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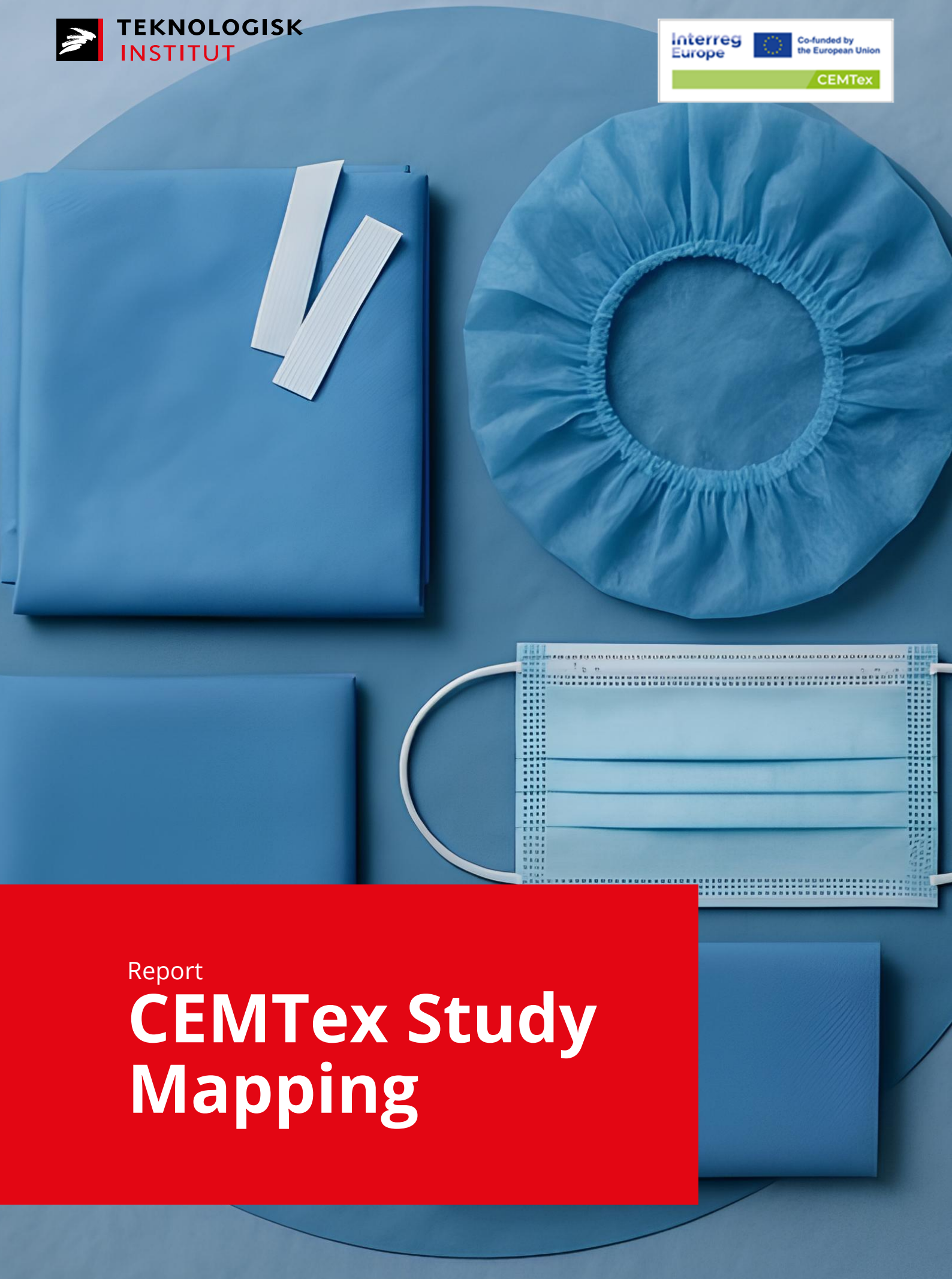

Report

CEMTex Study Mapping

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Report

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Introduction

CEMTex is an Interreg Europe project that supports European regions in shifting from single use to circular, multiple use medical textiles. It addresses hospitals' dependency on disposable gowns, drapes and other textiles, which generate large amounts of waste, increase CO_2 emissions and depend on vulnerable global supply chains.

Partners from seven EU countries, plus Ukraine and two associated authorities, are working on improving regional policies on circular economy, healthcare, waste, innovation and public procurement. Through interregional learning, peer review, thematic seminars and stakeholder groups, they identify barriers and good practices, then adjust their policy instruments to enable wider circular use of medical textiles, reduce waste and emissions, and strengthen regional value chains.

At the request of the consortium, the Danish Technological Institute (DTI) conducted the research for this study mapping report. The report combines findings from a literature review on circular (reusable) medical textiles with regional case studies, as well as input from a workshop organised by DTI in November 2025, where the regions commented on preliminary findings of the study. The regional case studies are based on questionnaires filled in by the following CEMTex partners representing the following regions: Central Denmark Region (Denmark), North-East Region (Romania), Province of Gelderland (the Netherlands), Prato Municipality (Tuscany, Italy) the Czech Republic's Kralovehradecky Region, Luxembourg and Galicia in Spain.

The report is organised into key thematic chapters covering market, technology, knowledge, culture, regulation and environment. Each chapter first presents findings from a literature review, then compares this academic context with real-world insights from the CEMTex partners' case studies and questionnaires. The consortium asked Danish Technological Institute (DTI) to conduct this research.

1. Summary

The following sections present a summary of the main findings of the report's thematic chapters.

1.1. Market

The literature review shows that the market for medical textiles is dominated by single-use, disposable products, a trend supported by ingrained procurement habits and established supply chains. Case studies from all participating regions confirm this, describing the market for reusable and circular textiles as "emerging" or "niche."

A primary factor driving this market dominance is the focus on low upfront unit prices in procurement. This practice makes single-use products appear cheaper than reusable textiles, despite the latter's lower lifecycle costs, which is a barrier reported by most regions. Other significant barriers include a lack of logistical infrastructure for collection and sanitation (highlighted by Central Denmark Region and the Kralovehradecky Region), persistent concerns about the quality, hygiene, and safety of reusables and limited or import-dependent local supply chains, which increases costs and delivery times (reported by North-East Region, The Province of Gelderland and Luxembourg).

When asked to identify opportunities for implementing circular medical textiles, the CEMTex partners highlighted several key strategies and enablers.

The reports from North-East Region, Tuscany Region, Kralovehradecky region and Luxembourg identify the "textiles as a service" model as a key opportunity. This strategy, which bundles product rental with integrated services like laundering, sterilising and repair, is highlighted as a promising path forward. This model achieves economies of scale, simplifies adoption for hospitals, and incentivises suppliers to maximise textile lifespan. The case of Tuscany is highlighted as a successful example of this approach.

Other key enablers include collaborative procurement among hospitals to increase negotiating power, growing demand for sustainable solutions driven by institutional green strategies, and the emergence of new, specialised suppliers.

1.2. Technology

The literature review indicates that modern reusable textiles are technologically mature and safe, with advanced fabrics offering high performance and durability through dozens of industrial laundering cycles. The regional cases confirm the maturity of non-sterile reusables (TRL 7-9) but emphasise a major real-world gap for sterile medical textiles like surgical gowns, which are at a lower Technology Readiness Level (TRL 4-6), a scale which measures how close a technology is to real-world deployment.

While the literature focuses on material-level challenges like performance degradation, the cases highlight more systemic barriers. These include a widespread lack of essential infrastructure for large-scale collection, sterilisation, and advanced recycling, as reported by the Central Denmark Region, North-East Region, the Kralovehradecky Region and Galicia. Another critical issue is material incompatibility; for example, in the Tuscany region, Italy's advanced recycling hub in Prato is optimised for natural fibres, not the synthetic materials common in medical textiles. Furthermore, the lack of viable, high-performance PFAS-free alternatives for sterile applications is a major technical hurdle reported by several regions.

When asked to identify technological opportunities to support or scale up production of circular medical textiles in the health care sector, several common technological opportunities were reported across the regions. A dominant theme is the adoption of digital solutions, such as RFID and other tracking systems, to improve traceability, manage textile lifecycles and build trust in reusable products. Many regions also point to significant potential in process improvements, specifically through optimising logistics and modernising sterilisation and laundry workflows to be more efficient and sustainable. Material innovation is another crucial opportunity, with a focus on developing durable, easily recyclable, and PFAS-free textiles. Several regions, including the Central Denmark Region, Province of Gelderland and Galicia emphasise the need to develop PFAS-free solutions.

Finally, regions identify scaling opportunities through collaboration, including public-private partnerships and R&D with universities to adapt and develop new technologies (North-East Region, Central Denmark Region, Galicia).

1.3. Knowledge

The literature review shows a robust, evidence-based international knowledge base supporting the safety and benefits of reusable medical textiles, including established performance standards and Life Cycle Assessment (LCA) data. The regional cases,

however, reveal a disconnect between this available knowledge and the situation within healthcare institutions, consistently reporting low, fragmented and uneven knowledge at the hospital level.

A critical gap identified across nearly all regions is the lack of accessible, comparative data (especially LCAs and lifecycle cost analyses) to support evidence-based decision-making. Hospital staff, procurement teams and managers often have a limited understanding of circular options, green procurement criteria, and the true environmental impact of disposables. This is compounded by weak cross-sector knowledge sharing; for instance, in the Tuscany region, textile recycling experts lack familiarity with medical requirements, while healthcare professionals are unaware of advanced circular technologies.

The main potential lies in bridging this knowledge gap by generating more standardised and comparable local data on performance and life cycle impacts of circular textiles, combined with targeted training for procurement teams, managers and clinical staff on the benefits and safe handling of circular textiles. Fostering structured collaboration between hospitals, industry and research institutions, as proposed by North-East Region and Galicia, is seen as essential for developing and validating local solutions, embedding new knowledge into practice, and moving beyond isolated pilot projects.

1.4. Culture

The literature review identifies a prevailing "throwaway culture" where disposables are perceived as safer and more convenient, while also noting that staff often prefer the superior comfort of reusables. The regional cases confirm this "throwaway culture", where single-use products are associated with safety, modernity and convenience.

This cultural inertia is a major barrier, rooted in decades of established habits and a safety-first focus on infection control. Staff are often described as "open but cautious," with resistance to change being a primary obstacle. This is reinforced by an organisational culture in many public hospitals that discourages experimentation and favours sticking to familiar procedures.

The most effective enablers for cultural change are showcased success stories and pilot results from peer institutions to build confidence and demonstrate feasibility. Involving clinical staff early in the decision-making process, or even in the co-creation of solutions (as suggested in the Province of Gelderland), is crucial for ensuring buy-in and ownership. Clear, data-backed education that directly addresses hygiene and safety

concerns can effectively counter misinformation. Literature draws attention to patient attitudes, finding that patients are generally far more open to reusable textiles than healthcare providers suppose. However, none of the regional cases address or investigate patient preferences as a cultural factor or a lever for change. This suggests that patients are not a lever, nor are they a barrier to adoption.

1.5. Regulation

The literature review describes a complex regulatory landscape where strict hygiene and medical device standards often create barriers for reusables, while highlighting proactive policies like green procurement as key enablers. The regional cases confirm this complexity, describing the framework as a multi-layered system of EU directives, national laws and technical standards that were not designed with circularity in mind.

A primary regulatory hurdle cited several regions (including the Central Denmark Region, the Province of Gelderland and Galicia) are public procurement laws that prioritise the lowest upfront cost, which inherently favours disposables over reusable systems with higher initial investments but lower lifecycle costs. Strict hygiene regulations are also seen as an indirect barrier, as they encourage risk-averse behaviour that defaults to single-use items. The lack of specific, dedicated national policies for circular, sterilised medical textiles creates uncertainty and a "wait and see" attitude, delaying investment and action.

The cases align on the key opportunity: using Green Public Procurement (GPP) as the most effective tactical lever to create market demand. Italy's mandatory environmental criteria (CAM) for textiles is a leading example of how GPP can be used to legally require public hospitals to prioritise circular solutions. Aligning national policies with overarching EU goals, such as the EU Waste Framework Directive and upcoming Extended Producer Responsibility (EPR) schemes, provides the strategic direction and political legitimacy needed to drive systemic change.

1.6. Environment

The literature review provides clear, evidence-based findings from Life Cycle Assessments (LCAs) demonstrating that reusable textiles are environmentally superior to disposables across metrics like energy use, emissions, water consumption, and waste. The regional cases align with this fundamental finding but add crucial real-world context, noting that this environmental advantage is threatened by operational inefficiencies and infrastructural gaps.

A critical challenge is the lack of end-of-life infrastructure. Without effective collection, sorting and recycling systems, even reusable textiles often end up incinerated or in landfills at the end of their life, as reported in North-East Region and Galicia. Furthermore, the laundering and sterilisation processes for reusables are highly energy- and water-intensive. If not optimised with modern technology and renewable energy, these processes can significantly erode the environmental benefits of reuse. A final barrier is the widespread lack of reliable, localised environmental data, which hinders healthcare providers from making informed, evidence-based procurement decisions.

Key opportunities include optimising laundry processes with renewable energy and efficient technologies to reduce the operational footprint of reuse systems. Developing robust, scalable infrastructure for textile recycling is essential for achieving true circularity. Several regions see great potential in using localised data to make informed decisions; for example, the Central Denmark Region has developed a "mini LCA" screening tool to help hospitals evaluate the environmental impact of their choices. Leveraging policy and economic incentives, such as taxes on virgin materials, as suggested in the Netherlands, can further drive the market toward more sustainable solutions.

1.7. Summary of findings

The table below summarises the key findings of the study mapping broken down into the six themes. For each dimension, it presents the main challenges/barriers on one side and the corresponding potential solutions and opportunities on the other. It should be read as an overview of where the main obstacles to circular medical textiles lie, and which actions could help address them.

	Challenges	Potential solutions and opportunities
Market	**Market Dominance of Disposable** single-use products. **Procurement Practices**: A focus on the lowest upfront unit price favors disposables. **Infrastructure Gaps**: Lack of logistical systems for laundering and sterilizing reusable textiles.	"**Textiles as a Service**": Outsource the entire textile lifecycle (rental, laundry, sterilization) to specialized providers to achieve economies of scale. **Collaborative Procurement**: Hospitals can form buying groups to increase negotiating power and market demand.
Technology	**Gaps in Sterile Solutions**: Non-sterile reusables are mature (TRL 7-9), while sterile options are less developed (TRL 4-6). **Material & Process Issues**: Lack of durable, PFAS-free alternatives.	**Implement Digital Tracking**: Use RFID to manage textile lifecycles and traceability, **Innovate Materials & Processes**: Develop durable, recyclable and PFAS-free materials and optimize sterilization workflows **Create public-private partnerships** to develop new technologies.
Knowledge	**Knowledge-Practice Gap**: A robust scientific evidence base exists, but knowledge at the hospital level is fragmented, and uneven. **Lack of Comparative Data**: Absence of Life Cycle Assessments (LCAs) and lifecycle cost analyses to support evidence-based decisions	**Develop comparable local data** (LCAs, cost analyses) to build a clear business case for circularity. **Provide Targeted Training** for procurement teams and clinical staff on the benefits, safety, and proper handling of circular textiles. **Create knowledge-sharing platforms** for hospitals, industry, and researchers.
Culture	**Pervasive "Throwaway Culture"**: Disposables are associated with safety and modernity, while reusables are seen as an "old system." **Resistance to Change** due to ingrained habits, a strong focus on infection control, and organizational inertia.	**Showcase Success Stories** from peer institutions to demonstrate feasibility and build confidence. **Involve Clinical Staff** early in the decision-making and co-creation **Provide Evidence-based Education** to counter misinformation about hygiene and safety.
Regulation	**Procurement Laws** favor disposables over circular systems. **Strict hygiene standards** lead to preference for single-use items. **Lack of Specific Policies**: The absence of dedicated national policies for circular medical textiles creates a "wait and see" attitude, delaying investment.	**Utilize Green Public Procurement (GPP)**: Actively use GPP as the most effective tactical lever to create market demand for circular solutions **Align with EU-Level Strategy**: Link national policies to EU goals and frameworks like the Waste Framework Directive and Extended Producer Responsibility (EPR) schemes to provide strategic direction.
Environment	**Lack of End-of-Life Infrastructure**: Reusable textiles often end up incinerated or in landfills due to a lack of recycling systems. **High Operational Footprint**: Laundering and sterilization processes are energy- and water-intensive, which can erode the environmental benefits	**Develop Recycling Infrastructure**: Invest in better infrastructure for efficient cleaning and recycling of textiles. **Implement Economic Incentives**: Use policy levers like taxes on virgin materials to drive the market toward more sustainable solutions.

2. Market

This chapter examines the current market conditions for circular medical textiles in the healthcare sector, drawing on the literary review and questionnaire responses from CEMTex partners.

The Market is Dominated by Disposable Textiles – and Ingrained Market Habits

The literature shows that disposables dominate global medical textile markets, with circular or reusable textiles continuing to be a small niche, about 20% of the isolation gown market in the US, and similar levels in the EU (McQuerry, Easter, & Cao, 2021; Martínés-Barbosa & Moreno-Corral, 2022; Easter & Dabbain, 2023). This dominance is supported by established supply chains and ingrained market habits that favour disposables (Bijlmer, 2022). The market is "inertia-driven," meaning people and organisations stick to established habits and systems out of familiarity or perceived safety, rather than because these are the best options (van der Klink & Demirel, 2025; REBLEND, 2023).

All regions confirm the dominance of disposables and describe reusable/circular textiles as early-stage or "emerging," despite policy attention.

In North-East Region in Romania, the market for circular medical textiles in the healthcare sector is characterised as disposable-dominated, at present, with an early-stage/low-demand for circular/reusable solutions. In the workshop, representatives of the North-East Regional Development Agency and stakeholders from the region commented that the national and regional markets for medical textiles remain dominated by single-use products and cheap imported items.

In the Czech Republic's Kralovehradecky region, hospitals prefer disposable textiles because they do not have support services for reusables. In the Central Denmark Region and the Province of Gelderland, Netherlands, there is a growing demand for reusable medical textiles that meet environmental goals, but the demand is still on a limited scale. In the Tuscany region (Italy), large-scale outsourcing to laundry/rental services is increasing, but full circular integration is uneven and regionally concentrated.

Luxembourg finds that domestic market conditions are characterised by low demand for circular medical textiles, driven by the small size of the country and a strong focus on lowest price in tenders without life-cycle criteria. With no local producers of textiles

or garments, the market is fully dependent on imports and external service providers. This makes it difficult to create a closed-loop system.

The Province of Gelderland finds that the current market structure economically favours suppliers of single-use textiles, as business cases are typically built on unit prices where disposables appear cheaper than reusables. It is reported that hospitals calculate costs in different ways and include different elements, which leads to inconsistent and often unfavourable assessments of circular options. They argue that a more top-down approach, such as national standards or a “national business case” like the National Health Service (NHS) in the UK, could help align methodologies, stabilise cost expectations, and create a level playing field where circular medical textiles can compete on transparent lifecycle cost and risk criteria. The NHS is the UK's publicly funded healthcare system. Being a large healthcare system and purchaser, its supplier policies, like the Net Zero Roadmap, are influential in driving market-wide changes toward sustainability.

Galician Health Knowledge Agency, Spain also confirms the pattern: the market is still dominated by disposable non-woven products and there is low adoption of reusables in hospitals. While circular medical textiles are at an early, niche stage, there are clear signals of growth. Even though the current supply of textiles specifically designed for circular use in healthcare is limited, there is a capable business base ready to adapt quickly to the demands of the circular economy. On the supply side, a textile ecosystem including the COINTEGA cluster is ready to meet circular demands. On the demand side, the Galician Health Service (SERGAS) is the key driver, committed to a green and circular purchasing strategy.

Service-Based Business Models Enable Reusable Medical Textiles

The literature review shows that business models of the market of medical textiles typically follow two approaches: 1) Traditional purchase-and-dispose: treating textiles as consumables or 2) Service and rental models: bundling processing and logistics into per-use fees. Historically, many healthcare facilities have operated under a direct purchase model. In this system, the facility purchases and owns its textile inventory and manages all aspects of laundering, maintenance and distribution in-house. An alternative approach is the “service-and-rental” business model, where the handling of medical textiles is outsourced to a specialised service. This model enables providers to scale operations across multiple hospitals, achieving economies of scale that make reusables more cost-competitive with disposables. Furthermore, these specialised

providers are often better equipped to optimise the washing, sterilisation and maintenance processes, maximising the textile lifespan and ensuring consistent compliance with health standards, which is a key factor in the overall sustainability and cost-effectiveness of reusable programs. (Vossola, E., Overcash, M., & Griffing, E. (2018a).

The case of the Tuscany region stands out as an example of how service-based business models can successfully enable the adoption and scalability of reusable medical textiles. Following the pandemic, Italian hospitals increasingly favour circular "service-and-rental" models for textiles. This approach boosts provider-led efficiency and sustainability and eliminates large capital outlays for hospitals. However, potential drawbacks include higher long-term operational costs (Lacity & Willcocks, 2009), a loss of direct control leading to provider dependency (Kakabadse & Kakabadse, 2002), and high switching costs that limit future flexibility (Baines & Lightfoot, 2013). Thus, the suitability of this model depends on the country and setup.

2.1. Barriers to Increasing the Use of Circular Medical Textiles

Price and Cost Structures based on Unit and Per-use Price

The literature review shows that reusables are frequently, though often incorrectly, perceived as more expensive because procurement decisions in healthcare tend to focus on upfront or per-use price, without accounting for lifecycle and hidden costs (van der Klink & Demirel, 2025; Bijlmer, 2022). Although comprehensive analyses demonstrate the cost advantages of reusable systems over time (Martinés-Barbosa & Moreno-Corral, 2022), prevailing price perceptions and rigid procurement structures continue to act as barriers (DE GROENE IC, 2024). Additionally, the absence of dedicated infrastructure and logistical support for reusables further complicates adoption (van Nieuwenhuisen et al., 2023; McQuerry, Easter, & Cao, 2021).

The case studies reflect similar market related barriers: Cost and pricing, product quality and safety concerns and logistical infrastructure barrier gaps, product quality and trust.

Unit Price-Focused Procurement

Looking across the cases, circular medical textiles are perceived as more expensive, either due to high upfront costs, unit price-focused procurement, or lack of scale and market maturity.

The Central Denmark Region experiences high initial pricing of circular alternatives, even when lifecycle costs could warrant adoption. Similarly, in North-East Region, Romania, public procurement's focus on the lowest unit price makes reusables uncompetitive. A national green procurement framework exists but is ineffective due to poor implementation and no specific legislation to promote circular textiles in healthcare. Also, in the Province of Gelderland, The Netherlands, pricing is cited as a barrier, as it needs to be proven that circular textiles are at least on par with disposables in terms of pricing.

In Tuscany, Italy, high investment costs are needed to adapt recycling infrastructure for medical synthetics, making circular options expensive. A key challenge is the discrepancy between Prato's traditional expertise in recycling natural fibres (like wool) and the healthcare sector's reliance on synthetics, which requires high-cost technological adaptations. In Luxembourg, it is reported that there are no activities related to development or use of new technologies for circular medical textiles.

The Galician Health Knowledge Agency, Spain reports familiar market barriers: a disposable-dominated market, limited circular supply, and slow adoption, all driven by the high R&D investment costs needed for the transition.

Product Quality and Safety Concerns

Across the participating regions, product quality and safety concerns are reported as a barrier. There are persistent doubts about the hygiene, durability, or technical equivalence of circular textiles, especially for sterility. The following examples illustrate these concerns.

In the Central Denmark Region, the adoption of circular textiles is hindered by the poor durability of new materials like PFAS-free textiles, which fail to withstand enough laundry cycles to be commercially viable. The problem is compounded by limited suppliers, logistical issues, and a lack of national coordination.

In the Czech Republic's Kralovehradecky region, there is a disinterest of the target group of hospitals or other healthcare centres to use circular textiles. Although suppliers are

available on the market, there is a lack of support services required to put circular textiles into operation, although suppliers are available on the market.

In the Tuscany region, Italy, the integration of bio-safety protocols within existing recycling infrastructure and strict hygiene regulations, including EN 14126:2003 and UNI EN ISO 14065:2004, creates a barrier to entry for circular options.

Logistical and Infrastructure Barriers

Circular systems depend on robust logistics for collection and reprocessing. Gaps in this infrastructure create a fundamental barrier to adoption.

The Central Denmark Region reports that scaling circular textiles is blocked by a lack of both PFAS-free products and dedicated sanitation logistics. The region argues that a unified business case requires shared national systems for procurement and logistics.

The North-East Region, Romania, highlights rigid supply chains in which specialised textiles (e.g., high-performance fabrics for gowns) depend heavily on imports, with delivery delays of over 90 days for imported products, creating serious barriers for hospitals with short procurement cycles.

The Kralovehradecky Region stresses that, although circular medical textiles and suppliers are available on the market, hospitals lack the chain of support services, logistics, washing and sterilisation needed to put circular textiles into operation.

2.2. Market related opportunities

The literature review shows that cost-effectiveness is a central driver for circular medical textiles, with studies showing reusables can lower annual costs by up to 58% compared to disposables (Overcash & Griffing, 2022). This financial advantage stems from their durability over 75–100 industrial laundering cycles (Baker et al., 2020; Easter & Dabbain, 2023). Comprehensive cost-benefit analyses that factor in waste disposal and supply chain risks further strengthen the economic case for reusables (Vossola, Overcash, & Griffing, 2018a).

Supply chain resilience also fuels adoption. The COVID-19 pandemic highlighted the vulnerabilities of relying on international disposable supply chains, whereas regional reusable systems improve supply continuity (Overcash & Sehulster, 2021; Bijlmer, 2022). Other key drivers include collaborative procurement strategies, where hospitals form buying groups for greater negotiating power, as seen in The Netherlands (Bijlmer, 2022; Circulair inkopen, 2022), and service-based rental models that make circular

systems more accessible (van der Klink & Demirel, 2025). While these cases align with literature, the opportunities they report tend to be dominated by a demand-side perspective.

Growing Demand for Sustainable Solutions and Collaborative Procurement

Rising demand for circular medical textiles, driven by green policies and awareness, is blocked by a lack of infrastructure and fragmented national strategies. While regions explore collaborative procurement to create scale, EU funding is considered a critical catalyst to de-risk the high initial investments required for the transition.

The Central Denmark Region reports a growing demand for sustainable solutions and the emergence of new suppliers, and improved logistics. It is assessed that there is a strong potential in developing national, shared systems for logistics and procurement, which could enhance scalability across the healthcare sector.

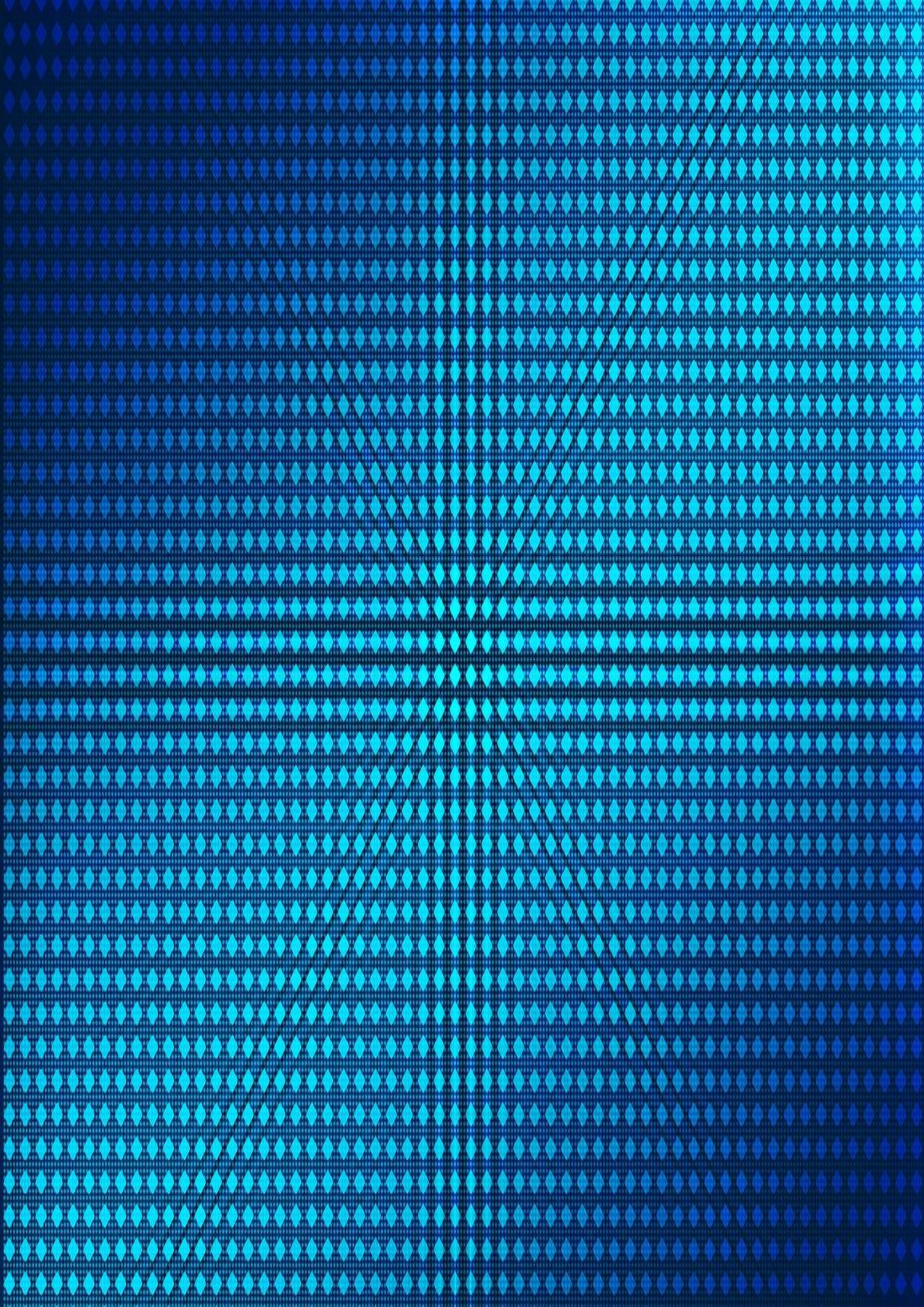
The Province of Gelderland notes that rising hospital demand and political pressure are driving a shift to circular textiles, supported by emerging startups. While national buyer groups have been established to promote sustainable procurement, their textile focus currently does not include the medical sector.[1]

The Galician Health Knowledge Agency reports high potential for circular medical textiles, where rising environmental awareness among consumers drives demand and a strong regional industry, backed by the Health Service's circular strategy, provides the supply.

The Kralovehradecky region reports that the uptake of circular medical textiles is strongly linked to the availability of inhouse support services. Hospitals that still operate their own laundry and sterilisation facilities are better able to use reusable medical textiles, whereas institutions that outsource laundry typically rely on single-use products because external laundries do not provide sterilisation.

The North-East Regional Development Agency now uses green procurement criteria with explicit ecological requirements. This policy aligns with EU objectives and emerging local demand, opening the door for circular textile models.

[1] Buyer Group Circulair textiel | PIANOo - Expertisecentrum Aanbesteden)



3. Technology

3.1. Current state of technology

The literature review shows that properly managed reusable medical textiles can effectively replace many single-use items, offering significant environmental benefits without compromising hygiene (Baker et al., 2020; Bouwman et al., 2023). Studies confirm that modern reusable textiles, like polyester gowns, maintain their protective qualities through 75–100 industrial wash cycles (Baker et al., 2020; Bouwman et al., 2023). Advances in textile engineering have integrated features like antimicrobial finishes and repellent coatings, which enhance usability, infection control and product lifespan (Baker et al., 2020; Šterman et al., 2022). Rigorous industrial laundering and quality assurance testing ensure that safety and performance standards are consistently met (Eseanya-Bakpa et al., 2022; Naito et al., 2022; McQuerry, Easter, & Cao, 2021). Furthermore, digital tracking technologies like RFID tags improve inventory management and traceability, ensuring product lifespans are monitored for safety and cost-effectiveness (Baker et al., 2020).

Cases confirm that modern reusable textiles are reliable for non-sterile applications, but adoption for sterile items remains low. However, ongoing innovation is addressing these gaps. For instance, the Central Denmark Region is testing PFAS-free materials, and Tuscany, Italy is applying advanced reprocessing technologies like NIR sorting, while Romania is researching mechanical textile disintegration.

In the Central Denmark Region, the adoption of circular medical textiles in the healthcare sector is progressing, and the Technology Readiness Level (TRL) for these non-sterile circular textile solutions is relatively high, typically between TRL 7 and 9. However, the TRL for sterile circular textiles, such as surgical gowns and drapes, is generally lower, often around TRL 4 to 6, as these solutions are still in the testing phases. The sterilisation setup is still not in place.

Similarly, in the Czech Republic's Kralovehradecky region circular medical textiles are widely available on the market in the necessary combinations for use in healthcare for all components of the health care system. For non-sterile medical textiles, the TRL level is 7-9, while only 5-6 for sterile medical textiles and biobased finishing on textiles.

In North-East Region, Romania, disposable non-woven textiles (gowns, drapes, PPE, caps) remain the dominant solution in hospitals, largely produced or imported at the

national level. Reusable textiles with protective finishes are still dependent on validated maintenance processes. Early-stage R&D projects in the region are testing mechanical disintegration and reprocessing of used textiles, at approximately TRL 2. Traceability technologies (RFID, barcoding) are technically available but only sporadically implemented in large networks, with low adoption in medium/small hospitals. Recycling technologies (mechanical or chemical fibre recovery) exist mainly at pilot scale or in other regions of the country.

In Luxembourg there is no activity related to developing or using new technologies for circular medical textiles or for textile sterilisation facilities.

In Galicia, circular medical textile technology is limited by low R&D investment and underdeveloped logistics. However, a strong commitment to change is driving gradual progress in recycling and traceability, supported by new government projects and growing corporate interest, signalling a positive but early-stage transition.

3.2. Technology Barriers

The literature review shows that, despite progress in reusable textile technology, several challenges persist that can limit their effectiveness and lifespan. The protective qualities of reusable gowns often decline with repeated laundering, as seams weaken and tear strength is reduced, which can lead to a higher risk of leaks and a shorter functional life (Easter & Dabbain, 2023).

Another key issue is the trade-off between comfort and protection. Materials that offer high water resistance typically have low breathability, causing discomfort for medical staff during long procedures and reinforcing a preference for disposable alternatives (McQuerry, Easter, & Cao, 2021).

The cleaning process itself degrades fabrics, limiting some surgical drapes to just five reuse cycles (Tomé & Lima, 2015). Furthermore, rare equipment malfunctions create a risk of incomplete decontamination (Eseanya-Bakpa, Inobeme, & Adekoya, 2022).

Finally, material compatibility is a concern. Interactions with certain disinfectants or the accumulation of detergent residues can damage protective coatings and block the pores in the fabric, further reducing the textile's efficacy (Shahane-Kapse, Patond, Deotale, & Narang, 2020; Easter & Dabbain, 2023).

The literature review and cases diverge in focus: the **literature highlights product-level barriers**, whereas **the cases stress systemic and operational issues** like infrastructure, logistics, and regulations.

The Central Denmark Region reports a lack of sterile, PFAS-free solutions that meet clinical and regulatory standards, and compatibility issues with existing logistics and sterilisation systems. There is regulatory complexity, especially for products requiring CE marking and documentation of reuse cycles. While non-sterile circular solutions are more mature, sterile applications remain underdeveloped.

Similarly, North-East Regional Development Agency reports an insufficient recycling infrastructure. No local facilities exist in the North-East Region for advanced recycling of medical textiles, particularly fibre blends. Contamination from medical use requires pre-treatment before recycling, adding complexity and cost. The insufficient recycling infrastructure also lacks IT systems and has a low adoption of traceability systems.

The Galician Health Knowledge Agency reports that the transition to circular medical textiles is stalled by a lack of suitable technologies and infrastructure, particularly for validated washing, disinfection, and end-of-life decontamination, needed to meet the sector's high safety and hygiene standards.

The Province of Gelderland also reports logistical challenges and lack of production facilities within the EU. Luxembourg also reports on insufficient infrastructure as there are no major players in this market, and the country does not have a textile sterilisation facility.

The Czech Republic's Kralovehradecky region reports insufficient recycling facilities, described as "limited infrastructure for large-scale collection, sorting, and reprocessing of used textiles." The region also mentions lack of sterilisation units for these products (large autoclaves) and lack of bio-based alternatives of PFAS finishing that meets standards for medical textiles.

The Tuscany region also reports barriers related to insufficient recycling facilities. A main challenge is the material adaptation as Prato's mechanical recycling processes are optimised for natural fibres (wool, cashmere) while healthcare textiles predominantly use synthetic materials (polypropylene, fibre blends).

In summary, technological barriers are related to missing infrastructure, product limitations and biosafety demands. Many regions lack adequate facilities for largescale collection, sterilisation and advanced recycling.

3.3. Technology Enablers and Opportunities

The literature review and regional cases diverge: the literature points to cutting-edge technologies like advanced sterilisation (Iyer et al., 2025; Qiu et al., 2025) and 'smart' antimicrobial fabrics (Galante et al., 2022; Oh et al., 2024) as key enablers. In contrast, the cases prioritise systemic upgrades, such as developing durable PFAS-free materials, deploying digital traceability, and improving existing logistics and laundry infrastructure.

In the Central Denmark Region, it is reported that there are opportunities related to developing PFAS-free materials, using digital tracking (e.g., RFID) for traceability and lifecycle management, and sterilisation and logistics so circular textiles fit into existing hospital workflows. Public-private pilots are key to testing and scaling these solutions.

In the North-East Region, it is reported that key opportunities lie in upgrading and automating existing barrier laundries, introducing digital traceability (RFID, software platforms), and fostering R&D with universities to develop durable, reusable/recyclable textiles. Pilot recycling projects (mechanical/chemical), better materials and processes, and integrated demonstration sites can together support largescale circular textile adoption.

In the Province of Gelderland, it is reported that the main opportunities are the development of PFAS-free textile solutions and organising production at a European, rather than a national, scale to reach sufficient volume and efficiency for circular medical textiles.

In Tuscany, it is reported that the technological potential is in adapting Prato's advanced textile-recycling ecosystem to healthcare. The recycling-system is using NIR (Near-infrared) for sorting for medical textiles, which is an automated technology that uses light to identify and separate different materials based on their unique chemical composition. The recycling-system is linking RFID lifecycle data to recycling processes, developing specialised treatments for synthetic medical fibres, digitally connecting hospital procurement with Prato's supply chains.

In Luxembourg, it is reported that opportunities include using the Product Circularity Data Sheet (PCDS) to identify and certify circular products, leveraging growing awareness of textile and packaging waste to drive change, and building on the interest of the dedicated hospital laundry (Spidolswäscherei) in new cleaning and circular solutions. Furthermore, while there is a local DuPont production site for geotextiles, the country lacks a dedicated facility for sterilising textiles.

In the Kralovehradecky region, it is reported that there is potential to improve sterilisation and logistics processes so circular textiles can be integrated into hospital routines. However, technological scaling is constrained by legislative uncertainties and delays in EU and national requirements, which affect investment and implementation.

In Galicia, there are significant opportunities to advance circular medical textiles. Local enterprises that currently rely on imported textiles and technologies are interested in investing in innovation to develop local technological solutions. Efforts are being directed towards new approaches in logistics, traceability, sterilisation and design.

3.4. Future Directions and Research Gaps

The literature review on circular medical textiles in healthcare identifies several urgent research needs. It is essential to enhance the performance and durability of reusable garments (Easter & Dabbain, 2023; McQuerry, Easter, & Cao, 2021; Šterman et al., 2022) and to validate new sterilisation technologies (Iyer, Ouyang, & Vinayak, 2025). Critical gaps also exist in the infrastructure for traceability and certification (Brasch, Kobold, & Klein, 2025), end-of-life recycling systems for mixed fibres, and robust, real-world evidence on the safety and benefits of circular options. Adoption is further constrained by weak standardization, skills deficits, and limited knowledge transfer.

Performance Trade-offs (Durability, Comfort vs. Protection)

The research gap concerning performance trade-offs is strongly confirmed by the cases, which frame it as an immediate, practical barrier. The North-East Regional Development Agency, Romania, for instance, directly addresses the technical challenge of material degradation, noting that "Technical textiles often degrade after repeated sterilisation, particularly hydrophobic or antimicrobial finishes, reducing barrier performance over time". This issue is compounded by user experience, as some materials are not resilient enough to withstand the sterilisation cycles or do not provide sufficient comfort or protection, raising doubts among healthcare staff. The Central Denmark Region also reports "concerns about long-term durability, especially when

using PFAS-free alternatives", as a primary obstacle to adoption. The Galician Health Knowledge Agency reports the need for further research by highlighting that the sector's "demanding standards of hygiene, security and comfort" make it essential to invest much more in developing technologies that can resolve these very trade-offs.

Advancing Sterilisation Technology

The cases repeatedly identify sterilisation and its associated infrastructure as a major bottleneck, underscoring the urgent need for disinfection technologies. The Kralovehradecky region cites a "lack of sterilisation units for these products (large autoclaves)" as a primary technological barrier". Luxembourg reports "We don't have a textile sterilisation facility in Luxembourg". The Central Denmark Region reports a similar problem, as they do not have a textile sterilisation facility.

Creating Technologies for Circularity (Sorting & Recycling)

The lack of sorting and recycling infrastructure for medical-grade textiles is a barrier to circularity. The Tuscany region reports a technology gap. The district's expertise in recycling natural fibres like wool is mismatched with the synthetic materials and blends used in most healthcare textiles, requiring significant technological adaptation.
The North-East Region reports an "Insufficient recycling infrastructure: No local facilities exist for advanced recycling of medical textiles, particularly fibre blends". This same infrastructural deficit is echoed across other regions, with both the Central Denmark Region and the Kralovehradecky region identifying a "Limited infrastructure for large-scale collection, sorting, and reprocessing of used medical textiles" as a key barrier.

4. Knowledge

The literature review and cases present a clear contrast: The literature shows well-established standards, safety evidence, and professional knowledge regarding reusable textiles (Baker et al., 2020; Karim et al., 2020; Naito et al., 2022; Overcash & Sehulster, 2021). The benefits and safety of properly laundered, reusable textiles are increasingly supported by evidence (Overcash & Sehulster, 2021), and robust life cycle assessment data offer environmental comparisons for decision makers (Vossola, Overcash, & Griffing, 2018a). The literature review shows that healthcare professionals possess a substantial base of knowledge regarding infection control and textile performance standards. Conversely, the cases demonstrate that this knowledge is limited in practice, with hospitals reporting low awareness of the benefits of circular solutions.

In the Central Denmark Region, it is reported that knowledge and data on circular medical textiles are increasing but still fragmented. Non-sterile circular textiles are relatively well understood thanks to pilots and operational experience, while for sterile, especially PFAS-free, textiles data are limited, and research is still ongoing.

In North-East Region, it is noted that awareness of circular medical textiles is low and fragmented. Staff and procurement lack knowledge of circular options and green criteria, data is not systematically collected, and expertise remains isolated in academia rather than integrated into the health system.

In the Province of Gelderland, despite the presence of knowledgeable frontrunners, many hospitals lack insight into textile environmental impacts. More robust LCA data comparing circular and disposable options is needed for widespread, evidence-based decision-making.

4.1 Gaps in Knowledge, Skills, or Information

The literature and case findings diverge on key barriers. The literature identifies knowledge gaps like lingering infection risk perceptions (Overcash & Sehulster, 2021), insufficient training protocols (Horn-Lodewyk et al., 2023), and a lack of standardised data (Vossola et al., 2018a). In contrast, the cases emphasize practical implementation challenges, including missing local data, weak procurement capacity, and cultural resistance.

In the Central Denmark Region, key gaps include low awareness of circular textiles, especially sterile textiles, limited skills in using them, insufficient data on performance

and reuse, and procurement teams that are not yet applying circular criteria. Scaling requires coordinated national efforts.

In the North-East Region, it is noted that major gaps include a lack of comparative data (LCA/LCC), weak green procurement skills, staff safety concerns about reusables, and insufficient infrastructure for testing and traceability.

In the Province of Gelderland, it is indicated that hospitals lack knowledge in procurement about circular alternatives, certification and traceability, and there are no clear guidelines or sufficient financial support for implementing circular solutions.

In the Tuscany region, it is highlighted that despite strong recycling expertise, Prato companies lack knowledge of healthcare-specific contamination and sterilisation requirements, healthcare managers poorly understand how to use Prato's technologies safely, policymakers lack integrated LCA comparisons, and data are fragmented across sectors.

Luxembourg reports cultural/behavioural gaps: hygiene departments and clinical staff are reluctant to change established procedures unless new circular solutions clearly provide added value within their comfort zone.

In the Kralovehradecky region it is observed that gaps include insufficient data and documentation on product performance and reuse, procurement frameworks that do not standardly apply circular criteria, and an absence of targeted education or training on (circular) medical textiles.

4.2 Main Potentials for Improving Knowledge and Information

The literature highlights key potentials for advancing reusable textiles: strengthening the evidence base through collaborative research (Georgievska et al., 2024), accelerating knowledge via professional networks (Easter & Dabbain, 2023; DE GROENE IC, 2024; Circulair inkopen, 2022), optimising management with digital tools like RFID (Baker et al., 2020), and stimulating demand with LCAs (Atay et al., 2021; Fehringer, 2024).
The regional cases confirm that the key challenge is not a lack of evidence, but the failure to integrate this knowledge into daily procurement, training, and certification.

In the Central Denmark Region, it is described that knowledge could be improved through training and awareness campaigns for healthcare staff, procurement teams, and management, better data collection, and development of certification and labelling schemes to support traceability and quality assurance.

The North-East Regional Development Agency sees potential in training stakeholders, running awareness campaigns, piloting digital traceability, and strengthening certifications. They emphasize collaboration between hospitals, suppliers, and universities as a key opportunity.

The Province of Gelderland identifies key opportunities in training procurement departments and running awareness campaigns on the benefits of circular solutions. They also emphasise developing certifications and standards, proposing EU-level guidelines for the entire value chain to help steer the transition toward circularity.

In the Tuscany region, Italy, improvements will leverage Prato's assets by creating a Textile Hub, demonstration facilities, and a "Circular Medical Textile Observatory" to support data integration, training, and research.

In Luxembourg it is reported that, although practical know-how is limited and circular textiles are not yet available, there is strong willingness to improve the knowhow of reusable medical textiles. It is considered that with reliable certification (e.g. PCDS) and proof-of-value testing, the potential for better knowledge and information is high.

In the Kralovehradecky region it is reported that potentials include developing certification and labelling schemes for traceability and quality, offering professional training, organising regular focus group meetings of relevant actors, and providing targeted education at health and textile congresses.

The Galician Health Knowledge Agency emphasizes training programmes and collaboration between universities, industry, and technology centres. They also highlight the need for databases to support decision-making, noting that the primary barrier is a lack of knowledge among healthcare professionals about the benefits of circular textiles.

5. Culture

5.1. Current state

The literature review shows that the culture surrounding the use of circular medical textiles in healthcare has been extensively shaped by decades-long preferences for single-use products, according to the literature (van der Klink & Demirel, 2025).

The prevailing "throwaway culture" in healthcare favours disposable textiles, which are often perceived as safer and more convenient (van der Klink & Demirel, 2025). However, attitudes are complex. While some healthcare workers resist change, many prefer reusable gowns for their superior comfort, viewing disposables as "paper-like" (Atay, et al., 2021; van Nieuwenhuisen, et al., 2023). Patients may be even more receptive, with one study showing 72% prefer reusable cloth products (Martinés-Barbosa & Moreno-Corral, 2022).

The COVID-19 pandemic had a paradoxical effect: it reinforced hygiene concerns favouring disposables but also exposed supply chain vulnerability, creating new openness to reusables (Karim, et al., 2020; Overcash & Sehulster, 2021).

The cases confirm several of the literature findings.

The "Throwaway Culture" and Safety Perceptions

The cases confirm that a culture favouring disposables, driven by ingrained habits and perceptions of safety and hygiene, is the dominant norm.

North-East Regional Development Agency, Romania, confirms that single-use products are linked to safety as well as modernity: "Doctors and nurses tend to associate single-use textiles with safety and modernity, while reusable ones are linked to an 'old system,' perceived not only as precarious but also as lacking resources, progress and freedom of choice". Hence, disposables are seen as the "modern standard and the only safe way of protection against infections".

Galician Health Knowledge Agency, Spain, validates the finding about safety perceptions, calling it a "widespread misbelief": "...there is a mistrust of reusable products compared to single-use ones, based on the widespread misbelief that the latter are safer for patients and professionals".

The Province of Gelderland, The Netherlands and the Central Denmark Region both point to the power of established routines. The Province of Gelderland, The Netherlands cites "Strong habits about using disposables" and notes that "Healthcare personnel are often hesitant to use circular textiles due to safety concerns". Central

Denmark Region adds that "traditional norms and routines still dominate daily operations, particularly in clinical settings where safety and hygiene are top priorities".

5.2. Cultural Barriers to Change

The literature review shows that the adoption of circular medical textiles is hindered by cultural and organisational barriers. Habits and a strong emphasis on infection prevention create a cultural bias for disposables, which are often perceived as cleaner and safer than reusable alternatives (Bijlmer, 2022; van Nieuwenhuisen, Friedericy, van der Linden, Jansen, & van der Eijk, 2023).

Staff resistance is also based on concerns over the comfort and convenience of reusable gowns during long procedures (McQuerry, Easter, & Cao, 2021). This cultural inertia is reinforced at an institutional level by established procurement practices that favour familiar, single-use systems over investing in circular models (van der Klink & Demirel, 2025). Looking across the cases, they confirm that the barriers of cultural habits, hygiene perceptions, convenience and organisational inertia are active challenges in the transition toward a circular economy for medical textiles.

Ingrained Habits and Cultural Bias for Disposables

The regions identify resistance to change and ingrained habits as primary cultural barriers. Ingrained habits and strong emphasis on infection prevention create a cultural bias for disposables, which are perceived as cleaner and safer than reusable alternatives. The fear of infection risk drives a powerful preference for single-use items.

To counter these ingrained cultural beliefs, the regions propose a multi-faceted strategy focused on communication, demonstration and top-down leadership.
A primary approach is to reframe the narrative through education and awareness. Regions suggest running awareness campaigns on environmental impacts (North-East Region), using storytelling and maintaining a close dialogue with clinicians to build trust (Central Region Denmark), and leveraging "influencers" to showcase new practices (Province of Gelderland,). This aims to shift the perception of reusable textiles from an "old system" to a modern, safe, and sustainable choice. To directly address the deep-rooted fear that reusables are less hygienic, several regions emphasise the need for tangible proof. The most common proposal is to implement pilot programmes that showcase innovative and safe circular solutions (Tuscany) and to widely share success stories (North-East Region). This practical, evidence-based approach is often coupled

with strong, top-down implementation. Suggested solutions include driving change through a formal circular economy strategy at the management level, forming dedicated "green teams" to lead the transition, and seeking more active support from public institutions. Top-down leadership is regarded as crucial for driving the transition to circular textiles. This is confirmed by several regions calling for greater government support, proactive management and supportive policy frameworks.

Cultural Enablers of Behavioural Change in Favour of Circular Medical Textiles
The literature review shows that several factors enable the cultural acceptance of reusable products in healthcare. Change is driven from both the bottom up, through the growing environmental awareness of healthcare workers (Bijlmer, 2022) and the top down, when organisational leadership prioritises sustainability (DE GROENE IC, 2024). Positive user experiences after implementation can overcome initial resistance, leading to high staff satisfaction over time (Baker, et al., 2020). This shift is supported by educational efforts and collaborative approaches that involve staff in product selection and decision-making (Baker, et al., 2020; Circulair inkopen, 2022). Furthermore, a sense of personal ownership, such as with individually assigned items, can increase acceptance (van der Klink & Demirel, 2025).

Success Stories, Role Models and Demonstrations
Confirming the finding that positive user experiences can dissipate resistance (Baker, et al., 2020), the cases consistently identify the power of showcasing proven examples. Both the Central Denmark Region and the Kralovehradecky Region emphasise presenting success stories and practical models from hospitals that have already piloted circular solutions. This approach is also mentioned by the Province of Gelderland, which suggests using ambassadors to promote good practices, and Luxembourg, which notes that a success story with clear "proof of value" is highly beneficial. The cases also stress the importance of influential individuals. Several regions highlight the impact of engaging recognised and respected clinical leaders as advocates to lend legitimacy to the change.

Tuscany region, Italy, reported that cultural barriers include institutional conservatism and the belief that the principle of "sterility" conflicts with circularity. The proposed solution is to implement pilot programs to showcase innovative and circular solutions. Galician Health Knowledge Agency points to the success of a specific hospital as a key example that can be shared to build confidence across the sector.

Collaborative Approaches and Staff Involvement

The literature's emphasis on collaborative and inclusive approaches (Circulair inkopen, 2022) is also validated by the cases. Several countries highlight that early and active staff involvement is crucial for building a sense of ownership. The Central Denmark Region explicitly recommends "involving staff early in the transition to ensure ownership and reduce resistance". The Province of Gelderland takes this a step further by suggesting the "co-creation of solutions together with healthcare personnel". The cases from North-East Region and Kralovehradecky Region specify the need to engage key influencers within the staff, such as department heads, epidemiologists, chief nurses and doctors, who play a decisive role in reshaping team norms and securing buy-in from their peers. Luxembourg reported that a major barrier to develop knowhow on reusable textiles is the absence of national guidelines on hygiene criteria. The proposed solutions are to create a dedicated "green team" to drive progress and to involve all required stakeholders.

Education, Training and Clear Information

In line with findings that educational efforts can shift attitudes (Baker, et al., 2020), the cases highlight the need for targeted training that directly addresses staff concerns. Awareness-raising should be supported by clear data, reliable documentation, and studies demonstrating the safety, quality, and environmental benefits of reusable textiles in order to build trust. Training in behavioural science, along with workshops, can help demonstrate the efficiency, safety, and comfort of the products. Practical demonstrations of product performance, such as barrier testing and visual comparisons, can also help overcome scepticism by providing tangible proof of quality.

Patient Perspectives: An Untapped Influence

The literature draws attention to patient attitudes, finding that patients are generally far more open to reusables than healthcare providers suppose (Martinés-Barbosa & Moreno-Corral, 2022). The cases indirectly confirm this by their “silence”: None of the regional cases address or investigate patient preferences as a cultural factor or a lever for change. The complete absence of the patient's perspective across all cases is a significant finding. The document confirms that the cultural discussion around circular medical textiles is currently an internal conversation within the healthcare system, driven by the priorities and perceptions of its staff.

6. Regulation

6.1. The Current State

The literature review shows that reusable medical textiles are regulated as medical devices in many jurisdictions (Martinés-Barbosa & Moreno-Corral, 2022). The regulation of reusable medical textiles is complex:

As regards **classification**, reusable medical textiles are often treated as medical devices, requiring strict compliance with safety, quality and performance standards.

In the **US**, bodies like AAMI and OSHA define requirements for liquid barrier protection and performance. In **Europe**, the regulatory compliance for products like surgical gowns and drapes follows two distinct pathways based on their intended use. For high-performance medical textiles, materials must comply with DS/EN 13795-1:2025 and fulfil the CE-marking requirements for Class I medical devices under the Medical Device Regulation (MDR 2017/745). Alternatively, when classified as protective equipment against infectious agents, they must comply with EN 14126:2003 and meet the CE-marking requirements for Category III Personal Protective Equipment (PPE) under Regulation (EU) 2016/425.

Although these standards provide a framework for evaluating both reusable and disposable products, specific approaches vary significantly by region. In Europe, any sold PPE must be in line with Regulation (EU) 2016/425, "which covers the design, manufacture, and marketing" of such equipment (Karim, et al., 2020).

Current Regulation

Looking across the cases, the CEMTex partners describe the regulatory framework as multi-layered, starting with high-level **EU directives** (like the Waste Directive and Medical Device Regulation) that drive national policy. These are implemented through **national laws and strategies** for waste management and the circular economy. At a national, operation level, the regulatory framework includes:

- **Public procurement regulations**, which create market demand for reusable products.
- **Technical and safety standards** (such as EN 13795 and EN 14065) define product quality and safety.
- **Health and hygiene rules**, which prioritise patient safety and can sometimes create barriers to circular models.

- **Emerging policies,** like Extended Producer Responsibility (EPR), are also beginning to influence the sector.

The sections below present the current regulatory framework as described by each case region.

Central Denmark Region: High-level strategies like *Grønne Hospitaler* (Green Hospitals) are constrained by a strict, multi-layered regulatory framework. Medical textiles must comply with EU regulations (MDR 2017/745, PPE 2016/425), Danish National Infection Control Guidelines (NIR) and specific CEN/ISO performance standards. This framework challenges circular models to prove they can meet rigorous safety requirements that have traditionally favoured disposables.

North-East Region, Romania: The framework follows EU directives (Waste, EPR), implemented through national laws on waste management and infection control. Green Public Procurement (GPP) is enabled, allowing circularity criteria in tenders. Product safety and performance are governed by technical standards like EN 13795 for surgical textiles and EN 14065 for biocontamination control in laundries.

The Province of Gelderland, The Netherlands: The regulatory framework is driven by the EU Green Deal and implemented via national policies like the "Green Deal Sustainable Care 3.0." It is guided by national health bodies (RIVM and IGJ) on infection prevention and supported by technical standards such as NEN-EN 13795 and ISO 13485.

Tuscany Region, Italy: Italy's framework combines EU directives with national laws on waste management (D.Lgs. 116/2020), which are then detailed at the regional level. Crucially, Tuscany drives circularity through its *Criteri Ambientali Minimi* (CAM), a legal mandate requiring public hospitals to prioritise reusable textiles in procurement. Safety is ensured by technical standards like EN 14126 and UNI EN ISO 14065.

Luxembourg: Luxembourg's approach is not based on specific regulations for medical textiles but is driven by its national circular economy strategy, *Null Offall Lëtsebuerg*. The national waste law provides the legal basis and government policy supports R&D.

Kralovehradecky region, **The Czech Republic:** The framework is governed by the EU Medical Device Regulation (MDR) and the national Waste Act. A key practical tool is the public procurement law, which is supported by a national strategy that encourages the use of life-cycle costing and environmental criteria in tenders.

Galician Health Knowledge Agency, Spain: The regulatory context follows a hierarchy from EU directives down to national and regional circular economy strategies, relying on technical standards like EN 13795 for safety. A significant challenge is that the

current public procurement law tends to prioritise economic (over environmental) criteria.

The Absence of Specific and Dedicated Policies for Circular Textiles

In summary, the case regions' current regulatory framework for medical textiles is a multi-layered system, encompassing broad EU directives, national waste laws, and specific operational rules for public procurement, hygiene, and technical safety standards. Several regions find that EU-level directives are a key catalyst for a more sustainable approach. The Central Denmark Region, for example, describes its regulatory context as "evolving rapidly," directly driven waste targets described in its regional strategy, the Sustainability Strategy of the Central Denmark Region. [2]

Galician Health Knowledge Agency also finds that the EU's Circular Economy package provides the guiding framework that influences both national and regional strategies.

However, looking across the case regions, the most widespread view is that a targeted regulatory framework for circular medical textiles is missing. Existing regulations are viewed as too general, leaving a policy vacuum where circularity is not explicitly supported. Several cases describe this as a passive or non-existent policy environment.

The general view across the regions is the lack of specific policies and regulations designed to encourage the use of circular medical textiles. Most regions report that dedicated regulations are "almost non-existent," with the shift often being just a "recommendation" with no clear action plan. This policy gap means that, even where related rules exist, they are not designed to support circularity, leaving hospitals with great freedom but little guidance or incentive to adopt circular models.

6.2. Regulatory Barriers

The literature review shows that the transition to circular medical textiles is hindered by a complex and fragmented regulatory environment (van der Klink & Demirel, 2025). Many guidelines are overly strict, favouring disposables despite evidence that reusables are equally safe (Bijlmer, 2022) or are based on outdated policies that ignore modern material and technological advances (van der Klink & Demirel, 2025). The lack of standardised testing methods for reusable fabrics creates major compliance challenges (Kieser et al., 2018; Bouwman et al., 2023). Additionally, stringent safety standards and "complex certification requirements" increase the time and cost of bringing innovative reusable products to market (Bijlmer, 2022). Healthcare systems

[2] https://www.rm.dk/om-os/organisation/baredygtighed/baredygtighedsstrategien/

also face practical difficulties in implementing approved laundering protocols, especially when home-laundering is a factor (Horn-Lodewyk et al., 2023).

The case studies confirm the findings from the literature review, as both identify the same major regulatory barriers. These include strict hygiene rules that favour disposable products, fragmented standards that create uncertainty, and complex compliance requirements that hinder the adoption of circular textiles.

The main difference is the cases' emphasis on powerful operational and economic barriers that the literature review does not highlight. Multiple cases cite procurement laws that prioritise low upfront costs as a primary regulatory barrier, effectively blocking investment in circular systems. In short, the cases broaden the definition of regulatory barriers to include the economic and structural systems that lock healthcare into a linear model.

In the Central Denmark Region, navigating the regulatory landscape is a key focus for implementing circular textiles. The challenge is not that regulations like MDR and NIR are prohibitive, but rather that a clear process for compliance with reusable products is still being established. For example, while public procurement frameworks are evolving to better prioritise circularity, practical methods for meeting national hygiene regulations (NIR) with reusable textiles are actively being developed. The approach is to use data and evidence, such as from the CDR textile project, to demonstrate how reusable systems can meet these existing standards, addressing the logistical and financial considerations of re-establishing the necessary washing and sterilisation infrastructure.

The Kralovehradecky region reports that challenges are rooted in a "lack of supportive national policies and standards for circular medical textiles." This policy gap is reflected in practice, as "public procurement frameworks are not yet adapted to prioritise circularity." Like the Central Denmark Region, a significant barrier is the "loss of infrastructure," because rebuilding the washing and sterilisation systems that hospitals dismantled decades ago is "both costly and complex." In addition, a key regulatory issue is the country's dependence on EU decisions, which are often delayed. A major barrier is the "No local/regional regulation above the framework of EU regulations." The proposed solution is to develop proactive "National action plans and approach to the topic" that are more than just "recommendations."

North-East Regional Development Agency, Romania, reports a complex web of barriers, starting with "no specific programs or policies for circular medical textiles," which creates ambiguity. The healthcare system operates under "very strict legislation on infection control" that places full responsibility on hospitals, encouraging them to favour single-use solutions. The framework is further fragmented with responsibilities divided between health and environmental ministries, and uncertainty around upcoming EU legislation generates a "'wait and see' attitude from suppliers and hospitals, delaying investments."

The Province of Gelderland identifies hygiene demands as a primary barrier inherent to the healthcare sector, alongside a fundamental lack of standardisation and certification for circular products, which creates uncertainty and makes it difficult for healthcare providers to adopt them with confidence. Workshop comments further noted that regulatory barriers stem from inconsistencies at both the national and regional levels. To address these challenges, the proposed solutions include developing guidelines across the entire value chain at the EU level and implementing standardised rules that dictate what garments are needed in cases where individual preferences or aesthetic demands are not a determining factor.

Tuscany Region reports that a regulatory barrier creates fragmentation, as there are "unclear classification boundaries between healthcare waste and recyclable textiles," creating uncertainty for recycling initiatives. There is "fragmented oversight between health, environment and waste authorities," which leads to regulatory gaps. Furthermore, public procurement regulations are a poor fit, as they are "not specifically designed to evaluate industrial recycling expertise and circular economy credentials."

Luxembourg's perspective is distinct, reporting that "there is no dedicated barrier" to circular textile initiatives. Luxembourg's view is that a hospital is "relatively 'free' to implement" a better, circular solution, if it continues to operate while "respecting hygiene and care standards."

Galician Health Knowledge Agency, Spain, reports that strict regulations on safety and hygiene indirectly create a barrier by appearing to "encourage the adoption of single-use products." This is amplified by Spanish public procurement law, which is primarily "committed to economic criteria over environmental criteria." The situation is further complicated by a general lack of supportive policies and the "heterogeneity of norms" on the issue across Spain's different regions.

6.3. Opportunities and Regulatory Enablers

The regulatory environment is evolving to incentivise circular medical textiles through proactive policies and procurement mandates. Frameworks like the NHS Net Zero Supplier Roadmap and the Dutch Green Deal on Sustainable Healthcare are integrating sustainability into supplier requirements, encouraging a shift to reusables (van der Klink & Demirel, 2025; REBLEND, 2023). Extended Producer Responsibility (EPR) legislation further favours durable product design by shifting end-of-life costs to manufacturers (Brasch, Kobold, & Klein, 2025). This transition is supported by safety endorsements from bodies like the WHO, which confirm reusables do not increase infection rates (Davis, Atkinson, El-Sayed, Saad, & Johnson, 2025). Broader trends, including regulatory harmonisation and lessons from the COVID-19 pandemic, are also creating a more favourable context for reusable alternatives (Martinés-Barbosa & Moreno-Corral, 2022; Wild, et al., 2023).

In summary, the literature review shows that the main regulatory enablers are proactive policies, procurement requirements, and Extended Producer Responsibility (EPR) legislation, all of which can create strong market and financial incentives for circularity. This shift is further supported by established safety standards from organisations such as the WHO, which show that reusable products can be just as safe as disposable ones.

Looking across the cases, they confirm the literature reviews' finding that strategic policy initiatives are important for advancing circular medical textiles. The cases' views are centred on two core pillars: high-level strategic commitment and tactical use of public procurement.

National and regional circular economy strategies provide the essential political direction for change. Examples include Central Denmark Region's *Grønne Hospitaler* strategy, the national "CE 2030 Strategy" driving the Province of Gelderland, Luxembourg's "government's coalition agreement for 2023–2028, and "Galician Circular Economy strategy." Upcoming EU regulations are also key drivers for North-East Region and Tuscany Region.

Green Public Procurement (GPP) is identified as the most potent lever for implementation. Tuscany Region already uses its "CAM (Criteri Ambientali Minimi) for textiles" to favour circular solutions in tenders. Similarly, Central Denmark Region and Galicia are actively embedding circular criteria into procurement documents, while North-East Regional Development Agency is working to develop standardised GPP models.

7. Environment

7.1. Environmental Impact of Textiles

The literature review and case studies agree that the healthcare sector's environmental impact is substantial, accounting for 4-8% of national greenhouse gas emissions, with disposable textiles being a major waste source (Keil, Viere, Helms, & Rogowski, 2022; Van Der See, et al., 2023; van der Klink & Demirel, 2025).

Life cycle assessments (LCAs) consistently show that reusable textiles are environmentally superior, significantly reducing energy, emissions, water use, and waste (Vossola, Overcash, & Griffing, 2018a; Atay, et al., 2021). For instance, reusable isolation gowns reduce energy use by 28%, emissions by 30%, water use by 41%, and solid waste by 93% (Vossola, Overcash, & Griffing, 2018a). Another LCA on surgical gowns found even greater savings for reusables: 64% less energy, 66% fewer emissions, and 83% less water (Atay, et al., 2021).

Despite these benefits, challenges persist. Current disposal methods like incineration release pollutants (Yuliana, Santoso, Putro, Wijaya, & Lunardi, 2022; Iyer, Ouyang, & Vinayak, 2025). Furthermore, true circularity remains elusive, as most systems focus on extending product life through reuse rather than on closed-loop material recovery (Brasch, Kobold, & Klein, 2025).

Case studies align with the literature, confirming the substantial environmental impact of single-use medical textiles (high CO_2, resource consumption, and waste). Both sources identify reusable systems as an environmentally superior solution. However, they also agree that true closed-loop circularity remains a distant goal, hindered by barriers like the dominance of incineration, a lack of recycling infrastructure, and a focus on reuse over end-of-life material recovery.

Here is a breakdown of how the cases align with each point from the literature:

High Emissions and Resource Consumption

The regions describe the environmental impact as significant, highlighting high levels of CO2 emissions, water use, and plastic waste, as well as a broader ecological footprint driven by a linear model. In some cases, this is also supported by concrete figures, such as annual emissions estimates that lend quantitative weight to the claims made in the literature.

Challenges in Disposable Textile Waste Management

The literature highlights the large volume of waste generated by disposable textiles, and regional input confirms this pattern. The CEMTex regions point to significant amounts of textile waste, very low recycling rates, and the energy-intensive handling of both infectious and non-infectious waste streams. Incineration is frequently described as the dominant disposal method for single-use textiles, while landfilling is also still common, both of which contribute to greenhouse gas emissions, plastic waste, and wider environmental pollution. At the same time, some of the regions note that virgin materials often remain cheaper than recycled alternatives, and that views differ on what should be considered a sustainable solution. Financial measures, such as taxing virgin materials or incentivising more sustainable alternatives, are therefore seen as important levers for change.

Confirmation of the Environmental Superiority of Reusable Textiles

Partners confirm the literature's finding that life cycle assessments (LCAs) generally show reusable textiles to be environmentally preferable. Reported evidence suggests that reusables can substantially reduce CO22 emissions, in some cases by 50–70%, while also lowering plastic consumption. Partners also note that circular models reduce the use of raw materials, including fossil-based resources, and improve waste management by shifting from incineration towards reuse and recycling.

Environmental Barriers to Circularity

The literature identifies several barriers to circular medical textiles, which the cases confirm. Reusable systems have higher upfront production costs and require sufficient reuse cycles to yield a net benefit (Martinés-Barbosa & Moreno-Corral, 2022; Shao, Klemes, Saxon, & You, 2022). The processes of laundering, sterilisation and transport contribute significantly to the climate impact through intensive energy and water use (Bijleveld & Uijttewaal, 2022).

Furthermore, a lack of recycling infrastructure for high-volume textile waste leads to incineration and landfill use (Brasch, Kobold, & Klein, 2025), while laundering can release chemical contaminants and microfibers (ibid.). The cases also emphasise that an absence of reliable environmental data hinders informed decision-making.

Here is a more detailed documentation of the main environmental barriers mentioned by the cases.

High Resource Consumption of Reprocessing Reusable Textiles

A commonly cited barrier among the CEMTex partners is the intensive use of resources, including water, energy, and chemicals, required for the repeated washing and sterilisation of reusable textiles. Several regions note that the environmental benefits of reusables are not automatic and may be reduced if laundering and sterilisation processes are not properly optimised, particularly when outdated technologies or carbon-intensive energy sources are involved. Another frequently mentioned challenge is the lack of adequate recycling infrastructure for medical and technical textiles at the end of their useful life, including limited capacity for large-scale collection, sorting, and reprocessing. Strict healthcare sterilisation standards can further complicate circular solutions by making recycling processes more energy-intensive and less efficient. In addition, the transport of textiles between healthcare facilities and centralised laundering services is identified as an added source of carbon emissions.

The Paradox: Lack of End-of-Life Infrastructure for Reusable Textiles

The widespread lack of infrastructure to manage circular textiles once they reach the end of their usable life often leads to the same linear disposal outcomes they are meant to prevent. North-East Regional Development Agency describes the gap in its national system: “After dozens of cycles, reusable textiles become waste. The North-East Region have an almost non-existent recycling infrastructure for technical textiles, which leads to incineration or landfilling.” Similarly, the Czech Republic’s Kralovehradecky region cites “limited infrastructure for large-scale collection, sorting, and reprocessing of used textiles”. Galician Health Knowledge Agency identifies “challenges in waste management, particularly for items that need decontamination” and “inadequate waste recovery and recycling infrastructures” as key problems. Also the Tuscany region cites the “need for dedicated processing lines to prevent cross-contamination between fashion and healthcare recycling streams”.

Absence of Environmental Data

The cases emphasise that a lack of reliable, localised, and comparative data makes it difficult to justify the transition to circular textiles and to make informed decisions. The Central Denmark Region highlights that “A lack of updated and context-specific environmental data can make it difficult for healthcare providers to evaluate the true impact of switching to reusable textiles”. To address this, the Region has collaborated with the Danish Environmental Protection Agency (Miljøstyrelsen) to develop a

screening tool (mini LCA). The absence of reliable data is also identified as a major barrier in the other regions. Several partners report that systematic studies are lacking, and that no consistent statistical data are collected, meaning that decisions are often based on general estimates rather than robust evidence. This weakens confidence in the claimed environmental advantages of circular alternatives, particularly where comparative data on carbon and water footprints are missing.

In summary, the cases show that making circular models work depends on essential changes. Cleaning/sterilisation and logistics systems need to be improved. Better data, such as life cycle assessments and tracking of textile use, are important for good decisions. Effective recycling and end-of-life solutions are needed, especially for non-hazardous textiles. Hospitals also need coordinated efforts to change behaviours and culture.

7.2. Environmental Opportunities and Potentials

The literature review shows that reusable textile systems present environmental opportunities through proven energy and CO_2 reductions (Overcash & Griffing, 2022; DE GROENE IC, 2024). Further benefits can be unlocked by circular design (REBLEND, 2023), operational enhancements (Bijleveld & Uijttewaal, 2022), and emerging technologies (Qiu, et al., 2025; Galante, et al., 2022).

Looking across the cases, they are aligned with the literature review on the core environmental and technological opportunities for circular medical textiles. However, the cases have a more policy-oriented perspective compared to the “technical” literature review, and they focus more on how to make the changes happen. Furthermore, the regions report growing demand for sustainable solutions from both institutions and the public.

Policy and Regulatory Support

A primary opportunity lies in leveraging policy and regulatory support. For instance, Green Public Procurement (GPP) is identified as a powerful tool by CEMTex partners for public hospitals to create market demand for more circular textile solutions. This is further supported by broader policy frameworks, including the EU Strategy for Textiles and national circular economy plans. In addition, economic incentives such as R&D subsidies and EU funding opportunities are seen as important enablers for helping to offset initial investment costs.

Technology, Innovation and Infrastructure

Technological advancements are critical for making circular systems viable and safe. Luxembourg, for example, highlights digital traceability through platforms like the Product Circularity Data Sheet. Another key opportunity is the use of data and evidence, such as the life-cycle assessment (LCA) data and the mini LCA tool developed in the Central Denmark Region, to build a business case and to overcome scepticism. Material and process innovation is another key area, with the Central Denmark Region developing PFAS-free solutions and the Kralovehradecky Region focusing on bio-based finishes. Developing the systems for managing circular textiles is a recurring theme. This includes optimising existing industrial laundries and creating robust infrastructure for end-of-life management, including collection, sorting, and reprocessing.

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