protocol, but not much more.	++ = No changes and/or education necessary for hospital staff + = Slight changes and/or education necessary for hospital staff - = Significant changes and/or education necessary for hospital staff -- = Changes and/or education are needed for hospital staff, but not possible
		Hospital staff trust in safety and performance	+	Specialized reprocessing service can ensure the product is brought back to good conditions beyond current reusable cuffs, and simultaneously will guarantee infection control.	++ = Perception of safety and performance of products is similar to using a new cuff on every patient + = Perception of safety and performance is maintained through measures - = Perception of safety and performance is significantly lower -- = Perception of safety and performance is extremely low
Average score: 4.25	Viability	Service operating costs	+	There will be some additional costs for specialized reprocessing people and space in/near the hospital.	++ = No service operating costs + = Manageable service operating costs - = Significant associated service operating costs -- = Extremely high associated service operating costs
		Regulatory compliance	+	For the cleaning, maintenance and repairs, the regulations are in check. However, for refurbishment and remanufacturing, the product will need additional certifications.	++ = Complete regulatory compliance as of now + = Changes needed, but easily done - = minor hurdles to overcome -- = Significant hurdles to overcome
		Scalability	+	This service is easily scalable to other hospitals, however with also reprocessing other SUDs, it will probably outgrow the facilities available in/near the hospital.	++ = Easily scalable to other disposables, as well as other hospitals + = Easily scalable to other disposables, or easily scalable to other hospitals - = Resource intensive scaling towards other disposables, or other hospitals -- = Not scalable
		product/service purchasing costs	-	There will probably be some costs involved with this extra service. Also, hospitals will need to have more cuffs than before, due to the reprocessing after every patient.	++ = Costs are lower than the current reuse system + = Costs are similar to the current reuse system - = Costs are higher to the current reuse system -- = Costs do not justify purchasing costs of the product service system

Specialised Reprocessing alternative

Alternative re-use model 3			Score	Comments	Measuring metrics
Average score: 3.3	Sustainability	Amount of CRFs	+ +	CRFs: maintain, repair, reuse, refurbish, remanufacture and recycle	++ = use 4 or more CRFs + = uses 2 or 3 CRFs - = 1 CRF -- = 0 CRFs
		CRF hierarchy	+ +	14 points	++ =12 points + = 9 or 12 points - = 5 to 8 points -- = 0 to 4 points Research, design and development CRFs = 4 points each Performance sustainment CRFs = 3 points each Reprocessing for intended use CRFs = 2 points each End of intended use transformation CRFs = 1 point Recovery of energy CRF = 0 points
		System logistics related additional CO2 impact (compared to current reuse model)	- -	Every used cuff needs to be reprocessed at an external location centralized in the Netherlands or region. This will have significant additional CO2 impact compared to more local alternatives. Especially for these kind of products which do not have much materials or electronics.	++ = Has less CO2 impact + = Has the same CO2 impact - = has minor additional impact -- = has an extreme additional impact
		System encourages sustainable behaviour	+ +	Due to how the system is set up, responsibility for sustainability is shifted towards specialized people. Next to that the system ensures that the cuffs are used as intended.	++ = System ensures sustainable behaviour + = Sustainable measures are implemented to encourage sustainable behaviour - = Tries to encourage sustainable behaviour, but lacks incentive -- = Does not have any measures in place to encourage sustainable behaviour
Average score: 1.75	Feasibility	Infrastructure readiness (new facilities or networks needed)	-	A whole new centralized hub within the Netherlands or region needs to be built.	++ = Fits within the current hospital infrastructure + = Fits within the current hospital infrastructure with minor adjustments - = Does not, but could potentially be feasible in the future with major adjustments -- = Does not, and will probably never be feasible in the future
		Implementation horizon	-	Will take multiple years to set up and built the facilities necessary. Next to that, multiple stakeholders will have to align, as this will only be feasible on a large scale where multiple OEMs work together.	++ = Can be implemented right now + = Can be implemented within months to 2 years - = Implementation would take 2 to 5 years -- = Implementation faces many hurdles, and will take 5+ years
		Hospital resources availability (staff, room, etc)	+ +	Direct device to disposal relieves hospital resources, as cleaning or quality checks or maintenance are not needed.	++ = Relieves hospital resources + = Does not use additional hospital resources - = Uses hospital resources, but is manageable -- = Uses significant hospital resources, which are not available
		Systemic change needed	- -	There will be some major systemic changes. From a business perspective, a new collaborative reprocessing partner should be set up, which does the reprocessing for multiple brands and for a large amount of hospitals. Business models for OEMs will have to shift.	++ = No systemic change needed + = Easy to implement systemic change - = Hard to implement systemic change -- = Reliant on extreme change of the current system / way of working for stakeholders
Average score: 7.9	Desirability	Patient infection prevention	+ +	Reprocessing is done by a specialized party, making a 100% infection risk free guarantee possible.	++ = 100% infection free guarantee + = n.a. - = System allows for non-correct use, making it susceptible to infection risks -- = Infection risks are apparent
		Product performance	+ +	As the specialized reprocessing service can upgrade components such as tubing, it can not only restore products to its original performance, but to potentially better than new performance.	++ = Product performance is potentially better than new + = Product performance as new - = Product performance could be maintained, but is reliant on correct use by hospital staff -- = Product performance cannot be guaranteed
		Burden on hospital staff	+ +	Responsibilities shift from busy nurses to specialized personnel, relieving hospital staff.	++ = Relieves hospital staff + = Similar burden on hospital staff - = Additional burden on hospital staff -- = High additional burden on hospital staff
		product/service purchasing costs	- -	As every used cuff on a single patient needs to be send to a specialized regional reprocessing centre, service costs could potentially outweigh the costs for such a low economic value disposable product. Highly dependent on economies of scale to be cost effective.	++ = Hospital costs are significantly lower than the current single-patient-use system + = Slightly lower costs for the hospital compared to the current single-patient-use system - = Similar costs for the hospital compared to the current single-patient-use system -- = Significantly higher costs for the hospital compared to the current single-patient-use system
		Hospital staff readiness	+	There will be some slight changes in protocol, but not anything groundbreaking for hospital staff.	++ = No changes and/or education necessary for hospital staff + = Slight changes and/or education necessary for hospital staff - = Significant changes and/or education necessary for hospital staff -- = Changes and/or education are needed for hospital staff, but not possible
		Hospital staff trust in safety and performance	+ +	Specialized reprocessing service can ensure the product is brought back to good conditions beyond current reusable cuffs, and simultaneously will guarantee infection control. A party this size can probably ensure a better perception of safety and performance of the product through extensive recertifications and guarantees.	++ = Perception of safety and performance of products is similar to using a new cuff on every patient + = Perception of safety and performance is maintained through measures - = Perception of safety and performance is significantly lower -- = Perception of safety and performance is extremely low
Average score: 5.0	Viability	Service operating costs	- -	The costs of the facilities and the logistics could outweigh the product value if not done at a significant scale.	++ = No service operating costs + = Manageable service operating costs - = Significant associated service operating costs -- = Extremely high associated service operating costs
		Regulatory compliance	+	For the cleaning, maintenance and repairs, the regulations are in check. However, for refurbishment and remanufacturing, the product will need additional certifications.	++ = Complete regulatory compliance as of now + = Changes needed, but easily done - = minor hurdles to overcome -- = Significant hurdles to overcome
		Scalability	+ +	This system only works if scaled to multiple hospitals within the region at once, who reprocess a multitude of disposable products to make us of economies of scale.	++ = Easily scalable to other disposables, as well as other hospitals + = Easily scalable to other disposables, or easily scalable to other hospitals - = Resource intensive scaling towards other disposables, or other hospitals -- = Not scalable
		product/service purchasing costs	-	Per cuff, the costs are lower, but as every patient needs a new cuff, within 10 patients, the current reusable system is more cost effective. There are also more recurring costs, due to the collection and dispense costs for hospitals.	++ = Costs are lower than the current reuse system + = Costs are similar to the current reuse system - = Costs are higher to the current reuse system -- = Costs do not justify purchasing costs of the product service system

L. Comparative LCA

Gentle Care Cuff (1 patient and single-patient-use)

Purpose: Estimate biggest impacts to set design priorities
Boundaries: See value map
Functional unit: Environmental impact per patient being NiBP monitored
Impact unit: kg CO2 eq.
Uncertainty rubric: 10% for database perfect match, 30% for plausible substitution, 100% for wild guess

Design option:
NiBP cuff Dutch hospital flow

Manufacturing	Eco-Intensity (Impacts/kg)	Mass per Item (kg)	Items per func.unit (#)	Uncertainty (%)	Index	Notes	Calculated Impact
Cuff sheet: Material (Polyester)	2,190	0,0317	1	10%	A.130.07.118.230701 PET (Polyethylene terephthalate) bottle grade		0,069423
Cuff sheet: Production of material spinning	0,918	0,0317	1	10%	A.140.03.116.230701 spinning extruder polymer filaments (80 - 500 dtex)		0,029096
Cuff sheet: Production of fibres	1,046	0,0317	1	10%	A.140.03.103.230701 heat setting and washing synthetic fabrics		0,033149
Cuff sheet: Processing into non-woven material	1,167	0,0317	1	10%	D.120.01.106.230701 injection moulding, production site		0,036994
Cuff sheet: EVA laminate material	3,619	0,00036	1	10%	A.130.05.103.230701 EVA (ethylene vinyl acetate rubber)		0,001303
Cuff sheet: Blow moulding	0,012	0,00036	1	10%	D.120.01.102.230701 blow moulding, production site		4,43E-06
Cuff sheet: cutting wide sheet from roll material			1			negl.	0
Cuff sheet: cutting individual NiBP shapes out of material			1			negl.	0
Cuff sheet: Trimming edges			1			negl.	0
Cuff sheet: UV screen printing	0,492	0,0016	1	10%	D.110.01.103.230701 Printing per m2, 100%, UV, inkjet		0,000788
Cuff sheet: RF welding outer perimeter	0,052	0,015	1	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,000774
Cuff sheet: Diecutting outer perimeter			1			negl.	0
Hook: Material (Nylon velcro)	4,520	0,0091	1	10%	A.130.07.104.230803 PA 6 (Nylon 6, Polyamide 6)		0,041132
Hook: Production of material	1,167	0,0091	1	10%	D.120.01.106.230701 injection moulding, production site		0,01062
Hook: Cutting to specification			1			negl.	0
Loop: Material (Nylon velcro)	4,520	0,011	1	10%	A.130.07.104.230803 PA 6 (Nylon 6, Polyamide 6)		0,04972
Loop: Production of material spinning	0,918	0,011	1	30%	A.140.03.116.230701 spinning extruder polymer filaments (80 - 500 dtex)		0,010096
Loop: Production of material	1,046	0,011	1	30%	A.140.03.103.230701 heat setting and washing synthetic fabrics		0,011503
Loop: processing into woven material	3,644	0,011	1	10%	A.140.03.125.230701 weaving 200 dtex		0,040082
Loop: Cutting to specification			1			negl.	0
Hook: RF welding onto cuff sheet	0,052	0,015	1	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,000774
Loop: RF welding onto cuff sheet	0,052	0,015	1	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,000774
Connector: Material (Nylon)	4,520	0,00047	1	10%	A.130.07.104.230803 PA 6 (Nylon 6, Polyamide 6)		0,002124
Connector: Injection molding	1,167	0,00047	1	10%	D.120.01.106.230701 injection moulding, production site		0,000548
Connector: RF welding onto cuff sheet	0,052	0,015	1	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,000774
Hose: Material (Kraton)	3,785	0,0066	1	10%	A.130.05.101.230701 BR and IIR (butadiene rubber and butyl rubber) in tires	Kraton has similar properties like rubber	0,024981
Hose: extrusion through die	0,335	0,0066	1	10%	D.120.01.104.230701 extrusion, production site		0,00221
Hose attachment: Material (EVA)	3,619	0,00036	1	10%	A.130.05.103.230701 EVA (ethylene vinyl acetate rubber)		0,001303
Hose attachment: Injection molding	1,167	0,00036	1	10%	D.120.01.106.230701 injection moulding, production site		0,00042
Hose lubricant: material (P80 grip it)			1			negl.	0
Enclosure 1: Material (paper)	0,405	0,00217	0,1	10%	A.120.01.106.230701 Paper, woodfree uncoated, bleached		8,79E-05
Enclosure 1: printing	0,012	0,09	0,1	30%	D.110.01.102.230701 Printing per m2, 100%, offset, conventional		0,000111
Enclosure 2: Material (paper)	0,405	0,01984	0,1	10%	A.120.01.106.230701 Paper, woodfree uncoated, bleached		0,000803
Enclosure 2: Printing	1,622	0,09	0,1	30%	A.030.26.101.230701 Printing Ink, Black, conventional		0,014595
Primary packaging: Material (PE)	1,870	0,00434	1	10%	A.130.07.112.230701 PE (LDPE, Low density Polyethylene)		0,008116
Primary packaging: Blow moulding	1,098	0,00434	1	30%	D.120.01.102.230701 blow moulding, production site		0,004766
Secondary packaging: Material (PE)	1,870	0,01083	0,1	10%	A.130.07.112.230701 PE (LDPE, Low density Polyethylene)		0,002025
Secondary packaging: Blow moulding	1,098	0,01083	0,1	30%	D.120.01.102.230701 blow moulding, production site		0,001189
Enclosure packaging: Material (PE)	1,870	0,00434	0,1	10%	A.130.07.112.230701 PE (LDPE, Low density Polyethylene)		0,000812
Enclosure packaging: Blow moulding	1,098	0,00434	0,1	30%	D.120.01.102.230701 blow moulding, production site		0,000477

Transport	Eco-Intensity (Impacts/ ton-km)	Mass per Item (ton)	Distance per Item (km)	Items per func.unit (#)	Uncertainty (%)	Index	Calculated Impact
Truck: Road transport to New York Port	0,076	6E-05	425	1	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	0,002064
Shipping: US to Rotterdam port	0,005	6E-05	5850	1	10%	C.070.01.106.230701 Container ship (min weight/volume ratio 0,41 ton/m3)	0,001785
Truck: Rotterdam to Böblingen Germany (warehouse)	0,076	6E-05	640	1	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	0,003108
Truck: Böblingen to Amsterdam hospital	0,076	6E-05	640	1	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	0,003108
Truck: Hospital to local waste management	0,076	6E-05	20	1	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	9,12E-05

Use	Eco-Intensity (Impacts/MJ or other)	Amount per Item (MJ or other)	Items per func.unit (#)	Uncertainty (%)	Index	Calculated Impact
Monitor inflation and deflation energy	0,052	0,00001333	1	30%	B.046.08.130.231201 Electricity New Hampshire production	6,88E-07

End of Life	Eco-Intensity (Impacts/kg)	Mass per Item (kg)	Items per func.unit (#)	Uncertainty (%)	Index	Calculated Impact
Incineration hazardous waste: NiBP cuff	2,532	0,064	1	30%	Figure by Philips LCA expert	0,161815
Incineration: primary PE bag	0,054	0,004	2	10%	F.108.01.102.230701 film LDPE 50 mu in mun waste inc	0,000469
Incineration: secondary PE bag	0,054	0,011	0,1	10%	F.108.01.102.230701 film LDPE 50 mu in mun waste inc	5,85E-05
Incineration: Cardboard/paper tertiary packaging	-1,222	0,200	0,1	30%	F.020.01.108.230701 Paper, Cardboard, Leather, Cotton (12% MC) co-firing in electrical power plant	-0,024442
Incineration: Paper (instructions)	-1,222	0,022	0,1	30%	F.020.01.108.230701 Paper, Cardboard, Leather, Cotton (12% MC) co-firing in electrical power plant	-0,00269
Landfill: inert waste	0,00	0,060216	1	10%	F.130.01.106.230701 landfill (inert waste)	0
						0
						0
						0
						0
						0
						0

Raw material contribution	0,216425012	39,6%			
Packaging impact	0,017911156	3,3%			
total supplier materials contribution	0,349361044	63,9%		Materials and mfg	0,4016	73,42%
Manufacturing	0,185148381	33,9%		Transport	0,0102	1,86%
Upstream transport	0,010065351	1,8%		Use	0,0000	0,00%
Downstream transport	0,0000912	0,0%		EoL	0,1352	24,72%
Incineration	0,162	29,6%		**Total**	0,5469	

Revo Care Cuff (1 patient and single-patient-use)

Purpose: Evaluate the impact of the redesign
Boundaries: See value map
Functional unit: Environmental impact per 200 patients being NiBP monitored (6 consecutive days of monitoring)
Impact unit: kg CO2 eq.
Uncertainty rubric: 10% for database perfect match, 30% for plausible substitution, 100% for wild guess

Design option:
NiBP cuff Dutch hospital flow

Manufacturing	Eco-Intensity (Impacts/kg)	Mass per Item (kg)	Items per func.unit (#)	Uncertainty (%)	Index	Notes	Calculated Impact
Cuff sheet: Material (PP)	1,630	0,02156	1	10%	A.140.01.120.230701 PP (Polypropylene) pellets		0,035136
Cuff sheet: Production of material spinning	0,918	0,02156	1	10%	A.140.03.116.230701 spinning extruder polymer filaments (80 - 500 dtex)		0,019785
Cuff sheet: Production of fibres	1,046	0,02156	1	10%	A.140.03.103.230701 heat setting and washing synthetic fabrics		0,022541
Cuff sheet: Material weaving	1,458	0,02156	1	10%	A.140.03.128.230701 weaving 500 dtex		0,031418
Cuff sheet: PP laminate material	1,630	0,00036	1	10%	A.140.01.120.230701 PP (Polypropylene) pellets		0,000587
Cuff sheet: Blow moulding	0,012	0,00036	1	10%	D.120.01.102.230701 blow moulding, production site		4,43E-06
Cuff sheet: cutting wide sheet from roll material			1			negl.	0
Cuff sheet: cutting individual NiBP shapes out of material			1			negl.	0
Cuff sheet: Trimming edges			1			negl.	0
Cuff sheet: UV screen printing	0,492	0,0016	1	10%	D.110.01.103.230701 Printing per m2, 100%, UV, inkjet		0,000788
Cuff sheet: RF welding outer perimeter	0,052	0,015	1	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,000774
Cuff sheet: Diecutting outer perimeter			1			negl.	0
Hook: Material (PP hook-to-hook) (2 counterparts together)	1,630	0,00306	1	10%	A.140.01.120.230701 PP (Polypropylene) pellets		0,004988
Hook: Production of material	1,167	0,00306	1	10%	D.120.01.106.230701 injection moulding, production site		0,003571
Hook: Cutting to specification			1			negl.	0
Hook: RF welding onto cuff sheet	0,052	0,015	1	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,000774
Loop: RF welding onto cuff sheet	0,052	0,015	1	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,000774
Connector: Material (PP)	1,630	0,00047	1	10%	A.140.01.120.230701 PP (Polypropylene) pellets		0,000766
Connector: Injection molding	1,167	0,00047	1	10%	D.120.01.106.230701 injection moulding, production site		0,000548
Connector: RF welding onto cuff sheet	0,052	0,015	1	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,000774
Primary packaging: Material (PE)	1,870	0,00434	1	10%	A.130.07.112.230701 PE (LDPE, Low density Polyethylene)		0,008116
Primary packaging: Blow moulding	1,098	0,00434	1	30%	D.120.01.102.230701 blow moulding, production site		0,004766
RFID tag		0,00434	1	10%	ENVIRONMENTAL IMPACTS AND IMPLICATIONS OF RFID TAGS (European Union)		0,0256

Transport	Eco-Intensity (Impacts/ ton-km)	Mass per Item (ton)	Distance per Item (km)	Items per func.unit (#)	Uncertainty (%)	IMPLICATIONS OF RFID TAGS	Calculated Impact
Truck: Road transport to New York Port	0,076	3E-05	425	1	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	0,000872
Shipping: US to Rotterdam port	0,005	3E-05	5850	1	10%	C.070.01.106.230701 Container ship (min weight/volume ratio 0,41 ton/m3)	0,000754
Truck: Rotterdam to Böblingen Germany (warehouse)	0,076	3E-05	640	1	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	0,001313
Truck: Böblingen to Amsterdam hospital	0,076	3E-05	640	1	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	0,001313
Truck: Hospital to local waste management	0,076	3E-05	20	1	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	4,1E-05

Use	Eco-Intensity (Impacts/MJ or other)	Amount per Item (MJ or other)	Items per func.unit (#)	Uncertainty (%)	Index	Calculated Impact
Monitor inflation and deflation energy	0,052	0,00001333	1	30%	B.046.08.130.231201 Electricity New Hampshire production	6,88E-07
Cleaning	0,031	1	1	30%	reusable microfiber cloth with QAC disinfectant (Maloney, et al., 2022)	0,0313

End of Life	Eco-Intensity (Impacts/kg)	Mass per Item (kg)	Items per func.unit (#)	Uncertainty (%)	Index	Calculated Impact
Collection and sorting of plastics	0,091	0,027	1	30%	F.130.01.108.230701 plastic waste, collection&sorting	0,002468
Recycling NiBP cuff	0,246	0,027	1	30%	F.120.01.116.230701 PP (Polypropylene), closed loop chemical upcycling credit	0,006643
Recycling: primary PE bag	0,246	0,004	2	10%	F.120.01.109.230701 PE (Polyethylene), closed loop chemical upcycling credit	0,002136
Incineration: Cardboard/paper tertiary packaging	-1,222	0,200	0,1	30%	F.020.01.108.230701 Paper, Cardboard, Leather, Cotton (12% MC) co-firing in electrical power plant	-0,02444
						0
						0
						0
						0
						0

Raw material contribution	0,04959278	23,8%			
Packaging impact	0,04512436	21,6%			
total supplier materials contribution	0,12746132	61,1%		Materials and mfg	0,1617	77,54%
Manufacturing	0,11211857	53,8%		Transport	0,0043	2,06%
Upstream transport	0,00425297	2,0%		Use	0,0313	15,01%
Downstream transport	0,00004104	0,0%		EoL	0,0112	5,39%
				Total	0,2086	

Gentle Care Cuff (200 patients single-patient-use)

Boundaries: See value map
Functional unit: Environmental impact per 200 patients being NiBP monitored (6 consecutive days of monitoring)
Impact unit: kg CO2 eq.
Uncertainty rubric: 10% for database perfect match, 30% for plausible substitution, 100% for wild guess

Design option:
NiBP cuff Dutch hospital flow

Manufacturing	Eco-Intensity (Impacts/kg)	Mass per Item (kg)	Items per func.unit (#)	Uncertainty (%)	Index	Notes	Calculated Impact
Cuff sheet: Material (Polyester)	2,190	0,0317	200	10%	A.130.07.118.230701 PET (Polyethylene terephthalate) bottle grade		13,8846
Cuff sheet: Production of material spinning	0,918	0,0317	200	10%	A.140.03.116.230701 spinning extruder polymer filaments (80 - 500 dtex)		5,8191495
Cuff sheet: Production of fibres	1,046	0,0317	200	10%	A.140.03.103.230701 heat setting and washing synthetic fabrics		6,6297928
Cuff sheet: Processing into non-woven material	1,167	0,0317	200	10%	D.120.01.106.230701 injection moulding, production site		7,3987628
Cuff sheet: EVA laminate material	3,619	0,00036	200	10%	A.130.05.103.230701 EVA (ethylene vinyl acetate rubber)		0,2605927
Cuff sheet: Blow moulding	0,012	0,00036	200	10%	D.120.01.102.230701 blow moulding, production site		0,0008852
Cuff sheet: cutting wide sheet from roll material			200			negl.	0
Cuff sheet: cutting individual NiBP shapes out of material			200			negl.	0
Cuff sheet: Trimming edges			200			negl.	0
Cuff sheet: UV screen printing	0,492	0,0016	200	10%	D.110.01.103.230701 Printing per m2, 100%, UV, inkjet		0,1575999
Cuff sheet: RF welding outer perimeter	0,052	0,015	200	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,1548226
Cuff sheet: Diecutting outer perimeter			200			negl.	0
Hook: Material (Nylon velcro)	4,520	0,0091	200	10%	A.130.07.104.230803 PA 6 (Nylon 6, Polyamide 6)		8,2264
Hook: Production of material	1,167	0,0091	200	10%	D.120.01.106.230701 injection moulding, production site		2,1239351
Hook: Cutting to specification			200			negl.	0
Loop: Material (Nylon velcro)	4,520	0,011	200	10%	A.130.07.104.230803 PA 6 (Nylon 6, Polyamide 6)		9,944
Loop: Production of material spinning	0,918	0,011	200	30%	A.140.03.116.230701 spinning extruder polymer filaments (80 - 500 dtex)		2,0192632
Loop: Production of material	1,046	0,011	200	30%	A.140.03.103.230701 heat setting and washing synthetic fabrics		2,300359
Loop: processing into woven material	3,644	0,011	200	10%	A.140.03.125.230701 weaving 200 dtex		8,0163358
Loop: Cutting to specification			200			negl.	0
Hook: RF welding onto cuff sheet	0,052	0,015	200	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,1548226
Loop: RF welding onto cuff sheet	0,052	0,015	200	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,1548226
Connector: Material (Nylon)	4,520	0,00047	200	10%	A.130.07.104.230803 PA 6 (Nylon 6, Polyamide 6)		0,476988
Connector: Injection molding	1,167	0,00047	200	10%	D.120.01.106.230701 injection moulding, production site		0,1096977
Connector: RF welding onto cuff sheet	0,052	0,015	200	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,1548226
Hose: Material (Kraton)	3,785	0,0066	200	10%	A.130.05.101.230701 BR and ElK (butadiene rubber and butyl rubber) in tires	Kraton has similar properties like rubber	4,9961898
Hose: extrusion through die	0,335	0,0066	200	10%	D.120.01.104.230701 extrusion, production site		0,4419818
Hose attachment: Material (EVA)	3,619	0,00036	200	10%	A.130.05.103.230701 EVA (ethylene vinyl acetate rubber)		0,2605927
Hose attachment: Injection molding	1,167	0,00036	200	10%	D.120.01.106.230701 injection moulding, production site		0,0840238
Hose lubricant: material (P80 grip it)			200			negl.	0
Enclosure 1: Material (paper)	0,405	0,00217	20	10%	A.120.01.106.230701 Paper, woodfree uncoated, bleached		0,017571
Enclosure 1: printing	0,012	0,09	20	30%	D.110.01.102.230701 Printing per m2, 100%, offset, conventional		0,0221309
Enclosure 2: Material (paper)	0,405	0,01984	20	10%	A.120.01.106.230701 Paper, woodfree uncoated, bleached		0,1606493
Enclosure 2: Printing	1,622	0,09	20	30%	A.030.26.101.230701 Printing Ink, Black, conventional		2,9190089
Primary packaging: Material (PE)	1,870	0,00434	200	10%	A.130.07.112.230701 PE (LDPE, Low density Polyethylene)		1,62316
Primary packaging: Blow moulding	1,098	0,00434	200	30%	D.120.01.102.230701 blow moulding, production site		0,9531167
Secondary packaging: Material (PE)	1,870	0,01083	20	10%	A.130.07.112.230701 PE (LDPE, Low density Polyethylene)		0,405042
Secondary packaging: Blow moulding	1,098	0,01083	20	30%	D.120.01.102.230701 blow moulding, production site		0,23784
Enclosure packaging: Material (PE)	1,870	0,00434	20	10%	A.130.07.112.230701 PE (LDPE, Low density Polyethylene)		0,162316
Enclosure packaging: Blow moulding	1,098	0,00434	20	30%	D.120.01.102.230701 blow moulding, production site		0,0953117

Transport	Eco-Intensity (Impacts/ ton-km)	Mass per Item (ton)	Distance per Item (km)	Items per func.unit (#)	Uncertainty (%)	Index	Calculated Impact
Truck: Road transport to New York Port	0,076	6E-05	425	200	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	0,4127974
Shipping: US to Rotterdam port	0,005	6E-05	5850	200	10%	C.070.01.106.230701 Container ship (min weight/volume ratio 0,41 ton/m3)	0,157224
Truck: Rotterdam to Böblingen Germany (warehouse)	0,076	6E-05	640	200	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	0,6216244
Truck: Böblingen to Amsterdam hospital	0,076	6E-05	640	200	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	0,6216244
Truck: Hospital to local waste management	0,076	6E-05	20	200	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	0,01824

Use	Eco-Intensity (Impacts/MJ or other)	Amount per Item (MJ or other)	Items per func.unit (#)	Uncertainty (%)	Index	Calculated Impact
Monitor inflation and deflation energy	0,052	0,00001333	200	30%	B.046.08.130.231201 Electricity New Hampshire production	0,0001376

End of Life	Eco-Intensity (Impacts/kg)	Mass per Item (kg)	Items per func.unit (#)	Uncertainty (%)	Index	Calculated Impact
Incineration hazardous waste: NiBP cuff	2,532	0,064	200	30%	Figure by Philips LCA expert	32,362984
Incineration: primary PE bag	0,054	0,004	400	10%	F.108.01.102.230701 Film LDPE 50 mu in mux waste inc	0,0937479
Incineration: secondary PE bag	0,054	0,011	20	10%	F.108.01.102.230701 Film LDPE 50 mu in mux waste inc	0,0116999
Incineration: Cardboard/paper tertiary packaging	-1,222	0,200	20	30%	F.020.01.108.230701 Paper, Cardboard, Leather, Cotton (12% MC) co-firing in electrical power plant	-4,888292
Incineration: Paper (instructions)	-1,222	0,022	20	10%	F.020.01.108.230701 Paper, Cardboard, Leather, Cotton (12% MC) co-firing in electrical power plant	-0,537967
Landfill: inert waste	0,00	0,060216	200	10%	F.130.01.106.230701 landfill (inert waste)	0
						0
						0
						0
						0
						0

Raw material contribution	43,28500231	39,6%			
Packaging impact	3,582231174	3,3%			
total supplier materials contribution	69,87220875	63,9%		Materials and mfg	80,3147	73,42%
Manufacturing	37,02967626	33,9%		Transport	2,0313	1,86%
Upstream transport	2,013070202	1,8%		Use	0,0001	0,00%
Downstream transport	0,01824	0,0%		EoL	27,0421	24,72%
Incineration	0,162	0,1%		**Total**	109,3882	

Revo Care Cuff (200 patients multi-patient-use)

Purpose: Evaluate the impact of the redesign
Boundaries: See value map
Functional unit: Environmental impact per 200 patients being NiBP monitored
Impact unit: kg CO2 eq.
Uncertainty rubric: 10% for database perfect match, 30% for plausible substitution, 100% for wild guess

Design option:
NiBP cuff Dutch hospital flow

Manufacturing	Eco-Intensity (Impacts/kg)	Mass per Item (kg)	Items per func.unit (#)	Uncertainty (%)	Index	Notes	Calculated Impact
Cuff sheet: Material (PP)	1,630	0,02156	1	10%	A.140.01.120.230701 PP (Polypropylene) pellets		0,035136
Cuff sheet: Production of material spinning	0,918	0,02156	1	10%	A.140.03.116.230701 spinning extruder polymer filaments (80 - 500 dtex)		0,019785
Cuff sheet: Production of fibres	1,046	0,02156	1	10%	A.140.03.103.230701 heat setting and washing synthetic fabrics		0,0225541
Cuff sheet: Material weaving	1,458	0,02156	1	10%	A.140.03.128.230701 weaving 500 dtex		0,031418
Cuff sheet: PP laminate material	1,630	0,00036	1	10%	A.140.01.120.230701 PP (Polypropylene) pellets		0,0005857
Cuff sheet: Blow moulding	0,012	0,00036	1	10%	D.120.01.102.230701 blow moulding, production site		4,43E-06
Cuff sheet: cutting wide sheet from roll material			1			negl.	0
Cuff sheet: cutting individual NiBP shapes out of material			1			negl.	0
Cuff sheet: Trimming edges			1			negl.	0
Cuff sheet: UV screen printing	0,492	0,0016	1	10%	D.110.01.103.230701 Printing per m2, 100%, UV, inkjet		0,000788
Cuff sheet: RF welding outer perimeter	0,052	0,015	1	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,000774
Cuff sheet: Diecutting outer perimeter			1			negl.	0
Hook: Material (PP hook-to-hook) (2 counterparts together)	1,630	0,00306	1	10%	A.140.01.120.230701 PP (Polypropylene) pellets		0,0049888
Hook: Production of material	1,167	0,00306	1	10%	D.120.01.106.230701 injection moulding, production site		0,003571
Hook: Cutting to specification			1			negl.	0
Hook: RF welding onto cuff sheet	0,052	0,015	1	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,000774
Loop: RF welding onto cuff sheet	0,052	0,015	1	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,000774
Connector: Material (PP)	1,630	0,00047	1	10%	A.140.01.120.230701 PP (Polypropylene) pellets		0,000766
Connector: Injection molding	1,167	0,00047	1	10%	D.120.01.106.230701 injection moulding, production site		0,000548
Connector: RF welding onto cuff sheet	0,052	0,015	1	10%	B.046.08.130.231201 Electricity New Hampshire production	See miro for calculation	0,000774
Primary packaging: Material (PE)	1,870	0,00434	1	10%	A.130.07.112.230701 PE (LDPE, Low density Polyethylene)		0,008116
Primary packaging: Blow moulding	1,098	0,00434	1	30%	D.120.01.102.230701 blow moulding, production site		0,004766
RFID tag		0,00434	1	10%	ENVIRONMENTAL IMPACTS AND IMPLICATIONS OF RFID TAGS (European Union)		0,0256

Transport	Eco-Intensity (Impacts/ ton-km)	Mass per Item (ton)	Distance per Item (km)	Items per func.unit (#)	Uncertainty (%)	IMPLICATIONS OF RFID TAGS	Calculated Impact
Truck: Road transport to New York Port	0,076	3E-05	425	1	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	0,0008872
Shipping: US to Rotterdam port	0,005	3E-05	5850	1	10%	C.070.01.106.230701 Container ship (min weight/volume ratio 0,41 ton/m3)	0,000754
Truck: Rotterdam to Böblingen Germany (warehouse)	0,076	3E-05	640	1	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	0,0013313
Truck: Böblingen to Amsterdam hospital	0,076	3E-05	640	1	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	0,0013313
Truck: Hospital to local waste management	0,076	3E-05	20	1	10%	C.060.01.105.230701 Truck+container, 28 tons net (min weight/volume ratio 0,41 ton/m3) (tkm)	4,1E-05

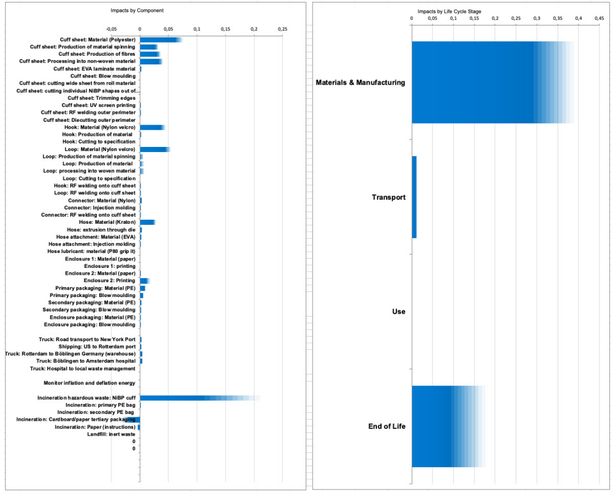
Use	Eco-Intensity (Impacts/MJ or other)	Amount per Item (MJ or other)	Items per func.unit (#)	Uncertainty (%)	Index	Calculated Impact
Monitor inflation and deflation energy	0,052	0,00001333	200	30%	B.046.08.130.231201 Electricity New Hampshire production	0,000138
Cleaning	0,031	200	1	30%	reusable microfiber cloth with QAC disinfectant (Maloney, et al., 2022)	6,26

End of Life	Eco-Intensity (Impacts/kg)	Mass per Item (kg)	Items per func.unit (#)	Uncertainty (%)	Index	Calculated Impact
Collection and sorting of plastics	0,091	0,027	1	30%	F.130.01.108.230701 plastic waste, collection&sorting	0,002468
Recycling NiBP cuff	0,246	0,027	1	30%	F.120.01.116.230701 PP (Polypropylene), closed loop chemical upcycling credit	0,006643
Recycling: primary PE bag	0,246	0,004	2	10%	F.120.01.109.230701 PE (Polythylene), closed loop chemical upcycling credit	0,002136
Incineration: Cardboard/paper tertiary packaging	-1,222	0,200	0,1	30%	F.020.01.108.230701 Paper, Cardboard, Leather, Cotton (12% MC) co-firing in electrical power plant	-0,02444
						0
						0
						0
						0
						0
						0

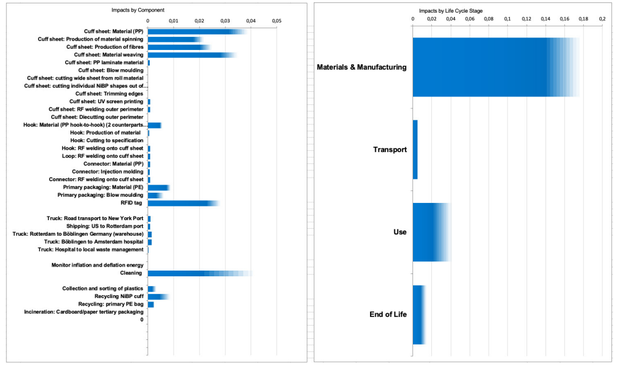
Raw material contribution	0,04959278	0,8%			
Packaging impact	0,04512436	0,7%			
total supplier materials contribution	0,12746132	2,0%		Materials and mfg	0,1617	2,51%
Manufacturing	0,11211857	1,7%		Transport	0,0043	0,07%
Upstream transport	0,00425297	0,1%		Use	6,2601	97,25%
Downstream transport	0,00004104	0,0%		EoL	0,0112	0,17%
				Total	6,4374	

*Local reprocessing with a reusable microfiber cloth with QAC disinfectant
(full lifecycle including laundry and max. 75 cycles of reusable wipe is taken into account)
(Maloney, 2022)

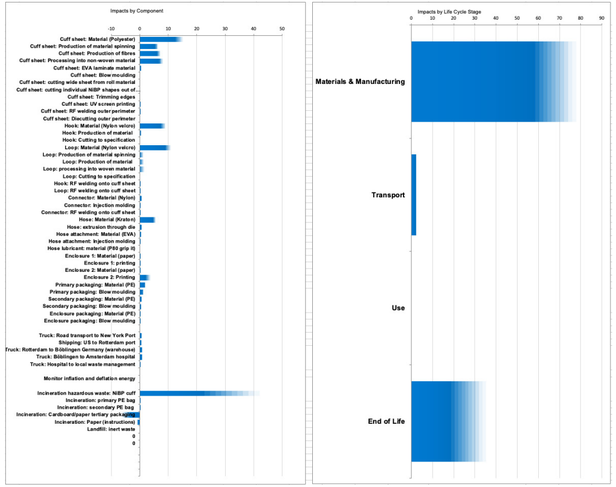
Gentle Care Cuff (1 patient and single-patient-use)



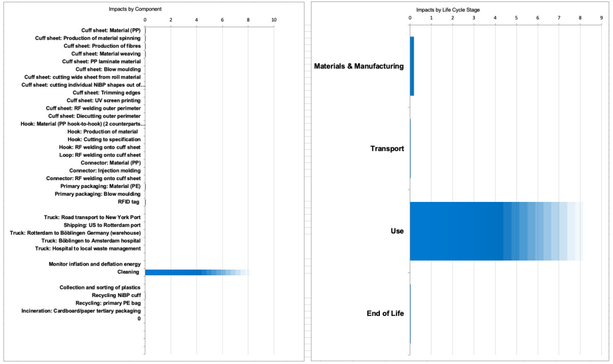
Revo Care Cuff (1 patient and single-patient-use)



Gentle Care Cuff (200 patients single-patient-use)



Revo Care Cuff (200 patients multi-patient-use)



IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME

Complete all fields and indicate which master(s) you are in

Family name	Badloe
Initials	J.A.R.
Given name	Jamil
Student number	4668502

IDE master(s) IPD ✔ Dfl ☐ SPD ☐

2nd non-IDE master

Individual programme *(date of approval)*

Medisign ☐

HPM ☐

SUPERVISORY TEAM

Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	Conny Bakker	dept./section	Design for Sustainability
mentor	Tamara Hoveling	dept./section	Design for Sustainability
2nd mentor	Margot Honkoop		
client:	Philips		
city:	Amsterdam	country:	The Netherlands

optional comments: Both Tamara and Conny are from the same department within IDE. They are both part of the consortium DiCE, for which this assignment is part of a bigger whole. Conny has profound and widespread sustainable knowledge, and Tamara specified to Healthcare.

! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why.

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in **by the Chair** of the supervisory team

Personal Project Brief – IDE Master Graduation Project

Name student Jamil Badloe **Student number** 4668502

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title Towards circular healthcare: An exploration of circular opportunities for wearable medical sensors

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

This graduation project focuses on redesigning single-use medical sensors used in hospitals, with the goal of optimizing them for circularity. A soon-to-be publicly announced Philips Medical Sensor, a single-use wearable device used for vital sign monitoring in hospitals, will serve as the practical case study. The project is part of research done by the EU funded "Digital Health in the Circular Economy" (DiCE) consortium, which addresses the growing environmental challenges posed by the waste generated through the upcoming innovation that is digital health devices (DiCE, 2024).

Digital healthcare devices have been shown to revolutionize healthcare delivery. The enable continuous tracking of vital signs, improve diagnostics, and provide real-time insights into the patients' health, which ultimately result in improved conditions for patients, enhanced care accessibility and efficiency in the overall healthcare (Chan et al., 2012; Eberly et al., 2020; Kang & Exworthy, 2022). However, despite their benefits, the rise of digital health devices also raises questions regarding sustainability within the healthcare sector. These devices are often not optimized for circularity, since challenges exist in balancing sustainability with stringent healthcare hygiene and safety requirements. Next to that, supply chain parties lack economic incentive, while hospitals favor the ease of use and efficiency of single use products (MacNeill et al., 2020).

Since the global healthcare sector accounts for 4,4% of global greenhouse gasses, redesigning these medical devices for circularity in hospital environments is a critical step towards reducing the environmental impact of healthcare systems (Hu et al., 2022; MacNeill et al., 2020).

Stakeholders for this product include various parties, such as every entity in the supply chain (suppliers, manufacturers, and distributors), regulatory organizations, hospitals, and the patients on whom the products are used. This requires a holistic approach to make sure that value is added for the supply chain companies, that it does not put further pressure on the healthcare workforce, while also maintaining patient safety and comfort. The stakeholders within the supply chain currently consist of material suppliers, the manufacturer Philips, and the distribution network; but could ultimately be extended with companies associated with circular flows, as depicted in earlier research done by DiCE.

Chan, M., Estève, D., Fourniols, J., Escriba, C., & Campo, E. (2012). Smart wearable systems: Current status and future challenges. Artificial Intelligence in Medicine, 56(3), 137–156. https://doi.org/10.1016/j.artmed.2012.09.003
Dice. (2024, 14 november). Homepage - Digital Health in the Circular Economy. Digital Health in The Circular Economy. https://circulardigitalhealth.eu/
Eberly, L. A., Kallan, M. J., Julien, H. M., Haynes, N., Khatana, S. A. M., Nathan, A. S., Snider, C., Chokshi, N. P., Eneanya, N. D., Takvorian, S. U., Anastos-Wallen, R., Chaiyachati, K., Ambrose, M., O'Quinn, R., Seigerman, M., Goldberg, L. R., Leri, D., Choi, K., Gilelman, Y., Adusumalli, S. (2020). Patient Characteristics Associated With Telemedicine Access for Primary and Specialty Ambulatory Care During the COVID-19 Pandemic. JAMA Network Open, 3(12), e2031640. https://doi.org/10.1001/jamanetworkopen.2020.31640
Hu, H., Cohen, G., Sharma, B., Yin, H., & McConnell, R. (2022). Sustainability in health care. Annual Review Of Environment And Resources, 47(1), 173–196. https://doi.org/10.1146/annurev-environ-112320-095157
Kang, H. S., & Exworthy, M. (2022). Wearing the Future—Wearables to Empower Users to Take Greater Responsibility for Their Health and Care: Scoping Review. JMIR Mhealth And Uhealth, 10(7), e35884. https://doi.org/10.2196/35884
MacNeill, A. J., Hopf, H., Khanuja, A., Alizamir, S., Bilec, M., Eckelman, M. J., Hernandez, L., McGain, F., Simonsen, K., Thiel, C., Young, S., Lagasse, R., & Sherman, J. D. (2020). Transforming the Medical Device Industry: Road map to a Circular economy. Health Affairs, 39(12), 2088–2097. https://doi.org/10.1377/hlthaff.2020.01118

→ *space available for images / figures on next page*

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

Digital health devices are predicted to increase rapidly over the coming years, with an annual global growth rate of almost 20% (DiCE, 2024). While they are increasingly used to improve healthcare efficiency and conditions for patients, they also form a challenge in terms of e-waste. The Philips medical sensor is one of such products, which is a device, worn around the patient's arm and connected to a hospital monitor, that acquires signals from the patient. This device is currently optimized for single-use in a hospital setting.

Sustainability and the healthcare sector have proven to be a difficult match, partly because there is a lack of awareness, but also because of a lack of economic incentive, regulatory barriers and strict safety and hygiene standards (Hu et al., 2022). The key challenge lies in identifying valuable circular redesign opportunities, which satisfy all stakeholders. These stakeholders include: supply chain companies, regulatory organizations, hospitals, and the patients themselves. Perceptions of multi-use products in hospitals will need to challenged, along with finding economically viable propositions, which do not put extra strain on the hospitals, while maintaining the safety and comfort for the patient.

Dice. (2024, 14 november). Homepage - Digital Health in the Circular Economy. Digital Health in The Circular Economy. https://circulardigitalhealth.eu/
Hu, H., Cohen, G., Sharma, B., Yin, H., & McConnell, R. (2022). Sustainability in health care. Annual Review Of Environment And Resources, 47(1), 173–196. https://doi.org/10.1146/annurev-environ-112320-095157

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Developing redesign solutions to improve the circularity of wearable medical sensors in hospital settings, to generate insights and recommendations for circular design in similar devices.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

As the redesign is part of a larger research about circularity in DiCE, the road towards redesigning the Philips medical sensor is just as important as the proposed redesign itself. Because of this, the project will consist of two parts:

- Developing redesign solutions for the case of the Philips medical wearable sensor used in hospitals.
- Evaluating the applied methods to generate insights and recommendations for circular (re)design of similar medical wearable sensors.

This project lends itself well for the "Sustainable North Star Approach", developed by Accenture. This approach focuses on holistic, end to end, design approaches, which look at engineering solutions, user experience and systemic changes. Within this method, the focus will lie first on literature on earlier DiCE research and overall sustainability in healthcare, while simultaneously diving into the product's value, LCA and user context. After this, opportunities will be identified, which will act as a starting point for the redesign of the Philips medical wearable sensor for the second phase of the project.

Project planning and key moments

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a ***kick-off meeting, mid-term evaluation meeting, green light meeting*** *and* ***graduation ceremony****. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	3-3-2025
Mid-term evaluation	25-4-2025
Green light meeting	16-6-2025
Graduation ceremony	26-7-2025

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

Sustainability has been a central theme throughout my academic career, and formed many of my decisions during both my bachelor's and master's programs. Beyond academics, I sought tangible ways to contribute to sustainability, which led me to join the Dreamteam Delft Hyperloop and the board of Students4Sustainability, where I focused on impactful, real-world applications.

During the AED course, I had the opportunity to dive into sustainable medical design and found it deeply rewarding to tackle a challenge within the healthcare sector. Particularly because it offers the ability to face difficult challenges, which can make a meaningful impact in such a high-stakes field.

This project aligns perfectly with my interests, combining sustainability with medical design. It also offers opportunities to pursue my personal learning ambitions, including:

- Deep diving into circular design literature and research methods.
- Exploring strategic product design elements while sharpening technical skills developed in IPD.
- Demonstrating my ability to lead a large-scale project independently, from project management to stakeholder engagement and hands-on design execution.

Ultimately, this project allows me to combine my passion for sustainability with my interest in medical design, while also further honing my soft- and hard skills for my future career.

Thank you for reading.

If you would like to know more about the project, please reach out.

Jamil Badloe

Graduate Student - MSc Integrated Product Design