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Waste in humanitarian Operations:
Reduction and Minimisation

D1.4. Supply market intelligence

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V1	Gyöngyi Kovács (Hanken)	19/12/2024	Final version for submission

LIST OF ACRONYMS

ACRONYM	FULL NAME
BPA	Bisphenol
CAGR	Compound annual growth rate
CS	Chitosan
DSC	Disposable sharps containers
EC	European Commission
FDA	Food and Drug Administration (USA)
FRC	Finnish Red Cross
HO	Humanitarian organisation
IFRC	International Federation of Red Cross and Red Crescent Societies
IPT	Information processing theory
IT	Information technology
LCA	Life cycle assessment
MWM	Medical waste management
NGO	Non-governmental organisation
PHA	Polyhydroxyalkanoates
PLA	Polyactic acid
PPE	Personal protective equipment
PVC	Polyvinyl chloride
RSC	Reusable sharps containers

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SMI	Supply market intelligence
WHO	World Health Organization
WM	Waste Management

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BACKGROUND ABOUT WORM

WORM aims to design guidelines and support actions for circular economy in the humanitarian sector. It integrates bio-based technological solutions, leverages procurement for waste reduction, improves waste management methods and prioritises the sustainable livelihoods of waste pickers. WORM focuses on two selected settings: field hospital deployments and humanitarian livelihood programmes with a waste picking component. Following a collaborative and multi-actor approach, WORM brings together medical and humanitarian organisations, procurement service providers, logistics providers, waste management services and academic partners.

EXECUTIVE SUMMARY

This document is a deliverable of the WORM Project, funded under the European Union's Horizon Europe research and innovation programme under the grant agreement No 101135392.

The aim of this document (D1.4) is to provide a literature review and report on the supply market intelligence on bio-based alternatives that have been prioritised for the WORM project: Syringes and needles, personal protective equipment, sharps containers, body bags, and temporary sludge bladders. Supply market intelligence applies an information processing perspective with established market assessment techniques from the humanitarian context. This is to establish, which bio-sourced and biodegradable alternatives already exist for these product groups, how ready they are for direct use in the humanitarian context, vs how they would need to be developed further.

NON-TECHNICAL SUMMARY

WORM seeks to find bio-based alternatives in a humanitarian context, in order to reduce the environmental impact of humanitarian operations. Two areas are particularly relevant to WORM: field hospital deployments, and livelihood programmes for waste pickers. This deliverable reports on the results of a supply market intelligence on the bio-based alternatives of prioritised product groups: syringes and needles, personal protective equipment, sharps containers, body bags, and temporary sludge bladders.

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INTRODUCTION

WORM aims to design guidelines and support actions for circular economy in the humanitarian sector. It integrates bio-based technological solutions, leverages procurement for waste reduction, improves waste management methods and prioritises the sustainable livelihoods of waste pickers. WORM focuses on two selected settings: (a) field hospital deployments and (b) humanitarian livelihood programmes with a waste picking component. Following a collaborative and multi-actor approach, WORM brings together medical and humanitarian organisations, procurement service providers, logistics providers, waste management services and academic partners.

WORM seeks to find bio-based alternatives in a humanitarian context, in order to reduce the environmental impact of humanitarian operations. Two areas are particularly relevant to WORM: field hospital deployments, and livelihood programmes for waste pickers. This document is part of work package 1 (WP1), which sets the foundation of the entire WORM project as the Scoping WP. Overall, WP1 has established the baseline for this and other WPs, thereby seeking to

- Assess the scope of use of bio-based innovative technological solutions and bio-based systems in relation to WORM's use cases (field hospitals, and waste picking humanitarian livelihood programmes),
- Prioritise product groups relevant to WORM's use cases, and conduct a life cycle assessment of these;
- Scope the supply market for relevant bio-based solutions; and
- Assess the technical and economic viability of proposed bio-based alternatives.

Deliverable 1.1 (D1.1) of WP1 has formed the initial scoping exercise of WORM, and resulted in the prioritisation of product groups with potential bio-based alternatives that are relevant to a field hospital setting (milestone MS1.1), waste treatment alternatives in field hospitals (MS1.2) and procurement practices across end users (MS1.3).

Several other deliverables are submitted in parallel with this deliverable in work package 1 (WP1) that focuses on the scoping of the project: D1.2 reports on the results of a life cycle assessment (LCA) of the prioritised product groups, and D1.3 on the LCA of waste treatment processes, especially focusing on hazardous medical waste in field hospitals. D1.5 extends these with a technical and economic viability assessment of bio-based alternatives. In other words, these and the earlier D1.1 form a package of deliverables that inform also one another. More in general, WP1 informs also other WPs in WORM.

This present deliverable (D1.4) reports on the results of a **supply market intelligence (SMI)** on the **bio-based alternatives of prioritised product groups**: syringes and needles, personal protective equipment, sharps containers, body bags, and temporary sludge bladders. These priorities had been set in a scoping exercise following a multi-actor approach and engaging both the consortium as well as a wider set of stakeholders. Results of the scoping exercise have been reported in D1.1 earlier, and informed a set of other work packages and deliverables since.

D1.4 presents the results of Task 1.3 (T1.3) of the WORM project. T1.3 was set out to acquire supply market intelligence on the bio-based alternatives of prioritised product groups (MS1.1), applying an information processing perspective with established market assessment techniques

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from the humanitarian context. This is to establish, which bio-sourced and biodegradable alternatives already exist for these product groups, how ready they are for direct use in the humanitarian context, vs how they would need to be developed further. D1.4 also includes an SMI of hazardous waste treatments, and showcases the use of the WORM catalogue and its use for SMIs.

This deliverable is structured as follows: It commences with presenting an information processing perspective to supply market intelligence, which forms the conceptual backbone of the work in this deliverable. It then presents the results of the supply market intelligence that has been conducted in WORM, first going through the five prioritised product groups of WORM, and then extending this to a field study of hazardous waste treatment in Vietnam. WORM has also launched a dedicated product catalogue and platform in October 2024, which supports the work of SMIs.

Next, drivers and barriers to the adoption of bio-based solutions are presented, as they have come up from stakeholder interviews and workshops conducted for this deliverable. Apart from the very SMIs, understanding these drivers and barriers is crucial for being able to include bio-based solutions in the humanitarian context.

Importantly, this deliverable is but one of the many outputs of the WORM project. Where appropriate, references are made to other earlier work, or to deliverables that are submitted in parallel. D1.4 finishes with conclusions and next steps in the project.

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1. An information processing perspective for supply market intelligence

The capability to develop valuable knowledge regarding suppliers and products in the field where your organisation is functioning, i.e. supply market intelligence (SMI), is a key step in increasing the strategic relevance of procurement within the organisation and as well, support a competitive advantage (Ellram et al., 2013; van Weele & van Raaij, 2014). The classic Kraljic-matrix (Figure 1) is used as a base for the level of information needed for the different levels of products highlighted in the framework. The products (and services) are categorised according to their financial impact on the organisation's activities and the risks associated with supply and suppliers.

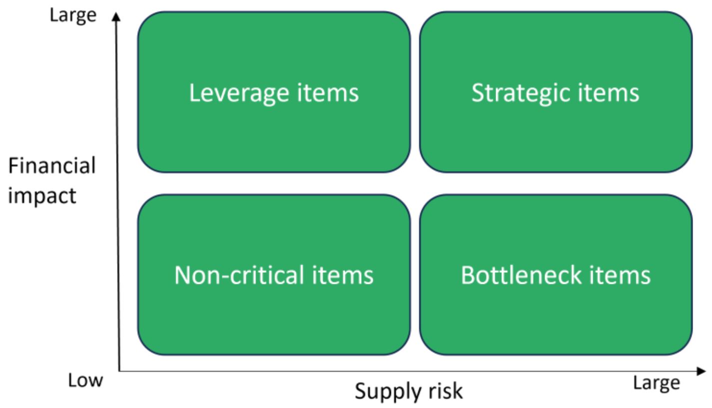

Figure 1 Kraljic-matrix (Kraljic, 1983)

The quadrants of the matrix require different levels of information processing. Strategic items need detailed market data, such as long-term trend information. These items are characterised by natural scarcity or high-value but are vital for the organisation's functions. Bottleneck items are typically sourced globally with a variable time-horizon. Medium-term supply/demand forecasts are needed on a higher level. Leverage items are generally widely available, but as their relevance to the organisation is high, vendor data needs to be accurate and market data good. Finally, the non-critical items require a good market overview, as these are widely available functional items (Kraljic, 1983).

The procedure for both market assessment and the tendering processing in WORM has been established in D2.2, Procurement guidelines for bio-based solutions. Figure 2 illustrates the general steps of this process.

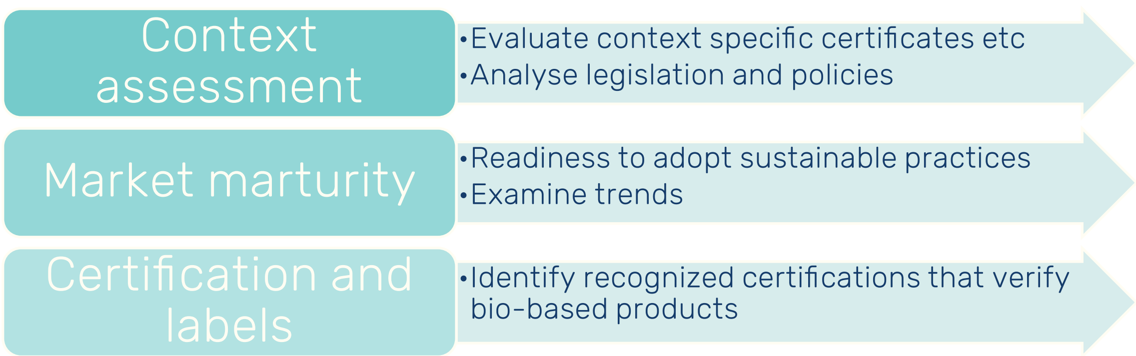

Figure 2 Market assessment steps

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Information processing theory balances between the information processing needs and the organisation's capacity for it. Within this framework, SMI is can be seen as the "pursuit of actionable knowledge of supply markets"(Lorentz et al., 2020, p. 2). This refers to defining the knowledge needed to gather, interpret, and disseminate the information and make decisions based on the data.

The main drivers for information processing needs are **uncertainty** and **equivocality** (Daft & Lengel, 1986; Tushman & Nadler, 1978). Uncertainty can be loosely defined as the lack of information, while equivocality refers to the ambiguous and diverse interpretations of whatever information is available. Elements that contribute to these are **complexity** and **dynamism of the environment** in which the organisation functions, and the tasks it is required to perform.

Furthermore, **interorganisational relationships** and **information exchange** are highly relevant in the supply chain. This further enhances the complexity of uncertainties as relational and partnership factors come into play requiring characteristics such as trust and asset specificity (Bensaou & Venkatraman, 1995). Uncertainties within the supply chain and the stakeholder network are particularly relevant when it comes to sustainability-related activities (Busse et al., 2017). The more complex the environment, the more uncertainties will arise.

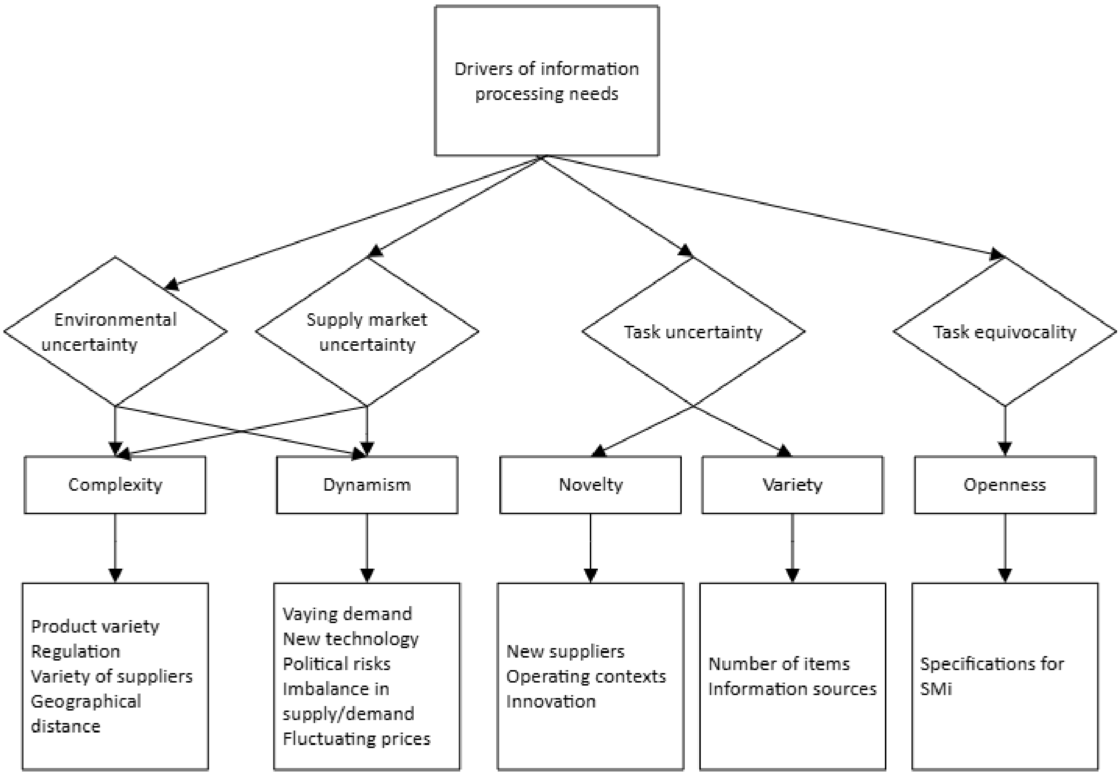

Figure 3 Information processing needs (adapted from Lorentz et al., 2020)

Lorentz et al. (2020) highlight several drivers for information processing needs. First, the complexity and dynamism that contributes to environmental uncertainty within the industry where the SMI acquisition is being conducted. Complexity refers to e.g. variety of products available, any regulations that dictate the supply market, as well as the geographical distance of suppliers, while dynamic factors such as varying demand, emerging technologies, new markets and political risks drive the need for information. Task uncertainty derives from the novelty and variety of the factors within the supply market. Operating contexts can be extremely diverse, there are new innovations and suppliers emerging constantly, which further highlight the need for information processing. In order for the tasks to maintain a level of openness for all stakeholders, the specifications for the SMI must be unambiguous and the levels of output clarified.

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To manage an organisation's information processing capacity, Lorentz et al. (2020) outline two different mechanisms; structural and information technology (IT). Reports, such as external market reports, competitor analyses, and internal accounts are an integral structural mechanism within SMI acquisition. Direct contact with the supply chain stakeholders through discussions, meetings and open information sharing is relevant as well. IT mechanisms include commercial databases, sourcing tools, news feeds, and collaborative platforms where stakeholders can share information with ease.

1.1. Bio-based and biodegradable materials in healthcare

Sustainability initiatives have brought the discussion around bio-based and biodegradable options into the mainstream. Plastic is particularly a topic of discussion due to the significant environmental challenges (Dahiya et al., 2020). Traditional plastics are widely used particularly in the medical field due to their durability and sterility, and bio-based products are considered a promising alternative. These products are derived from materials such as plant biomass, which to a degree aligns with the circular economy (Baranwal et al., 2022a). When paired with effective waste management (WM) systems, these types of products can reduce waste, as well as reduce dependence on fossil fuel-based materials. However, despite their promise, bio-based materials do not offer a straightforward solution to the WM challenge, as integrating these materials can be at odds with the safety and sterility requirements of healthcare. Biodegradable products may also require very specific conditions to properly degrade, and therefore are demanding to arrange in many contexts (Yu et al., 2024a).

At the same time, the healthcare sector is in a unique position to invest and be a pioneer in the usage of bio-based materials in their crucial products and materials. There are, however, significant economic and technical barriers that require further research to ensure the actual contribution to sustainability goals as well as the stringent product standards within the healthcare industry (Ladu & Morone, 2024).

The healthcare sector's dependency on plastics for safety reasons brings forward WM challenge. WORM's scoping exercise (D1.1) has highlighted that bio-based and biodegradable products can support the healthcare sector's transition toward more sustainable solutions. Procurement guidelines for bio-based solutions (D2.2) have identified relevant products groups for bio-based solutions such as packaging and some distribution items, which could be leveraged to reduce the environmental impact of healthcare operations.

Comprehensive life cycle assessments (LCAs)and robust WM systems are a key feature of ensuring the feasibility and effectiveness of bio-based materials (Morone et al., 2021). Attitudes towards bio-based materials in general have been favourable, particularly if the products come with appropriate certifications (Gaffey et al., 2021). As the healthcare sector is a high-volume consumer of these types of products, they play a relevant role in demand and have significant opportunity in shaping market trajectories. However, their adoption depends largely on aligning cost, performance, and industry-specific regulatory compliance (Rizan et al., 2023). For WORM, LCAs have been conducted both on the priority products for WORM (D1.2) and the medical waste management (MWM) options that have been identified as alternatives in a field hospital setting (D1.3). Furthermore, technical and economic viability assessments are presented in D1.5.

In humanitarian field hospitals, the choice between bio-based and biodegradable materials becomes even more critical as balancing sustainability with efficiency is critical. As established in D2.2, bio-based materials, derived from renewable sources like corn starch, sugarcane or cellulose bring numerous benefits such as improving efficiency, reducing greenhouse gas emissions and enabling a transition from fossil-fuel dependency through alternatives like bio-based plastics and fuels. Biodegradable products can mitigate waste generation and support circular economies by creating secondary material markets. In D1.1 we establish how these materials are used for various medical products, including packaging, disposable utensils, and instruments.

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1.2. Supply market intelligence in the humanitarian context

Any supply market intelligence (SMI) in humanitarian contexts differ from commercial counterparts, largely due to the unique conditions of crises and meeting urgent needs in an equitable manner (ICRC & IFRC, 2014). The conditions under which humanitarian markets operate are characterised by volatility, supply chain disruptions, limited, dilapidated or destroyed infrastructure, and increased vulnerabilities. The SMI must therefore focus not only on availability and economic factors, but also on fairness, on the "do no harm principle", as to say, to not unintentionally harming local economies or further exacerbating vulnerabilities. The focus of humanitarian aid is also on the most vulnerable populations, which further highlights the fairness factor to include e.g. gender and cultural sensitivities.

Humanitarian SMI assesses the functionality of local markets, with a focus on local traders' capacities to respond to sudden surges in demand. As HOs generally function under strict budgetary constraints, it is crucial to also monitor price fluctuations, which may be significant in crisis situations. But even though monitoring costs is relevant in any kind of SMI, in the humanitarian context the focus is not so much on competitive advantage, consumer trends, or profitability, but rather on minimising suffering and loss of life with limited resources. Commercial entities have no responsibility to prevent distorting local markets or artificially inflating prices, while this is a key component of the do no harm-mandate of HOs. The humanitarian SMI must therefore include engagement local stakeholders, such as government officials, other HOs working in the same area, and market actors (MiC, n.d.).

One of WORM's main focus areas is that of field hospitals. As defined in D1.1, field hospitals are temporary medical facilities, designed to deliver rapid and urgent healthcare services in areas where existing infrastructure is insufficient or has been disrupted (Fardi et al., 2022; Tekin et al., 2017). Field hospitals operate in resource-constrained and high-stakes environments, and face unique challenges in managing medical waste while ensuring patient safety (Fardi et al., 2022). While there has been a call to shift towards exploring sustainable alternatives like bio-based, biodegradable materials, and extending the lifecycle of products within the healthcare sector (Ertz & Patrick, 2020; Jiang et al., 2022), recent studies underscore the complexities and trade-offs of adopting these solutions (Yu et al., 2024b). The more contaminated and possibly infected the waste gets, the fewer options to recycle plastic waste exist (Huysman et al., 2017). Thus, where possible, the first and foremost part of waste management in a field hospital is to "segregate at the source", thereby minimising contamination. This supports both the minimisation of contagion and thereby the spread of diseases, as well as the potential to safely engage in circular economy activities.

In field hospitals, balancing environmental sustainability with practicality is a constant challenge. The costs of adopting bio-based or biodegradable materials often include hidden factors, such as rising extraction and production costs, transportation, and compliance with medical device regulations (Syms et al., 2023). Herrmann et al. (2015) highlighted the importance of incorporating all costs into decision-making, including the environmental impact of resource depletion and waste disposal. Reusing materials, where possible, and opting for recycling or energy recovery solutions can positively impact resource efficiency in field hospitals.

This study focuses on bio-based and biodegradable solutions that could be implemented in field hospitals. Table 1 highlights the key differences and intersections of these two options.

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Table 1 Differences and intersections between bio-based and biodegradable solutions

Aspect	Bio-based solutions	Biodegradable solutions
Source	Derived from renewable biological sources (e.g., corn starch, sugarcane, cellulose)	Can be made from either renewable or non-renewable sources but designed to break down naturally
Purpose	Reduces dependency on fossil fuels, minimises carbon footprint	Breaks down quickly in the environment through natural processes
Application	Medical products like packaging, disposable utensils, and certain medical instruments	Medical applications such as wound dressings and temporary implants
Common examples	Polylactic acid (PLA) used for biodegradable sutures and drug delivery systems	Polycaprolactone (PCL), Polyhydroxyalkanoates (PHA) for wound dressings and implants
Environmental benefits	Reduces reliance on fossil resources, lowers carbon emissions	Helps mitigate environmental impact, especially in areas with limited waste management infrastructure
Degradation mechanism	May or may not be biodegradable; PLA degrades into lactic acid	Designed to degrade quickly via microorganisms and natural processes
Use in humanitarian context	Contributes to sustainability by reducing fossil fuel use	Reduces medical waste disposal challenges in field hospitals

However, as noted in the literature, there is no magic bullet for MWM (de Titto & Savino, 2020; Hantoko et al., 2021; Irianti, 2013; Mang et al., 2023; Zechel et al., 2024). While bio-based and biodegradable solutions have potential, in health care in particular, their technical, regulatory and financial components must be carefully weighted (Yu et al., 2024b), even more so in resource-limited settings such as field hospitals.

In the humanitarian sector, different HOs have developed their own standard product catalogues. Two examples of these are the catalogues by the International Federation of Red Cross and Red Crescent Societies (IFRC), and by Solvoz (International Federation of Red Cross and Red Crescent Societies (IFRC), n.d.; Solvoz, 2023c).

2. Supply market intelligence for WORM

This deliverable (D1.4) focuses on the supply market intelligence for WORM. This includes the five priority product groups as identified in D1.1 as well as a first study on waste treatment services.

This section focuses on five categories of items identified in WORM's scoping exercise (D1.1): syringes and needles, personal protective equipment (PPEs), sharps containers, body bags, and temporary water sludge and bladders. While there are multiple other products with great potential for bio-based and biodegradable alternatives, these have been selected while taking a multi-actor approach and thereby focusing where (a) the impact is estimated to be greatest, while (b) the product groups are not yet tackled in other parallel endeavours.

To support the evaluation of priority product groups, the following table provides a detailed overview of market insights. Table 2 highlights key characteristics such as market size growth, demand trends, and challenges for bio-based alternatives adoption. This information serves as a basis for identifying relevant supplies and aligning procurement strategies with organisational priorities.

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Table 2 General SMI on priority products

Product group	Market size and growth	Trends	Challenges & hesitations for bio-based alternatives
Syringes and needles	2024-2030 CAGR 6,6%, $13,8 billion in 2030	Needle-stick injury reducing safety syringes	High production costs, competition from conventional material
PPE	$92 billion in 2021, significant growth to be expected	Faster degradation in natural conditions	Higher cost of bio-based and -degradable materials
Body bags	2022-2026 CAGR 6,7% $1,1 billion in 2026	Gaining importance due to health crises (COVID-19)	Limited production capacity and higher costs
Sharps containers	2022-2031 CAGR 3,9% $632,8 million in 2021	North America leading market, Asia-Pacific expected to grow faster	Re-usable and bio-based require advanced WM systems
Temporary sludge bladders	Niche market	Mostly used in industrial and medical WM	

An LCA on these product groups is conducted in D1.2.

2.1. Syringes and needles

Medical plastic waste, particularly from single-use devices, makes up a large portion of healthcare-related waste, with syringes and needles being major contributors (Quronfuleh et al., 2024). Although recycling polypropylene syringes has been explored, challenges like rubber granules, ink residues and stringent regulations hinder widespread recycling efforts (Quronfuleh et al., 2024). Lee et al. (2002) identified plastic syringes as a strong candidate for recycling due to their high plastic content (85%) and substantial contribution to medical plastic waste (21%).

Neither Solvoz nor IFRC catalogues include biodegradable or bio-based solutions for syringes and needles. Many syringes are still incinerated to avoid risks associated with reuse, as sharing these medical devices has historically led to severe medical disasters, such as the tartar emetic injection disaster in Egypt, which caused a hepatitis C epidemic (Elgharably et al., 2016). This has driven some countries to introduce self-destructing syringes to enforce single use and prevent such incidents (Elgharably et al., 2016).

IFRC has introduced a syringe that can be autoclaved up to 50 times, extending its lifespan (IFRC, 2018) and contributing to waste reduction. Autoclavation is a sterilisation process that uses pressurised steam to kill microorganisms, helping to maintain cleanliness and prevent contamination (ScienceEquip, n.d.).

Recycling experiments showed that, although recycled syringes retained their shape and texture, the process led to visual and operational changes. Combined with strict regulations and limited recycling infrastructure, these challenges make it difficult to implement circular recycling in healthcare settings (Quronfuleh et al., 2024), particularly in resource-limited environments.

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To improve recycling outcomes, design changes like self-sealing syringes to eliminate rubber sales and alternative marking methods such as engraving or using water-soluble ink have been proposed (Quronfuleh et al., 2024). Methods to collect, disinfect, shred, and recycle syringes have been developed, showing that recycling could significantly reduce medical plastic waste (Lee et al., 2002). However, infection risks and contamination remain obstacles to more widespread syringes recycling, requiring advanced sterilisation and processing techniques to ensure safety (Lee et al., 2002).

2.2. Personal protective equipment (PPE)

The Covid-19 pandemic has highlighted the critical role polymers play in preventing the spread of infections (Jiang et al., 2021). Whether in protective gowns that repel liquids, in masks that block pathogens, or in gloves made from a rubber-based polymer (Zechel et al., 2024), polymers are essential (Preece et al., 2021). However, their disposal poses significant environmental challenges. While incineration of medical waste can generate electricity, it also harmful emissions from burning plastics and other synthetic materials releases. Thus, managing waste through recycling, incineration, and adopting biodegradable alternatives remains a complex issue in field hospitals settings.

Bio-based and biodegradable polymers are gaining attention as alternatives to traditional fossil-based materials (Jiang et al., 2022). Bio-based polymers are derived from renewable sources, while biodegradable polymers can break under environmental conditions. Despite their potential, these materials currently make up less than 1% of the total polymers used in hospitals (Baranwal et al., 2022b; Zechel et al., 2024).

Next, we zoom in on PPE such as gloves, surgical gowns, and protective boots.

Gloves

Rubber gloves alone account for 24% of medical solid waste (Rahman et al., 2019). However, making these gloves involves substantial resources: water for preparing and cleaning latex, energy for drying and curing, and electricity for lighting, machinery, and waste treatment (Jawjit et al., 2015). Traditional disposal methods such as open burning or incineration are costly and energy-intensive (Misman & Azura, 2013). Additionally, burning natural rubber latex gloves releases harmful gases like carbon dioxide, which is detrimental to the environment (Misman & Azura, 2013).

There are two main types of medical gloves: examination gloves used for routine medical exams and minor procedures, and surgical gloves which are worn by surgical staff during operations (Preece et al., 2021). Common materials for medical gloves include natural rubber, polyisoprene, acrylonitrile, butadiene rubber, chloroprene, polyethylene, and poly(vinyl chlorine) (Srinivasan, 2018) (Figure 4

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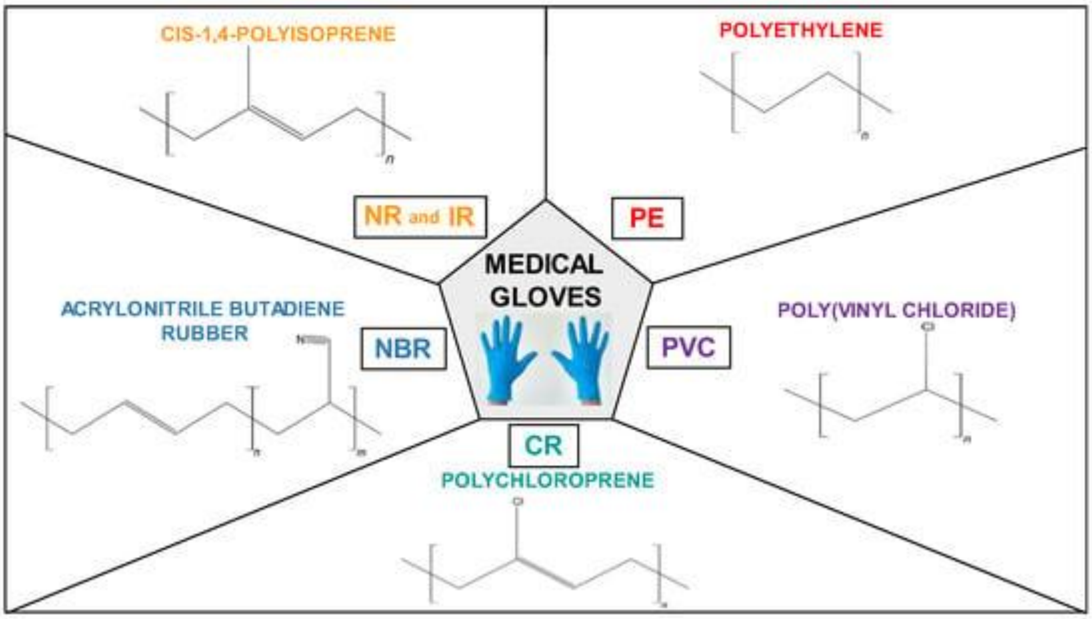

Figure 4 Chemical structure of common types of medical gloves (according to Lovato et al. (2023))

Single-use gloves, however, take more than two years to decompose due to chemical additives like sulphur and antioxidants, which hinder natural degradation (Misman & Azura, 2013). Sulphur, in particular, slows down the breakdown of latex or rubber gloves by environmental processes and microorganisms (Misman & Azura, 2013). Additionally, the elasticity of latex and rubber makes these gloves difficult to recycle, especially after use (Diniz et al., 2023; Rakib et al., 2021).

To address these challenges, biodegradable and bio-based alternatives to traditional gloves are being explored, as summarised in Table 3.

Table 3 Biodegradable and bio-based gloves alternatives

Type of gloves	Source	Biodegradability and bio-based
Natural rubber latex	Havea brasiliensis tree	Improved with biopolymers (starch, cellulose, chitosan)
Bio-based additives	Food waste, plants, algae	Faster degradation in natural conditions
Polyhydroxyalkanoates (PHA) gloves	Produced by bacterial fermentation of sugar or lipids	Variable, depends on structure
Guayule-based rubber	Guayule plant	Bio-based
Body Bagsz	Biopolymer technology Renewable plant-based materials	Decompose into natural plant food when composted
EcoGloves	Corn, cassava, sugarcane, and other starch-based components	Biodegradable only under the right conditions, unless contaminated

First, natural rubber latex, from the Hevea brasiliensis tree (Johns & Rao, 2008) is being used for making thin elastic gloves due to its strength, elasticity, and comfort (Ghani et al., 2019). Research has

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investigated using biopolymers like starch, cellulose and chitosan as fillers to help the biodegradation of natural rubber latex (Johns & Rao, 2008).

Second, incorporating bio-based materials into nitrile gloves can speed up their degradation in natural conditions. These additives are derived from food waste, plants or algae (Yew et al., 2020).

Another option is using polyhydroxyalkanoates (PHAs), which are bioplastics produced by bacterial fermentation of sugar or lipids (Baranwal et al., 2022b). PHAs can have various physical properties depending on their structure (Taguchi & Matsumoto, 2021). Despite being available since the 1980s, PHAs face challenge such as high production costs and variability in their physical properties due to energy intensive processes and the slow growth of microorganisms used in their production (Drzyzga & Prieto, 2019). To address these challenges, researchers are exploring ways to lower costs, such as using industrial waste as raw materials (Mourão et al., 2021), chemically modifying PHAs (Chen et al., 2020), and improving production techniques (Drzyzga & Prieto, 2019). Integrating PHA production with processes like wastewater treatment and using by-products from other industries could lower costs and improve efficiency while also addressing environmental concerns (Drzyzga & Prieto, 2019).

Lastly, private companies are developing biodegradable gloves. For example, Body Bagsz offers gloves made from renewable plant-based materials using advanced biopolymer technology (Bodybagsz, 2024). These gloves decompose into natural plant food when composted and are resistant to ripping, tearing, or leaking. They are also free from latex, powder, and bisphenol (BPA), making them versatile and suitable for various applications (Bodybagsz, 2024). EcoGloves provides another biodegradable alternative, made from plant-based materials like corn, cassava, and sugarcane (Ecogloves, 2024). These gloves can be disposed of with regular waste, unless contaminated with hazardous substances and are free from chemicals, fragrances, essential oils, sodium benzoate, propylene glycol, latex, powder, parabens, phthalates and from BPA (Ecogloves, 2024).

Surgical gowns

Efforts to shift toward bio-based and biodegradable materials in healthcare settings have gained momentum, driven by environmental concerns. Laing & Kean (2011) highlighted the potential of bio-based polymers as alternatives to conventional plastics, with the added benefit of compostability. However, as transitioning to bio-based materials requires a comprehensive analysis of associated costs, including the extraction of natural resources, packaging, and environmental impacts (Herrmann et al., 2015). These considerations are particularly crucial for field hospitals, where cost constraints and logistical challenges are often paramount.

IFRC and Solvoz offer reusable tunics for surgical and general use, which are either 100% made of cotton, cretonne fabric or from 50% polyester and 50% cotton fabric (IFRC, n.d.-a). While the 100% cotton surgical gown is recyclable, the mixed one is not. In addition, medical gowns for surgical gowns are only available as single use products which are sterilised with ethylene oxide gas before being discarded (Solvoz, 2023a).

However, field hospitals struggle with the survival of antibiotic-resistant bacteria on medical materials. Neely & Maley (2000) conducted a study on the survival of staphylococci and enterococci on various hospital fabrics and plastics. Their findings suggest that these bacteria can persist for extended periods, particularly on polyester fabrics commonly used in hospitals, such as privacy drapes and aprons, where they can survive for months. Cotton-polyester blends used in scrubs and lab coats also provide a conducive environment for bacterial survival, posing risks for cross-contamination between healthcare workers and patients. In addition, traditional polyester fabrics, though durable and easily cleaned, may contribute to the spread of infections due to their tendency to harbour bacteria for long periods where the rapid spread of infections can exacerbate already critical conditions (Neely & Maley, 2000).

Moreover, recent research has shown that biodegradable medical gowns, while designed to be more eco-friendly than conventional plasticised gowns, may not be the greener option they were thought to be.

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Zhao et al. (2022) revealed that biodegradable gowns decompose faster in landfills, but their rapid degradation produces harmful greenhouse gases like methane and carbon dioxide at a faster rate than conventional gowns. This results in an 11% higher ecotoxicity rate compared to conventional gowns. Moreover, biodegradable gowns pose challenges such as higher toxicity to humans and freshwater ecosystems. While biodegradable gowns reduce the use of landfill space, the unintended consequence of faster gas emissions raises questions about their overall sustainability. However, improving landfill gas capture efficiency and employing onsite power co-generation could reduce these emissions by nearly 10%, making biodegradable gowns more environmentally sustainable. Without such systems in place, conventional gowns may be the lesser of two evils, producing fewer greenhouse gases and posing a lower toxicity risk (Zhao et al., 2022).

Protective boots

Protective boots are essential within field hospitals, but also by waste pickers which is WORM's other focus area. While protective boots for waste pickers are not regularly and widely used, they are a crucial aspect of protective equipment (Yusuf et al., 2022). Rubber shoes and tyre slippers are instead the preferred solution (Yusuf et al., 2022).

Creating biodegradable boots for waste pickers involves challenges such as achieving sufficient durability, puncture resistance, and waterproofing while maintaining biodegradability. The focus is also on integrating natural fibres or additives that speed up the breakdown process without compromising protective capabilities. As such, some biodegradable alternatives to synthetic rubber have been explored in the literature to address environmental concerns. Table 4 presents the key options:

Table 4 Biodegradable and bio-based alternatives to rubber protective boots

Options	Properties
Natural rubber latex	• Harvested from the latex of rubber tres • Inherently biodegradable • Degradation occurs under specific environmental conditions with microbial activity
Guayule-based rubber (Rasutis et al., 2015)	• Derived from guayule plant (American biorubber, n.d.; Nakayama, 2005; Rasutis et al., 2015) • Similar properties to conventional rubber but is biodegradable and hypoallergenic (Nakayama, 2005) • Low water usage compared to cotton and alfalfa • Only FDA-approved for surgical gloves for now (American biorubber, n.d.)
Biopolymer composites	• Blending of natural rubber with biodegradable polymers like polylactic acid (PLA), polyhydroxyalkanoates (PHA), or starch • Biodegradability • Strength and flexibility maintained
Synthetic rubber substitutes	• Innovations include materials made from bacterial fermentation, such as bio-isoprene

Moreover, waste pickers can also use protective boots made of polyvinyl chloride (PVC) (Oberoi & Malik, 2022), a waterproof, resistant to chemicals and relatively inexpensive alternative (Chiellini et al., 2013; Stull, 2003). However, PVC necessitates the use of non-renewable chemicals and non-biodegradable waste materials as well as poor thermal stability, stiffness and brittleness, raising concerns about the

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negative impact of non-degradable PVC waste on the environment (Chiellini et al., 2013; Darie-Nita et al., 2022). Therefore, biodegradable and bio-based solutions should be considered, as presented in Table 5.

Table 5 Biodegradable and bio-based alternatives to PVC protective boots

Options	Properties
Bio-ethanol	• Renewable resource and lower environmental impacts (Alvarenga et al., 2013) • Still presents dangers to biodiversity and ecotoxicity (Alvarenga et al., 2013)
PVC bio composites	• Fillers like wood fiber and lingin derived from renewable materials (Klapiszewski et al., 2015; Markarian, 2005) • Natural fibers: jute, bamboo, sisal and rice straw
PVC starch blends	• Made of biodegradable starch (Rasutis et al., 2015)
PVC/Chitosan (CS) Blends	• Materials like chitin derivatives showcase antimicrobial and antifungal activities (Rasutis et al., 2015) • Antimicrobial and antifungal • Biocompatible, biodegradable, and non-toxic (Rasutis et al., 2015)

However, as the biodegradable and bio-based solutions to rubber protective boots are still limited, the best options would be to invest in high-quality boots to ensure safety of waste pickers and a longer lifespan of the product, reducing the overall impact of its production on the environment.

2.3. Sharps containers

Reusable sharps containers (RSCs), made from durable materials, have gained popularity (Grimmond & Reiner, 2012). They go through similar testing as disposable sharps containers (DSCs) and can be reused around 10-15 times a year, potentially lasting for decades (Grimmond & Reiner, 2012).

DSCs, on the other hand, are mostly disposed of through non-incineration methods like autoclaving and landfilling, with a small percentage incinerated for energy recovery (Grimmond & Reiner, 2012). While some DSCs are made with recycled content, they still produce significant emissions due to manufacturing and transportation (Grimmond & Reiner, 2012).

Grimmond & Reiner (2012) conducted a lifecycle analysis to compare RSCs and DSCs and found that RSCs have a much lower environmental impact, especially in terms of greenhouse gas emissions. The primary contributor to emission for RSCs were decanting and washing processes, but overall, RSCs reduced emissions by 83,5% compared to DSCs (Figure 5). Even when considering transportation, RSCs still showed significant environmental benefits (Grimmond & Reiner, 2012).

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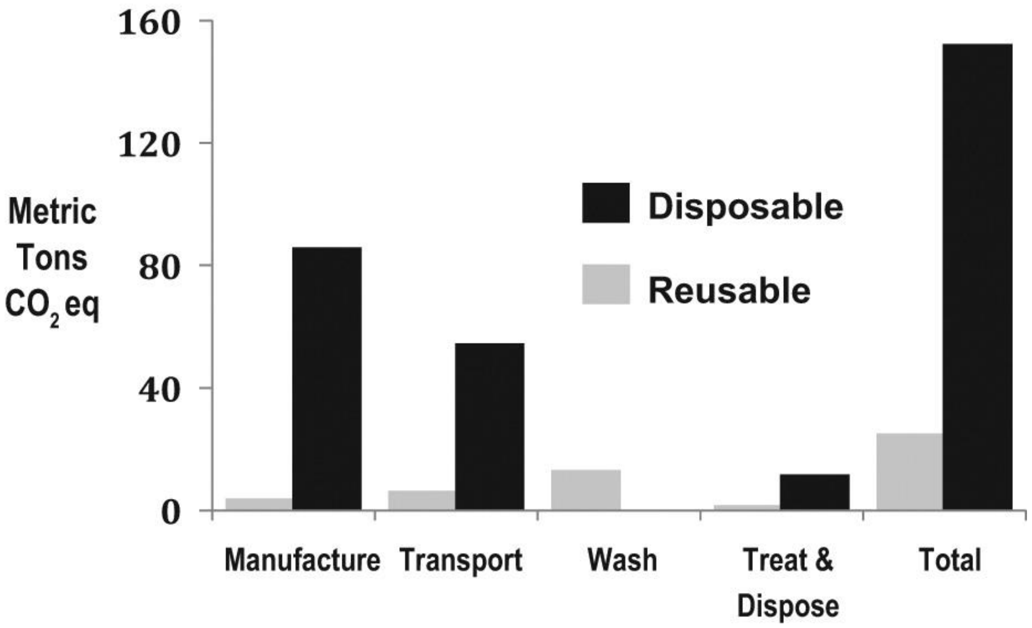

Figure 5 Annual greenhouse gas emission by life stage of disposable and reusable sharps containers in Northwestern Memorial Hospital (US), normalised to occupied beds (taken from Grimmond & Reiner (2012))

Regarding sharps disposal containers solutions, both IFRC and Solvoz provide sharps containers made of carboard (IFRC, n.d.-b; Solvoz, 2023b). However, while Solvoz's containers allow to efficiently contain, transport and store used sharps injection devices until final destruction, it is not leaking proof and therefore can pose health issues. In addition, the procedure would be because the materials it contains are hazardous, to incinerate the entire container (Solvoz, 2023b).

There are also other suppliers for RSCs. For example, the Finnish Red Cross (FRC) has been procuring cardboard sharps containers from Pa-Hu Oy and using them in their Emergency Response Unit working on various crises around the globe. Sharpsmart System is a reusable sharps container solution, made from puncture-resistant cardboard.

Finally, Buyoplastic, a Vietnamese company specializing in bioplastic solutions offers rigid packaging made from bio-cellulose material (Buyo, n.d.). While these boxes are not currently used as sharps container, the company's focus on medical applications such as wound dressings and medical packaging, suggests the potential to adapt their rigid boxes to meet medical standards (Buyo, n.d.). Bio-cellulose isa material well-suited for medical use as it is fully biodegradable in natural environments, produced through eco-friendly bioprocesses that consume less water and energy and free from toxic chemicals (Buyo, n.d.).

2.4. Body bags

Circular alternatives, particularly biodegradable and bio sourced options for body bags also called cadaver pouch or human remains pouch have been considered (Thompson, 2024). While body bags have traditionally been made of plastic, medical supply companies have recently been exploring eco-friendly options that reduce long-term waste. In addition, researchers are also exploring cost-effective bio-sourced alternatives, through challenges remain in minimising their environmental impact while maintaining functionality and safety in the field (Thompson, 2024).

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Certain biodegradable solutions have been identified. First, the company Bodybagsz offers 100% compostable body bags, made from corn starch (Bodybagsz, 2024). This allows the body bag to break down in months instead of years (Bodybagsz, 2024). In addition, Solvoz offers a biodegradable single-use body bag option made of polyethylene and cotton (Solvoz, n.d.). The body bag is certified EN13432 which ensures that the packaging is biodegradable (Europeanbioplastics, n.d.).

2.5. Temporary water and sludge bladders

Hospital wastewater poses a significant issue due to the diverse medications and chemicals used in wards, surgeries, laboratories, and kitchens (Khan et al., 2019). Unlike domestic sewage, hospitals effluent contains a wide array of toxic substances, including antibiotics, radionuclides, and disinfectants (Chonova et al., 2016) (see Figure 3).

Biopolymers have useful properties like renewability, environmental compatibility, antibacterial activity and biodegradability, which make them suitable for various industries including pharmaceuticals, medicine, wastewater treatment, and environmental management (Elgarahy et al., 2023).

Figure 6 Schematic diagram showing types of hospital wastewater (taken from Khan et al. (2019); p.58)

2.6. Hazardous waste treatment – a field study

For a holistic assessment of biodegradable and bio-based alternatives, it is also important to ascertain their potential waste treatment processes. Earlier, D1.1 (and MS1.2) have listed relevant waste treatment processes, which were then included in a life cycle assessment (LCA) in D1.3. Here in D1.4, the focus is on assessing hazardous waste treatment service options and providers in Vietnam, which is one of the geographical focus areas of WORM.

Biodegradable and bio-based alternatives are sometimes not suitable to certain contexts with limited resources and therefore efforts must be provided to ensure proper and efficient MWM (Zechel et al., 2024). A three-week field visit to Vietnam was conducted in December 2024 to assess the current situation regarding medical waste management (MWM) in the country and to gain a deeper understanding of the challenges involved. A meeting and site visit of a waste collection and treatment company in Ho Chi Minh City was organised. Figure 7 details its fields of activity.

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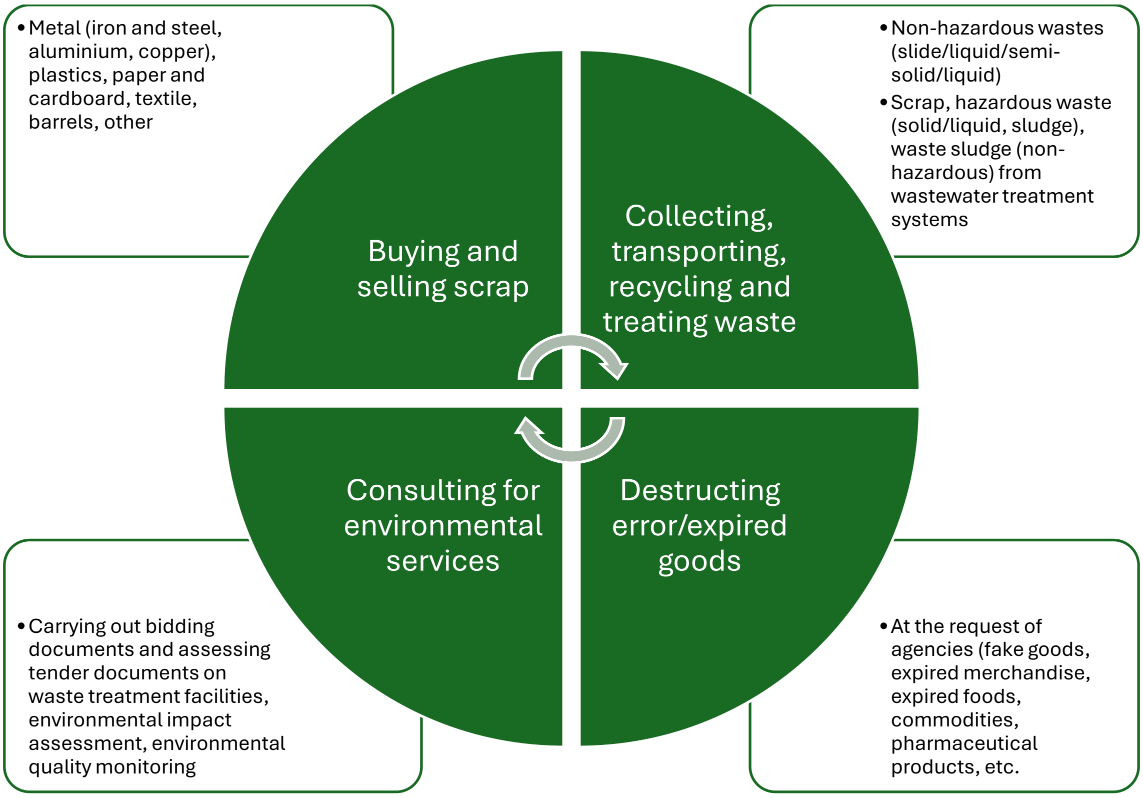

Figure 7 Company's field of activity

As part of the Project "Industrial – Hazardous Waste Recycling and Treatment Factory with a total capacity of 500 tons/day", the company incinerates 14,400,000 kg of waste per year, collected from several areas (Figure 8). However, it does not treat wastewater from hospitals as they usually have an internal treatment system in place for that type of waste.

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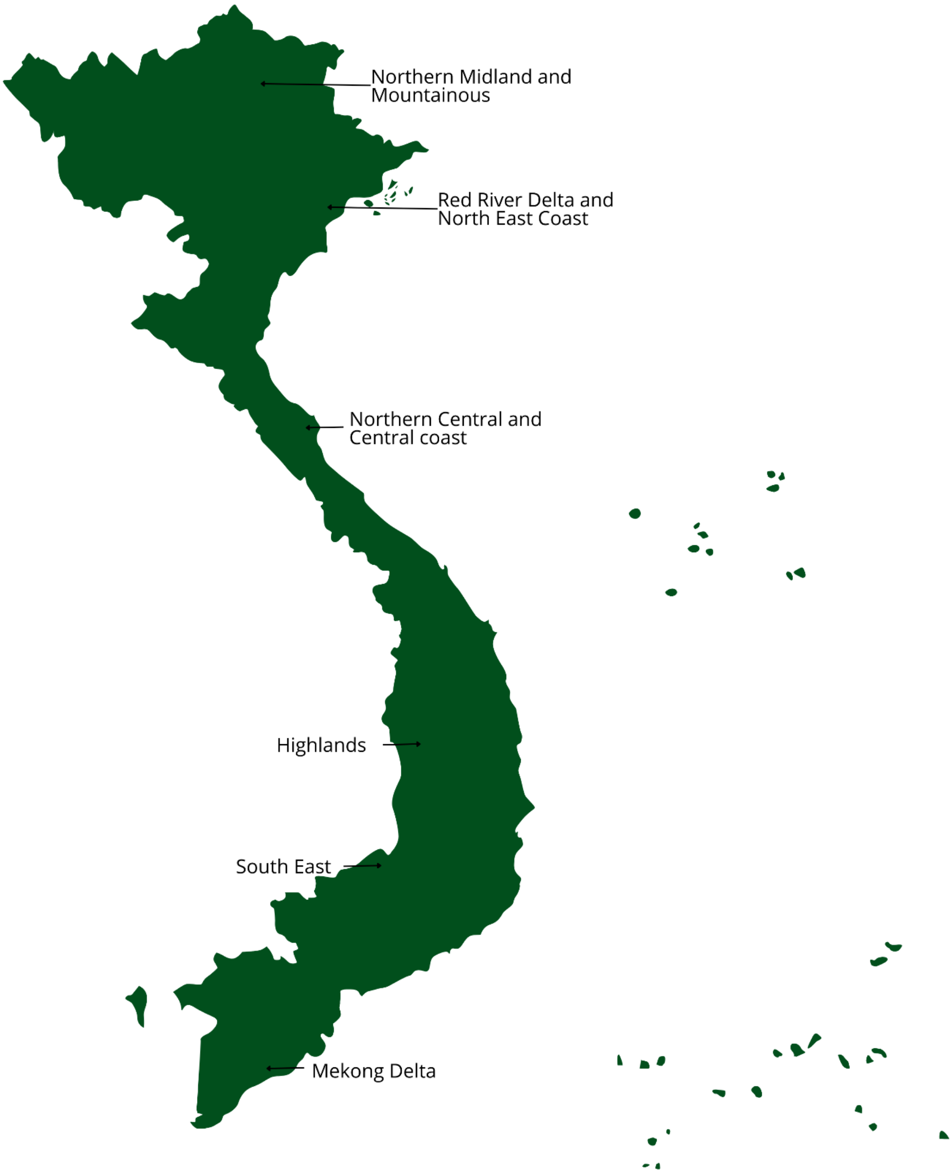

Figure 8 Waste collection areas

The visit revealed that all types of hazardous and infectious waste, including medical waste providing from Ho Chi Minh City's two biggest hospitals, are incinerated indiscriminately, regardless of their specific nature, as they are considered potentially contaminating. The hazardous waste treatment process for a hospital follows steps portrayed in Figure 9.

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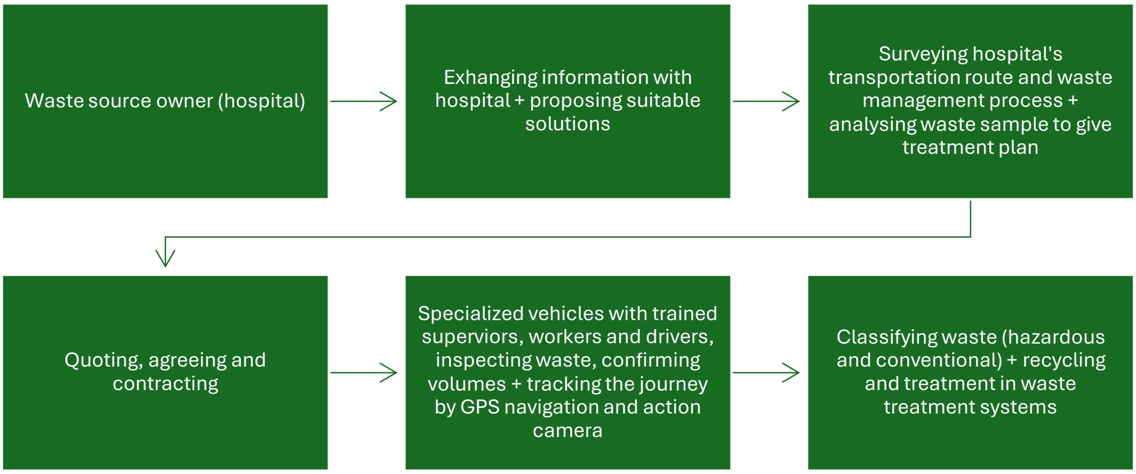

Figure 9 Hospital hazardous waste treatment process

Specifically, the company's work, systems, and equipment for the preliminary processing, treatment and recycling of hazardous waste are detailed in Table 6. Medical waste is stored in an indoor storage area of 14,7 m2, housed within a 20-feet container equipped with doors, air conditioners, ceilings, wall, an electric systems, galvanised tole flooring with 2 cm raised edges to ensure water tightness and prevent leakage. The storage container located in the incinerator factory.

Table 6 Treatment of hazardous waste

Name of project, system, equipment	Treatment method
Cloths, protective clothing contaminated by hazardous substances	Incinerator
Sludges containing hazardous substances from the treatment of industrial wastewater	
Solid waste from on-site effluent treatment containing hazardous substances	Mixing other types of combustible waste, incinerating in the incinerators
Wastes whose collection and disposal are subject to special requirements in order to prevent infection (including sharps)	
Organic waste containing hazardous substances	
Other flammable waste	
Other waste containing hazardous organic substances	
Other waste containing hazardous inorganic and organic substances	
Wastewater containing hazardous substances	Treating the wastewater and liquid waste treatment system and sludge after treatment is incinerated in the incinerator
Premixed wastes composed of at least one hazardous waste	
Solutions and wastes containing cyanide, isocyanide	
Other wastes containing hazardous substances	

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Waste plastic containing hazardous substances	Recycling plastic. The generated wastewater will be treated by wastewater and liquid waste treatment system
Cleaning system of container contaminated hazardous components	Semi-automatic washing technology

Finally, the visit revealed that, although the company has developed some alternative waste management methods, the choice of treatment method for medical waste must comply with Ministry of Natural Resources and Environment regulations and cannot be altered without the Ministry's approval.

Apart from this field study for D1.4, WP4 has focused on waste management, and waste treatment methods at field hospitals. For example, D4.1 presents a SWOT analysis of non-destructive disinfection methods of infectious waste. Next, WP5 (that has started in M9 of the project) will further analyse recycling and WM at field hospitals.

2.7. Using the WORM catalogue for SMI

To facilitate supply market intelligence, Solvoz launched in October 2024, a catalogue tailored to the WORM project's needs (WORM, 2024a). While lifecycle assessments and market assessments for bio-based and biodegradable solutions are ongoing, this WORM platform seeks to systematically capture and share information to benefit both the humanitarian and healthcare sectors (WORM-EUproject, 2024). The catalogue serves as an open-access repository for bio-based criteria, enabling anyone, including NGOs, healthcare providers, suppliers and manufacturers, to explore and contribute to this knowledge base (WORM, 2024a).

The WORM project's five priority product groups are highlighted in the WORM catalogue, allowing buyers to define tailored specifications for each product category, to ensure that the most relevant supplies are identified (WORM, 2024a). The WORM catalogue supports both broad browsing and specific search. Each product comes with pictures and technical criteria which include materials (e.g. latex, polyisoprene), size, or powder-free features, as well as certification standards like ISO, ensuring compliance with regulatory or organisational requirements. Additionally, buyers can filter sustainable options by including complementary features like recyclability, eco-friendly packaging or durability.

To evaluate market fit, the platform enables buyers to assess supplier responses based on key criteria:

- Sustainability: does the product meet environmental goals?
- Cost: Is pricing competitive for the product group?
- Lead time: Can the supplier deliver within the required timeframe?
- Quality: Does the product meet quality standards?

When submitting a product request, buyers must also attach a questionnaire to filter products and align supplier responses with their needs. This questionnaire specifies expectations and priorities for the desired products.

The platform offers visibility into the product's specifications, enabling buyers to evaluate whether a product meets their needs. This questionnaire specifies expectations and priorities for the desired products, which are showcased on the platform according to three levels of visibility:

- Personnel level: accessible and editable only by the creator
- Organisational level: accessible and editable by all members within the buyer's organisation
- Community level: publicly available to all platform users, enabling wider access and collaboration

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The community level is particularly valuable as it allows buyers to discover shared solutions already being used by other organisations. This provides valuable insights into widely used, innovative and highly recommended products. It also facilitates the adoption of sustainable options, such as biodegradable and bio-based solutions for priority product groups.

Moreover, the platform offers flexibility to buyers to request products that might not even be available in the catalogue. For example, if biodegradable gloves are not listed, an NGO can create a product request and launch a market assessment to identify suppliers and manufacturers globally. Suppliers can then respond by creating public profiles, listing their solutions, and publishing them to the platform for buyer access. In essence, this way the WORM platform enables supply market intelligence for WORM and beyond, while following the information processing perspective as outlined in this deliverable.

Suppliers and manufacturers are actively encouraged to share solutions that match the specified criteria. This initiative enables global suppliers and manufacturers to:

- Showcase their bio-based and biodegradable solutions and associated criteria (operational and technical specifications)
- Inform organisations about available products and solutions
- Contribute to knowledge sharing across the market

Suppliers offering bio-based or biodegradable solutions in other product categories are also free to add them to the catalogue, which allows the platform to function as a central hub where suppliers can showcase their offerings while informing NGOs and health facilities of available options.

This platform serves as a bridge between buyers and suppliers, facilitating collaboration between demand and supply. Additionally, academia can contribute by refining or defining new criteria for biodegradability, which can in turn, be adopted by buyers or/and suppliers.

The WORM catalogue will remain active throughout the duration of the project, ensuring the information collected is accessible for the long term, even after the end of the project.

3. Supply market drivers and barriers for bio-based solutions

While bio-based and biodegradable materials present promising alternatives to conventional plastics in field hospitals, their adoption is fraught with challenges. Medical plastic recycling and incineration, particularly of needles, syringes, and PPE, remain critical components of waste management strategies. However, these methods are not without environmental consequences. The survival of bacteria on synthetic medical fabrics, combined with the emission of greenhouse gases from biodegradable materials, further complicates the choice of sustainable materials for field hospitals.

Ultimately, the balance between cost, safety, and environmental impact must guide decisions regarding MWM in humanitarian field hospitals. Integrating advanced waste capture technologies, improving recycling programs, and evaluating the lifecycle impacts of materials will be key to developing more sustainable practices in these challenging environments.

Overall, there is considerable interest in the humanitarian community to integrate bio-based products into the context. However, significant challenges also arise. This section discusses the findings of empirical interviews done with a humanitarian organisation to outline the principal drivers and barriers within the specific supply market of the WORM priority product groups. The data can be categorised into five overarching themes (Figure 10), within which we will analyse the supply market drivers and barriers in more detail.

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Figure 10 Overarching supply market themes

3.1. Material feasibility and product design

The design of the medical supplies and their feasibility holds significant importance in the incorporation of bio-based/bio-degradable medical supplies. Functionality and re-usability of the sustainable supplies act as key drivers. For example, cardboard-based items like sharps containers are valued for their compact design, affordability, and convenient disposal options. Carboard sharps containers require significantly less space than a conventional plastic container. As well, reusable supplies provide effective solutions in conflict areas by minimising reliance on daily supply chains. In many humanitarian contexts, the conditions can be unpredictable and regular shipments of disposable items can be difficult to organise.

Several barriers were also highlighted. First, durability. For instance, inability of the cardboard sharps containers to withstand wet waste, and allergies caused by hypersensitivity created by the long-term usage of latex gloves were such challenges. Moreover, reusable materials require extra infrastructure and resources for cleaning, drying, and sterilisation, which is frequently lacking in field hospital and other humanitarian environments. Access to sufficient water to maintain hygiene of certain reusable items was discussed as an example of a practical concern. Therefore, although materials and design offer promising possibilities, their successful implementation depends on overcoming these operational challenges. Table 7 synthesises the drivers and barriers encountered in the empirical data in this category.

Table 7 Material feasibility and product design drivers and barriers

Drivers and barriers	Highlighted in data
Functionality of Biodegradable Materials	Space saving design. Shelf-life is an important factor in choosing products.
Re-usable Options	Practical for long-term use in conflict areas. Reduced dependency on daily supply chains.
User comfortability and quality	Equipment must be comfortable and easy to use to ensure adoption.
Durability Concerns	Extra resources requirement for cleaning. Extra staff requirement for sterilisation.
Practicality Concerns	Lack of promotion by manufacturers on their sustainable alternatives. Lack of public awareness on sustainable alternatives
Reusability Challenges	Water sourcing for re-usable cotton gowns. Wastewater management for re-usable cotton gowns. Extra resources requirement for cleaning/sterilisation.

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3.2. Procurement and decision-making process

The adoption of sustainable alternatives for medical supplies is significantly shaped by the organisation's procurement framework, information processing capacity, and decision-making processes. Additionally, external pressures from stakeholders and donors serve as key motivators. Expectations for transparency and environmental accountability further encourage organisations to explore and evaluate sustainable options. This is apparent in the empirical data. HOs are often required to be transparent in their actions, as they are working in a public domain. The emerging changes in regulations and standards that act as catalysts for the adoption of certified biodegradable products by regulatory bodies like the WHO. These standards incorporate both sustainability and quality into medical supply chains.

On the other hand, there are instances were existing practices constraint procurement decisions. A significant obstacle in the FRC procurement process is the predominant role of medical officers in decision-making, often leading to the neglect of sustainability considerations. Medical officers always have the final say in item-related decisions, and this highlights the fact that sustainable criteria embedded within the procurement framework itself will not be enough but institutional integration of environmental policies are required to address this situation. The insufficient emphasis on sustainability highlights a wider systemic issue: it has yet to be integrated as a fundamental criterion within healthcare procurement processes. Bridging these gaps necessitates well-organised strategies that harmonise clinical needs with environmental goals.

Table 8 Drivers and barriers within procurement and decision-making processes

Drivers and barriers	Highlighted in data
Evolving Regulations and Certifications	Compliance considered to be number 1 criterion. Adoption of global standards such as WHO by sustainable supplies
Decision-Making Constraints	Procurement decisions dominated by medical officers. Lack of sustainability criteria in procurement
Absence of Sustainability as a Core Criterion	Lack of institutional emphasis on sustainability in procurement. Lack of framework that includes sustainability as a criterion.
Donor Influence and Public Pressure	Push for transparency and sustainability from donors and public stakeholders

3.3. Supplier market dynamics

Even though there are successfully incorporated sustainable medical supplies like the cardboard sharps container, which is identified as cost-effective, logistically advantageous (due compact storage design) and readily available, insufficient supplier engagement and supplier approach is outlined as a critical barrier. Sourcing becomes increasingly difficult when there is less engagement from the suppliers to purchase sustainable supplies. In urgent decision-making scenarios, there is often a preference for readily accessible supplies, which often are non-sustainable. HOs highlight the need for increased and transparent information, which is not always available for them within their information processing

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capacities. This issue is further exacerbated by the insufficient marketing efforts of manufacturers. Additionally, the difficulty in sourcing high-quality, surgical-grade materials further intensifies procurement inefficiencies.

To challenge these barriers, there are potential opportunities that can be influenced for improvement. One such is increasing the engagement of the suppliers with the procurement teams by actively advertising their sustainable products and creating collaborations with organisations like the RCRC movement. Additionally maintaining the required availability within the market remains vital. Ultimately, closing the gap between suppliers and procurement is essential for increasing the adoption of sustainable alternatives in healthcare.

Table 9 Drivers and barriers in supplier and market dynamics

Drivers and barriers	Highlighted in data
Potential for Supplier Engagement	Manufacturers can drive adoption through targeted marketing and collaboration with procurement teams.
Lack of Supplier Engagement and Catalogue Gaps	Absence of sustainable alternatives in supplier catalogues
Lack of publicity and promotion of sustainable alternatives by manufacturers	Suppliers of sustainable alternatives don't approach Red Cross Limited information about sustainable options hinders adoption
Availability Concerns	Irregular stock levels of reusable products Shortages of products in the market Absence of ready-made cotton gowns as per the requirement

3.4. Operational and logistical considerations in procurement

Some of the existing bio-degradable healthcare supplies have received positive feedback for their light weight and compactness which are useful in transportation situations. On the other hand, for some items which are bio-degradable and reusable, extra infrastructure and resources are required for the maintenance which is a challenge in most disaster situations. For instance, when using re-usable cotton gowns, clean water is needed for washing and the wastewater created needs to be treated. Drying and sterilisation also requires infrastructure and additional human resources. Many contexts would require a dryer in addition to the washing machine, as the climate and/or disaster situation does not allow drying outside, or if pests would nest in wet garments. Thus, while reusable supplies are beneficial in minimising the challenges associated with importing replacements when stocks are depleted, these obstacles continue to hinder their adoption in certain situations. Notably, cost appears to be a lesser concern then quality and usability, indicating a shift in emphasis toward operational practicality. Overcoming these logistical challenges is crucial for the effective integration of bio-sourced alternatives in emergency healthcare environments.

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Table 10 Operational and Logistical Considerations in Procurement

Drivers and barriers	Highlighted in data
Logistical Practicality of Biodegradable Products	Lightweight and space-efficient
Price as a Lesser Concern	Cost is secondary to factors like quality, availability, and usability.
Transport Limitations	Concerns with transportation due to volume
Water and Infrastructure Needs	Lack of infrastructure to manage reusable alternatives in the field.

3.5. Environmental and organisational motivators

The organisational awareness of environmental sustainability is increasing due to the climatic changes the world is facing. Awareness among healthcare providers is being driven by the growing recognition of the importance of reducing carbon footprints. These kinds of broader environmental objectives perfectly align with the adoption of bio-degradable/bio-sourced healthcare supplies into humanitarian supply chains and act as drivers pushing the authorities to consider them.

Efforts put forward by the organisation itself to create awareness regarding sustainable alternatives is crucial. In order to incorporate sustainable medical supplies into procurement requires a great institutional emphasis and training. If protocols for sustainable products are integrated, it ensures their inclusion. This highlights the importance of having a framework of internal guidelines. Nonetheless, gaps in knowledge continue to pose significant challenges. Numerous procurement teams find it difficult to evaluate certifications and pinpoint dependable sustainable options. The importance of improving awareness and education and streamlining certificates across the industry cannot be emphasised enough. Tackling these obstacles can enable organisations to align their practices more effectively with sustainability goals while fulfilling healthcare requirements.

Table 11 Environmental and organisational motivators

Drivers and barriers	Highlighted in data
Institutional Awareness Building	Initiatives to incorporate sustainability into procurement workflows
Environmental Responsibility	Growing recognition of reducing carbon footprints in healthcare operations
Lack of Awareness and Knowledge Gaps	Lack of awareness on sustainable alternatives and how to identify them. Lack of thought on sustainability criteria in procurement

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4. Conclusions

The bio-based and biodegradable materials market is growing at a considerable pace and is expected to reach a value of about $400 billion by 2033, indicating a CAGR of 25% over the preceding decade. Environmental sustainability has also become a relevant topic for humanitarian procurement due to for example the do-no-harm mandate. This mandate is thought to expand to the natural environment in addition to the beneficiary populations. The field hospital context, along with the healthcare sector in general, is in many ways more complex due to stringent regulations and functionality requirements of the products used. We have explored the bio-degradable options available and what the key drivers and barriers are in their adoption in a field hospital context.

While the procurement function is constantly gaining more strategic relevance within HOs, there are still inconsistencies in the information processing capabilities in this area. HOs generally work in unpredictable and irregular environments, which makes conducting thorough SMIs challenging. As well, their needs may differ in different types of situations and their demand is unpredictable and uneven. Following classic procurement guidelines such as the Kraljic-matrix is still a useful avenue for general SMI queries, as this will give an indication of the type of information required for e.g. the priority products identified in this study.

Information processing needs are crucial to establish within the humanitarian context as the complexity and dynamism within the environment and supply market is particularly high. HOs are often based in the Global North, whereby the regulations they need to adhere to are different than in the areas where the operations take place. Factors such as geographical distance, product variety, and political risks play a relevant role in the SMI of humanitarian procurement. Mechanisms to manage HOs' information processing capacity include access to SMI resources such as industry reports of leverage and strategic items, communication amongst the HO community on what kind of items are causing bottlenecks, and/or which ones have biodegradable alternatives. Different IT solutions, such as catalogues for certain types of items can also be established for industry-wide use.

Like in any supply chain context, there is increasing pressure from stakeholders, such as donors, the general public, and regulatory bodies to invest in more sustainable options wherever possible. With this and the complexity of the humanitarian context in mind, WORM has launched a catalogue to bring together suppliers of biodegradable and bio-based items to be used in field hospitals. This will not only bring awareness to the availability of these types of items but make it easier for HOs in practice to find a selection of pre-approved items. In this deliverable the overall situation of the supply market of bio-based items for medical items has been established.

While circular and sustainable solutions are crucial to mitigate the environmental harm caused by field hospitals, the waste in hospitals remains extremely complex and has very different compositions which influences the ability for a circular and sustainable transition. Therefore, a crucial first step to the transition is better waste separation, especially for uncontaminated materials. While contaminated items are often incinerated for safety reasons, exploring methods to disinfect or sterilise these materials before recycling could reduce the risks of infection and allow for their reuse. SMIs importantly also consist of the market for services and WM as a service is an integral part of WORM. WM has several stages, and HOs need not be responsible for a majority of them, meaning that this needs to be acquired as a service. Therefore, an SMI study is crucial.

Apart from a focus on the supply market, understanding the drivers and barriers of adopting bio-based and biodegradable alternatives is crucial. As this deliverable highlights, alternative products and materials require different handling, processing, and other operational equipment. At the same time, a sheer lack of knowledge may be a barrier to seeking alternatives; while awareness of environmental concerns is seen as a motivator and driver. The interrelations of such material choices and their implications for also other

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decisions will be investigated more closely in WORM's WP6 that puts the use of bio-based solutions into a wider humanitarian context and assesses their potential limitations in a causal loop diagram. This deliverable is a first step to support that effort. Based on causal loop diagrams, not only the consequences of specific choices can be better understood, but also potential mitigation strategies for possible unintended consequences of such choices derived.

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