BIO4HUMAN

Gap Analysis Report

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Contents

List of Tables

List of abbreviations

DG ECHO	Directorate-General for European Civil Protection and Humanitarian Aid Operations
DRC	Democratic Republic of Congo
HA	Humanitarian Action
HO	Humanitarian Organization
HSC	Humanitarian Supply Chains
IBF	Irish Bioeconomy Foundation
ICRC	International Committee of the Red Cross
NGO	Non-Governmental Organisation
PIN	People in Need
PAH	Polish Humanitarian Action
SC	Supply chain
SW	Solid Waste
SWM	Solid Waste Management
UC	University of Cantabria
WFP	World Food Programme

Executive summary

This deliverable (D4.2), presented in the form of a Gap Analysis Report, summarises the works concluded within the Humanitarian Sector Needs Assessment Report (D3.3), tasks 4.2.1, 4.2.2. and 4.3 with the cooperation of Bio4HUMAN consortium partners: PRO CIVIS, AIMPLAS, ITENE, Irish Bioeconomy Foundation (IBF) and University of Cantabria (UC).

The report is divided into six chapters. The introductory part provides context for the gap analysis, describing the aims of the Bio4HUMAN project and Work Package 4 (WP4). Chapter 2 provides insight into the methodology that combines literature reviews, interviews with supply chain (SC) leaders and data collection to map Solid Waste Management (SWM) gaps across nine supply chain stages. Task 4.2.2 identifies gaps through three investigation lines—supply chain links, management techniques, and SWM technologies—while Task 4.3 uses a structured gap analysis with a 1-5 rating scale across six dimensions (e.g., resource availability, technology). Chapter 3 provides conclusions on existing SWM practices in humanitarian contexts, focusing on waste types, management techniques, and supply chain stage-specific challenges, with reference to the Democratic Republic of Congo (DRC) and South Sudan. Chapter 4 presents the Desired State of SWM in Humanitarian Actions (HA)which means that it defines an ideal SWM for HA, incorporating sustainable, bio-based solutions and effective infrastructure, based on stakeholder needs from D3.3 and T4.2.2 outcomes. Chapter 5 describes the differences between the current and desired SWM state, analyzing basic needs and supply chain-specific challenges using a structured gap analysis. Finally, Chapter 6 presents actions and strategies to address identified SWM gaps, focusing on governance, technology, and stakeholder engagement. In other words, it addresses how to bridge the gaps. It also outlines the communication strategy, which is very important part in implementing changes.

The report successfully identifies critical SWM gaps in Humanitarian Supply Chain (HSC)and proposes concrete actions to bridge them, which supports successful implementation of Bio4HUMAN project’s aims. By integrating collected data, stakeholder insights, and innovative technologies, it provides a practical framework for sustainable waste management.

1. Introduction

1.1 Context and aims of Bio4HUMAN Project and WP4

The general objective of the *"Bio4HUMAN"* project is *"Identifying bio-based solutions for waste management applicable to humanitarian sector"*, assessing the scope to which bio-based innovative technological solutions and bio-based systems have the potential to be applied within a humanitarian context, with a simultaneous positive effect on the environment. This deliverable brings new knowledge to the work done in the WP4 "Scoping exercise", which aimed to better understand which bio-based innovative technological solutions and bio-based systems are environmentally friendly and may be applicable within different humanitarian contexts.

This report synthesizes findings from multiple sources to address challenges and opportunities in HSC (Humanitarian Supply Chains), with a focus on SWM. Firstly, the "D3.3 Humanitarian Sector Needs Assessment Report," which aimed to identify and prioritize the current needs within the humanitarian sector, provided a critical foundation for aligning our analysis with real-world demands. Secondly, we have used the "D4.1 List of Bio-Based Solutions," aimed at scoping and listing sustainable bio-based solutions to enhance humanitarian operations and SWM. The conducted consultation processes gave rise to establishing the final list of 27 bio–based products and technologies potentially applicable within humanitarian contexts and helping in the process of SWM. The list comprises ~~of~~ solutions contributing to a more circular bioeconomy, with functional properties, comparable with fossil-based counterparts. The selection of bio–based products was determined by features such as: possibility of local production (i.e. in the humanitarian destination), quality, actual demand from Humanitarian Organisations (HOs)), "end of life" scenarios~~,~~ local resources needed for the implementation of technologies and functional and operational elements.

The issues of "applicability, suitability and effectiveness of the products in the humanitarian context" and "transferability of the technology to humanitarian destinations / feasibility of implementation and operation of the technology" were also very important in the selection of bio-based products and technologies.

Furthermore, we incorporated insights from "Task 4.2.2: Identification of Supply Chain Gaps in the SWM System for Humanitarian Action". This task aimed to pinpoint gaps in supply chains supporting humanitarian efforts by analyzing their links, management techniques, and solid waste technologies. Through literature reviews, interviews with supply chain leaders, data collection, and supply chain mapping, we have gathered unique knowledge across various stages. Additionally, "Task 4.3: Gaps Identification" aimed to identify gaps and areas for innovation. It employed tailored dimensions, point scales, a common data extraction sheet, and a rating scheme based on humanitarian priorities, culminating in a detailed gap analysis report.

By integrating these efforts — each with distinct aims of assessing needs, proposing solutions, and analyzing gaps — we present a comprehensive view of the challenges and potential innovations in HSC and SWM.

1.2 Overview of HSC and SWM

According to definition made by Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG ECHO) supply chains are "All activities that an organisation must undertake in order to acquire and deliver goods and services to beneficiaries in the required timeframe and location"[1]. Most of the humanitarian logistics consist of these stages: planning, procurement, storage, transport, distribution, monitoring and evaluation. Depending on the type of response and its implementation stage, diverse resources and capacities are required. To adequately respond to the complexity of each very specific humanitarian action at all stages of the supply chain, high diversity and quantity of actors is required. This is necessary to cover different requirements in staff capacity and its competence, technical, technological and logistical capacity, geography, climate conditions and culture recognition, network of local partners along the supply chain and at the location, etc.

Logistics is the backbone of humanitarian aid, representing 60-80% of expenditure and a major starting point for improving humanitarian operations cost effectiveness[2]. The 'humanitarian supply chain' is defined as: "The planning, procurement, storage, transport and delivery of different forms of supplies, works & services used for projects and to respond to emergencies. This includes the flow of supplies from origin to destination but also more complex work of forecasting, optimising resources, value for money to ensure the most efficient process, and decreasing the environmental footprint of related operations"[3].

Based on the D3.2 Scoping Plan, three main areas have been identified: logistics flow or supply chain, operational logistics and support logistics.

Table 1: Humanitarian Actions Logistics areas and its functions

SUPPLY CHAIN LOGISTICS	OPERATIONAL LOGISTICS	SUPPORTING LOGISTICS
Identification of needs	Distribution	Infrastructure (municipal type)
Planning	Water (tanks or bottled)	Technical equipment
Procurement	Rehabilitation works	Information and Communications Technology
Custom clearance	Construction of shelters or camps	Security
Transport	Sanitation, hygiene	Transport vehicles for persons
Storage	Health and vaccination	Energy supply
Waste collection, cleaning up residues, waste sorting, grading, and valorisation		

Each of the logistics area presented above is responsible for and specific to its functions production of side products and wastes. This approach has been used during the work in WP4. The supply chain gaps in SWM were identified based on the analysis of different links in the supply chain, the techniques used to manage the supply chains and the current techniques to manage the solid waste generated at each supply stage.

[1] DG ECHO Thematic Policy Document. Humanitarian Logistics Policy (2022) https://ec.europa.eu/echo/files/policies/sectoral/humanitarian_logistics_thematic_policy_document_en.pdf
[2] "Strength in Numbers - Towards a More Efficient Humanitarian Aid: Pooling Logistics Resources," published by the Réseau Logistique Humanitaire (Humanitarian Logistics Network - RLH)
[3] https://plan-international.org/eu/blog/2022/12/13/supply-chain/

2. Methodology

In this chapter, we will provide information on the methodology behind the reports, starting with Task 4.2.2, which hasn't been described in previous reports and deliverables. Moreover, we will describe the Gap Analysis approach used in this report.

2.1 Initial remarks

When starting to work on the issues covered by Task 4.2.2, certain assumptions and defined boundary conditions were made as to the issues that require special attention in the field of waste management, as well as to the basic challenges faced by HOs and their Humanitarian Actions (HA) partners in developing effective SWM solutions.

The first assumption involves the availability, concentration, and segregation of solid waste (SW) across the supply chain and at HA sites. Despite advanced waste collection systems, litter persists globally in public spaces , varying by system efficiency, public awareness, and culture. In humanitarian settings, SW collection, sorting, and management are limited, with significant amounts escaping into public spaces without planned management. Natural forces — rainfall, rivers, dams, water currents, wind — often concentrate, pre-segregate, and "partially manage SW" as seen in public media and Bio4HUMAN consortium materials. While these phenomena can support SWM, reliance on them should be minimal, with systemic solutions prioritized. Effective SWM requires technologies to aid HAs in collecting, sorting, and concentrating waste, given HO's limited technical, organizational, and staffing capacities during crises. Studies and materials from consortium partners PIN (People In Need) and PAH (Polish Humanitarian Action) suggest few high-concentration SW sites in HA areas (South Sudan and the DRC), necessitating identification and tailored solutions. Current knowledge indicates decentralized solutions will likely dominate effective SWM implementation.

2.2 SWM in SC - study tools

In HAs, gaps analysis will consist of study of the different links in the supply chain, the techniques used to manage the SC and the current techniques and technologies used to manage solid waste that is generated at each supply stage. The identification process was divided into exploratory (literature review, interviews with HSC leaders, data collection) and inductive phases among others. SC mapping was also considered.

The analysis of the SC gaps in the SWM system for HA was conducted through the following forms:

1. EXPLORATORY PHASE

- Review of literature regarding SC management in humanitarian contexts;
- Interviews and discussions with HSC leaders;
- Data collection on SWM from humanitarian operations through multiple studies.

2. INDUCTIVE PHASE

- Analysis of SWM at SC stages;

- Gaining new insight into waste management to identify gaps for improvement;
- Provision of fact-based evidence to support SWM in HA.

To stay "In line with the European Green Deal and DG ECHO's approach to reducing the environmental footprint of humanitarian aid, the greening of logistics is also a primary objective of this policy. DG ECHO will promote long-term, sustainable and green improvements in the humanitarian sector's approach to logistics, using all means available, including its funding instruments, coordination, and advocacy"[4] On the basis of major phases of crisis management we have identified 9 HSC stages taking into account specific type of actions required to implement, intensity and scale of used tools, techniques and technologies, external staffing and local human resources involvement and finally scale and type of SW generated. The techniques and systems were analysed within the context of the potential use of bio-based solutions and their environmental impacts.

The following 9 supply chains stages were investigated: Identification of needs, Conceptualization and planning, Procurement – sourcing/ purchasing of products and services, Goods in warehouses destination, Custom clearance, Transport to the destination country, Transport to the final destinations, Storage at the final destination, and Operational logistic at final destination.

2.3 Investigation lines for identification of supply chain gaps (Task 4.2.2)

This exercise aimed to learn how the HAs supply chains are managed in practice within context of SWM. The techniques and systems have been analysed within context of the potential use of bio-based components and their environmental impacts.
The SC gaps in the SWM system for HA were identified based on:

- An analysis of the different links in the SC;
- The techniques used to manage the SC;
- The current techniques and technologies used to manage the SW that is generated at each supply stage through the three investigation lines:

I. Reviewing the literature on evolvement of relevance of supply chain management in humanitarian contexts

The review aimed to synthesize existing knowledge on SWM in HAs, addressing research questions such as How is waste generated? What are the proceedings to manage this waste? Is the waste handled in any form? Has a waste management approach been used in any humanitarian action? Among other relevant questions. The scope was defined to include studies published in peer-reviewed journals, conference proceedings and relevant literature, focusing on publications in English from the last 20 years.

During this task, a comprehensive search strategy was employed, utilizing electronic databases such as Scopus, Elsevier and Google Scholar. Keywords relevant to the

[4] https://ec.europa.eu/echo/files/policies/sectoral/humanitarian_logistics_thematic_policy_document_en.pdf

topic were applied, including “Waste Management”, “Supply Chain” and Humanitarian Action” along with synonyms and related terms to maximize coverage.

II. Interviewing / discussing with humanitarian supply chains leaders

The sources of information for this investigation line were the following:

1. Interviews done with HSC leaders – 5 people;
2. Dedicated webinar with logisticians from PIN and PAH – 2 people.

The interviews were the main source of information. From the database of different humanitarian aid organizations, 19 people were contacted by e-mail. From those people, only 3 answered, 2 from the International Committee of the Red Cross (ICRC) and 1 from World Food Programme (WFP).

III. Collecting the data on SWM from humanitarian operations through multiple studies

Qualitative research and SWM Policies and Guideline documents from different international organizations, along with extensive examples of SWM practices from humanitarian settings across the world, have been selected as sources of data to use. The data collection was initially open to any form of media including videos, interviews, etc. After looking through data, it was decided to use documents only, as they best addressed many SC stages.

IV. Template for collecting data

For collecting the data, we have prepared a table entitled "Supply chain gaps analysis", which serves as a structured framework for evaluating and documenting the management of SW across various stages of a SC (Annex 1). Designed with flexibility and clarity in mind, it aims to identify inefficiencies, tools, technologies, and gaps in waste management practices by breaking down the SC into distinct phases and analyzing key aspects of each phase.

The SC stages trace a logical progression from inception to execution (Annex 1). It starts with "Identification of needs," where requirements are first defined, and moves into "Conceptualization and planning," where strategies are formulated. From there, it covers "Procurement– sourcing/purchasing of products and services," addressing the acquisition of necessary goods, followed by "Goods in warehouses destination," which focuses on initial storage. The process continues with "Custom clearance," tackling regulatory hurdles, and then "Transport to the destination country" and "Transport to the final destinations," which detail the movement of goods across borders and to their ultimate locations. Finally, "Storage at the final destination" and "Operational logistic at final destination" round out the journey, focusing on end-point storage and operational logistics.

This table is a narrative tool, presenting the SC’s lifecycle highlighting the waste management at every stage. It supported the investigators to map each stage.

2.4 Identifying the gaps (Task 4.3)

The methodology for this task centers on conducting a gap analysis which was to identify and prioritize deficiencies in SWM systems within humanitarian settings, with a focus on integrating bio-based solutions. This process systematically bridged past findings with future deliverables under the Bio4HUMAN project, ensuring alignment with the overarching goal of enhancing sustainable SWM practices in humanitarian contexts.

The gap analysis commenced by defining the "gap" as the disparity between the current state — existing SWM systems in humanitarian settings — and the desired state — effective, sustainable, and environmentally friendly SWM practices. This definition guided the identification of key challenges and deficiencies. Data drawned from two primary project documents: (1) *D3.3. Humanitarian Sector Needs Assessment Report*, which outlines sector-specific needs, and (2) *Task 4.2.2. Identification of Supply Chain Gaps in SWM System for Humanitarian Action*, which details SC-related shortcomings. These sources provided a robust foundation for understanding the current SWM landscape.

A comprehensive set of challenges was identified and analyzed. Each challenge was evaluated across key dimensions to assess its scope and impact. These dimensions, derived from project objectives and stakeholders' inputs, which ensured a holistic evaluation tailored to the humanitarian context.

To quantify the severity of each gap, a 1–5 rating scale was applied: minimal (1), minor (2), moderate (3), significant (4), and critical (5). This scale will measure the extent to which each challenge affects SWM performance and operations across the 6 dimensions.

By defining priority areas for improvement, the gap analysis will serve as a roadmap for future project activities, guiding the development of targeted recommendations and actionable outputs, mainly for coming project deliverables: 5.2. Hotspot analysis of the current and innovative solutions, 5.3. Identification of the best available innovative solutions based on LCA, 6.1. Socio-economic and governance aspects analysis report and 6.3. SWOT analysis report. These efforts will address the identified deficiencies, paving the way for bio-based solutions that enhance the sustainability and effectiveness of SWM in humanitarian settings.

2.5 Gap Analysis rules, objectives and measurements

A (waste) gap analysis is a process used to review relevant data to determine if there are gaps between current waste processes and desired performance levels assumed by all humanitarian actors' strategic goals[5]. As part of this analysis, we examined and assessed a range of criteria relating to the current waste management practices and idetified opportunities for improvement. A gap analysis may also be referred to as a "needs analysis", "needs assessment" or "need-gap analysis". The "gap" in the gap analysis process refers to the space between "where we are" and "where we want to be" (the target state or desired state)[6].

[5] https://www.wasteplan.co.za/waste-management-services/waste-audit/
[6] https://www.techtarget.com/searchcio/definition/gap-analysis

When supply chain managers use the Gap Analysis, they benefit from (Gap Analysis objectives):

- Gaining a clear understanding of the current state of their SC operations;
- Identifying gaps and areas of improvement to optimize processes and enhance efficiency;
- Setting realistic and measurable goals to achieve desired SC performance;
- Prioritizing actions to address the most critical gaps and improve overall performance;
- Enhancing communication and collaboration among team members, suppliers, and stakeholders;
- Making data-driven decisions to streamline operations and reduce costs;
- Improving customer satisfaction by ensuring timely and accurate deliveries;
- Increasing efficiency through better inventory management and reduced lead times.

3. Current state of SWM in HA

The main findings of the 3 investigations lines under T4.2.2, presented above, gave an overview of the current state of art of the SWM within humanitarian contexts. In particular, it shed light on the techniques and tools used to manage the SW at each of the SC stage. The analysis of the types of waste, the tools and techniques used to manage the SW at the very final stage of the SC (country of destination) have been presented in the deliverable D3.3 Humanitarian Needs Assessment report[7].

The most often mentioned type of humanitarian items and packaging in the research locations indicated in the report is plastic "which is used for food and nutrition supplies packaging and other relief items". In general, the type of waste in the DRC and South Sudan were grouped into the following categories:

Table 2 Types of waste identified in DRC and South Sudan according to Humanitarian Needs Assessment Report

Type of material/waste	Packaging	Items
Plastic	• Sachets, e.g. RUTF sachets (LDPE or aluminium laminate plastics) • Bottles, e.g. for oil (PET and PP) • Recipients, e.g. for disinfectant and liquid soap (HDPE) • Woven bags or sacs, e.g. for food items (PP)	• Jerrycans and basins (HDPE)
Organic matter	• N/A	• Bins (HDPE)
Metal	• Containers and tins, e.g. to conserve oil	• Cups and spoons (HDPE)
Cardboard	• Boxes used as primary (e.g. soap, Aquatabs59) or secondary packaging (e.g. RUTF)	• Watering cans (HDPE)
Paper	• Sacks for food items, e.g. flour	• Tarpaulin (HDPE, PP, nylon, canvas, PL)
Medical	• Medicament's packaging, e.g. blister packs (paper, plastic, aluminium foil etc.)	• Foodstuffs and agricultural inputs, e.g. flour, oil, legumes, vegetable seeds etc. (become waste if expired or contaminated)
Textile	• N/A	• Cooking tools, e.g. plates and casseroles
Construction materials	• N/A	• Farming tools or their parts

[7] *Humanitarian Sector Needs Assessment Report*, 2024

According to the report, the SWM practices in the DRC and South Sudan are very limited and most types of waste are simply thrown away (plots, pits, roads, water canals, and unofficial dumpsites, notwithstanding the setting), while only a small portion of the waste is picked by waste collectors and transported to official or unofficial landfills. Additionally, the report indicates:

- **Waste sorting in the DRC and South Sudan** is generally limited and not widely practiced at household level due to, among other reasons, a lack of awareness and insufficient SWM infrastructure. Consequently, most waste is mixed and disposed of in open dumps and poorly managed landfills without sorting.
- **Waste collection systems in the DRC and South Sudan**, both direct collection and collection at collection points were observed, but the first approach was more frequent. However, it must be emphasized that waste collection exists practically only in urban centres, and even there, covers only limited areas.
- **The informal sector and household-level practices** are the backbone of recycling and reuse activities in the DRC and South Sudan. The government is notably absent from the waste transformation sector, while a few HOs engage in small SWM pilots. Informal waste pickers, often operating independently or in small groups, collect recyclable materials from household waste, streets, water channels, and official or unofficial landfills. These materials typically include plastics, metals, and aluminium, which are sorted and sold to recycling businesses at home or abroad. A very common local level practice, also practiced by children, is collection of plastic bottles to be reused by small milk, alcohol or juice businesses.

On the other hand, the report indicates that local bio-based initiatives have been observed in both the DRC and South Sudan, however such initiatives were usually on a small local and even individual scale. Most of the projects implementing some bio-based solutions and led by HOs that the research team discovered tended to be unsustainable, as they ceased after projects' end. On the other hand, most bio-based solutions initiated by local actors (mostly businesses) or supported by research institutes proved to be more sustainable and durable.

The most commonly identified bio-based practice is compost and fertilizer production from organic waste:

Table 3 Bio-based practices currently identified in the DRC and South Sudan according to Humanitarian Needs Assessment Report

Bio-based practices identified in the DRC & South Sudan

• Animal feed production
• Black soldier flies' larvae feeding on organic waste (IITA, UOB, AALI, BK)
• Fish feed from organic waste (household level; mode of expired food destruction by Provincial Environmental service)
• Biogas production in biodigesters (Diobas, UOB, UNIGOM, Carnak Tobacco)
• Bio-charcoal production from different wastes:
  ○ Carton (BK)
  ○ Mixed organic household or field waste (RDG, UNIGOM)
  ○ Sugarcane husks (GIZ)
• Fertilizer and compost from organic waste
• Ignition stimulant produced from paper waste (BK)
• Mushroom growing on agricultural waste. The rest of the waste is used as fertilizer (UOB, GIZ, Rikolto, UNIGOM)

The analysis presented in the Needs Assessment Report, along with the findings from the investigation lines under T4.2.2, constitute the basis for analysis of gaps in SWM and further, for matching them with the identified bio-based solutions.

Below, we present the summary of findings from the analysis of gaps in SC in terms of SWM (T4.2.2)

3.1 Literature review on SWM in HA

The analysis in this task involved aggregating the data into a structured table. Table was made based on the provided template to collect the data on SC. The numbers are the occurrences of each topic in the evaluated papers. The greater the number the easier it is to find information in the literature. Last column and row are the sum of each column and row:

Table 4 Summary of results from literature review

Supply chain stages	Implementing entity	Key SWM supporting elements	Tools and technologies used in HAs	Waste generated	Logistical and organisational solutions used to manage SWM	Tools and technologies applied up to date	New bio-based technologies and solutions to improve SWM	Final products or services	TOTAL
Identification of needs	10	8	8	8	8	7	0	7	56
Conceptualization and planning	11	11	10	3	11	8	0	8	62
Procurement – sourcing/ purchasing of products and services	11	12	8	6	10	8	1	7	63
Goods in warehouses destination	4	6	6	6	5	4	0	2	33
Custom clearance	5	4	3	1	3	2	0	2	20
Transport to the destination country	5	5	4	5	5	4	2	2	32
Transport to the final destinations	8	9	9	8	8	6	1	4	53
Storage at the final destination	9	9	6	7	11	4	0	5	51
Operational logistic at final destination	10	10	10	9	10	8	5	7	69
TOTAL	73	74	64	53	71	51	9	44	439

The analysis revealed a disparity in focus, with early and final SC stages receiving more attention than intermediate phases, like goods handling and transport. This suggests a potential misalignment between stages that demand SWM innovation and the stages most frequently discussed in the literature. The analysis of the structured data on SWM across SC stages reveals key trends and gaps in current practices.

From a column perspective, the focus on "Implementing Entity", "Key SWM Supporting Elements" and “Logistical and Organisational Solutions” highlights a well-documented understanding of roles and baseline elements for SWM. However, advanced dimensions such as "New Bio-Based Technologies" and "Final Products and Services" are underrepresented, suggesting limited documentation or adoption of innovative approaches. This uneven distribution underscores the need for a balanced and comprehensive SWM strategy.

From a row analysis, stages like "Conceptualization and Planning", "Procurement and Sourcing" and “Operational Logistics at Final Destination” receive considerable attention, reflecting their critical roles in SWM. Conversely, intermediate stages like "Custom Clearance" and "Goods in Warehouses Destination" are consistently under-documented. This may reflect either a lack of attention in practice or insufficient recording in existing literature, which can create inefficiencies and missed opportunities for optimization in these areas.

The clustering analysis (by occurrences) highlights distinct patterns in how SWM is addressed. Most mentions fall within the 7–10 cluster, showing a focus on standard practices and foundational efforts across the SC. However, the presence of 0–3 clusters in critical areas, such as bio-based technologies and logistical solutions, signals persistent gaps that could hinder advancements in SWM. The sparse representation in the 11–12 cluster indicates a lack of comprehensive or universal best practices across all stages, pointing to variability in the maturity of SWM strategies.

One of the main conclusions from the analysis that the report indicates is the limited adoption of advanced technologies: there is a significant gap in the documentation and implementation of advanced tools and bio-based technologies, such as anaerobic digestion systems and automated waste tracking.

3.2 Humanitarian supply chain leaders overview on SWM

The longer the SC, the more difficult it is to manage, and the bigger quantities of waste are produced. Nearly 90% of waste is produced due to the logistics operations (Transport to the country of destination, Transport to final destination, Storage at final destination, Operational logistics at final destination), almost 9% of waste comes from procuring and storage of products. The rest comes from the stages of “Identification of needs” and “Conceptualization and planning”. The quantity of each stage of the chain depends on a many factors like country of destination, economic situation of the country, logistics network and infrastructures.
Environmental impact and sustainability criteria are often considered for choosing a supplier of goods/products, but they are not considered key. The most important part of the SC is to provide the aid on time. Also, the cost factor is crucial when

deciding between different suppliers or goods/products. Biodegradability is not considered as a criterion because it affects directly the lifetime and resistance of logistics. Reusability can be considered a criterion, but it depends on the context and it is not easy to be applied.

The quantity of wastes produced during the purchasing stage is not very high, but it can influence the rest of the SC directly, so a HO's team conducting the needs assessment should cooperate with the team responsible for planning the operations to reduce the wastes downstream. There is not much awareness of waste generated in the SC because HO's team consider it secondary.

Planification is key to reducing the quantity of products that are not usable after long-time waiting and the arrival to the location[8].

3.3 SWM in HA – multiply case studies

HOs generate waste in their operations as well their programs, and this is harmful to the environment if it is not managed appropriately. This commonly-held position has been widely articulated throughout the analysis of the documents reviewed under this investigation line. The literature reviewed was predominantly looking at SWM practices in different regions and there is clearly some emphasis on strengthening this as part of organisations' humanitarian core function. However, many of the policy documents studies reviewed demonstrate that the issue of waste management is not sufficiently taken into account in HOs operations and programs (Annex 5). Some of the HOs, according to the review, do not reference how they procure products for humanitarian responses, and moreover, do not have information or evidence to validate the environmental sustainability of products procured.

As an indicative example, the Haiti case study (2015) demonstrated that many aid actors are generally not aware of the types and the quantity of waste that they generate, nor the way that it is being managed beyond having a contract with a collection company. In addition to this, they are generally poorly equipped, mainly due to underfinancing strategies to reduce waste or improve waste management. However, the study also highlights the fact that there is growing recognition of the importance of this issue amongst aid actors. The *Study on the issues and opportunities of Solid Waste Management within Internally Displaced Persons (IDPs) settings in West and Central Africa (2020)* were one of many publications that considered SWM issues in their respective region but also described good practices and recommendations in terms of SWM and reduction, re-use, recovery and job opportunities.

3.4 Cumulative results of the investigations lines under 4.2.2

The table below presents the collective information on the tools and techniques currently used to manage the SWM at each stage of the SC:

[8] Conclusions based on the interviews with the supply chains leaders done in the Task 4.2.2

Table 5 Tools and techniques used to manage the solid waste – investigations lines 4.2.2

SC stage	Current SWM tools and techniques
Identification of needs	• Home composting, anaerobic digesters as small and very small units or as pilot projects • Collected by local community units or waste brokers • Street waste pickers and itinerant waste brokers • Reuse and recycling based on local knowledge on standardisation • Reuse or combustion • Managed by community
Conceptualization and planning	• Using the local organic waste collection and management systems • Waste accumulation monitoring tools for camps and settlements
Procurement – sourcing/ purchasing of products and services	• Segregation and municipal collection systems • Incineration, landfill or dumping sites, open fire • Community fundraising, local participation • Private vehicles used for waste transport • Structured contracts for recyclers and transporters • ICRC Software • Advanced procurement techniques for waste segregation • Tendering processes, public-private partnerships, environmental criteria in contracts, Basic waste collection and disposal equipment, green-certified materials • Joint procurement initiatives with WFP and UNHCR • Specifications for recyclable materials in contracts • Collaboration with suppliers for environmentally friendly products • Leveraging supplier networks; centralised sourcing for economies of scale
Goods in warehouses destination	• ICRC software • Incineration in coordination (not always) with the Ministry of Health of the country of destination • Periodic waste collection, Basic collection points • Centralised tracking and redistribution of stock to balance inventory levels. Automated inventory tracking; stock segmentation models. • Collaboration with WFP for inventory management • Efficient storage techniques, FEFO (First Expired First Out) rules, Digital warehouse management, enhanced inventory systems • ICRC software
Custom clearance	• Pre-planning for documentation and environmental compliance checks • Partnerships with customs agents to streamline clearance. Real-time customs clearance status tracking tools. • Shared freight and customs clearance for outbound logistics
Transport to the destination country	• Reverse logistics for disaster waste • Private vehicles used for waste transport • Logistics for waste transportation • Optimisation of transport routes; use of intermodal transport solutions. AI-driven route optimisation; carbon emission tracking tools • Route optimization, collaboration with certified transporters, Low-carbon logistics strategies • Joint outbound logistics for efficiency
Transport to the final destinations	• Community-managed waste transport initiatives, Informal transportation tools • Maximising vehicle utilisation; shared delivery services. Smart fleet management technologies; route planning apps. • Use of tracking technologies to enhance last-mile delivery visibility • Community fundraising, local participation, Private vehicles used for waste transport, optimized vehicle usage
Storage at the final destination	• Incineration in coordination (not always) with the Ministry of Health of the country of destination • Labelled containers for waste segregation • Landfill improvements (e.g., Fukuoka method), green circular practices • Proper labelling and storage to prevent environmental contamination • Periodic waste removal services, Temporary storage solutions • Community-based management of local storage; training for local staff. Digital stock tracking for small-scale storage facilities • Designated storage sites at community locations, reporting systems • Establishing storage protocols, ensuring safety measures, Storage facilities with segregation capabilities

	• New storage guidelines proposed for HCFs. Storage bins and containers
Operational logistic at final destination	• Waste incineration • Waste sorting and composting at community collection sites • Adherence to Waste Management Hierarchy: reduction, reuse, repurposing, recycling, and proper disposal • Worker supervision, waste compaction, soil cover application, landfill improvements (e.g., Fukuoka method) • Designated storage sites at community locations • Operational logistics for SWM campaigns, Basic operational frameworks • Increased collaboration in emergencies; regular communication frameworks between departments. Emergency-specific logistics tools; rapid needs assessment frameworks • Reverse logistics planning for unwanted or expired goods (e.g., safe disposal of contraceptives) • Collaborative logistics models, enhanced operational coordination, Waste segregation and recycling practices

All in all, the table above shows that within the investigated studies, there is limited or no use of the bio-based technologies throughout the humanitarian SC.

As was indicated in the reports from Investigation Lines I-III, at some point there is a notable gap in the documentation and implementation of advanced tools and bio-based technologies across multiple SC stages. Key SC stages, such as customs clearance and goods in warehouses at the destination, are often under-documented and overlooked, leading to inefficiencies and missed opportunities for optimization. One of the most significant conclusions arising from the analyses refers to proper planning and procurement of the supplies. Setting up the sustainability criteria for the purchased products at the beginning of the SC may become crucial, because of the fact that in HAs environmental concerns are not the top priority.

4. Desired state of SWM in HA

The Desired state of SWM in HA is defined as the goal or target state, reflecting an effective, sustainable, and environmentally-friendly SWM practices within humanitarian settings[9]. It has to be highlighted that this chapter refers to best case scenario, in which HOs are able to have all the needed support from the stakeholders and sufficient funding.

The starting point for defining the desired state was the identification of the needs and expectations of humanitarian actors and the beneficiaries of HAs, presented in document: “The humanitarian sector needs assessment report”, delivered in D3.3. To properly define the desired state of SWM in HA, recognition how the HA SCs are managed in practice was also crucial. The functioning of the HSCs has been analyzed in the document “Identification of supply chains gaps in SWM system for humanitarian actions”, in T.4.2.2 and numerous opportunities have been identified in D3.3.

As highlighted in the aforementioned reports, the desired state of SWM in HAs is reflected in:

[9] Definition from the own research made by University of Cantabria, please see Annex 2.

Design for recycling, repair and reuse

- Ecodesign, using recyclable products and packaging;
- Developing suitable alternative materials, especially to petroleum–derived plastic packaging (possible to use, taking into account the specific conditions of humanitarian settings) such as: biodegradable plastics, compostable plastics, bio-based plastics, bio-regenerative materials (seaweed, hemp, mushroom), natural fibres (jute and cotton), cardboard/paper, recycled plastics.

Sufficient and adequate waste management systems and infrastructure

- Well-developed infrastructure for waste reduction, segregation, collection and recycling, such as: adequate equipment for household and centralized waste collection infrastructure, waste treatment plants and proper/safe landfills, to be developed by promotion and direct support to local authorities
- Access to public utilities such as electricity, water, sewage system, internet connection, public waste collection.

Effective SW treatment and disposal methods

- Using bio-based technologies and systems that ensure natural biodegradation of residues or their easy disposal;
- Using bio-based technologies that offer the possibility of further use by the local community;
- Proper monitoring systems, access to comprehensive data on SW (including characterisation, quantification, information on recycling, disposal, standardization in measurement and reporting of waste and establishing the composition of the waste streams, etc.) in humanitarian settings.

Sustainable SC and procurement optimization

- Sufficient human resources, expertise and knowledge on how to properly assess the sustainability of products to be purchased, supplier screening, life-cycle assessment for relief items, HOs engaging with environmental audits;
- Prioritizing SWM in HOs;

Stakeholder collaboration and capacity building

- High social awareness and motivation for different SWM issues (properly segregate the source of waste in households, restaurant, shops, markets etc.);
- Good cooperation between private and public entities dealing with SWM, HO teams;
- Involvement of qualified local suppliers in humanitarian settings who could guarantee the international quality and safety standards required by HOs (ability to provide goods that meet specific technical specifications or health and safety regulations);
- Involvement of qualified recyclers;
- Comprehensive national policies and standards;
- Waste policies effectively implemented on the ground;
- Comprehensive national policies addressing all aspects of SWM (hazardous waste management, recycling, sustainable practices);

- Strong institutional capacity and good coordination among stakeholders (HOs, NGOs, private sector, agencies/different levels of the government);
- Strong regulatory framework for SWM.

Sufficient funding

- Adequate financing to cover the costs of an effective SWM systems and the real cost of environmental sound waste management by HO.

It has become clear that there is a variety of different tools and techniques used to manage the SW within humanitarian contexts (identified during Bio4HUMAN research) at each stage of the SC.

Although some of the identified practices are quite common, there should be efforts made to minimise or even eliminate some of them, due to their negative impact on the environment. Examples of such negative practices by the communities are:

- Combustion, open fire; Use of unsecure, not dedicated to the purpose dumping sites (including streets, rivers, channels, etc.);

Collecting waste by unsecured, untrained waste-pickers; On the other hand, among the existing practices for SWM, there are some concrete solutions which, if strengthened with relevant enforcement actions (best practices), have the potential to be multiplied in other locations or types of actions. The best practices actions are centred around the following key areas:

- Technological;
- System solutions;
- Human resources;
- Regulatory aspects;
- Stakeholders' engagement.

Finally, in addition to already existing tools and techniques, Bio4HUMAN efforts were focused on finding the innovative bio-based practices that have the potential to complement (in some cases even replace) the products which are commonly used in the HAs, and small-scale technologies which could contribute to better handling of SW in the final destinations.

The practical examples of bio–based innovative solutions of potential relevance for Bio4Human were presented in the D4.1: "The list of bio-based solution relevant to waste management in the humanitarian context" delivered in M14 of the project. Annex 6 presents the list of 27 selected innovative bio-based solutions that have been divided into **products** and **small – scale technologies.** A comprehensive analysis of the entire SC in SWM system for HAs have become the basis for precise positioning of the identified bio-based solutions in different stages of SC. The currently used solutions to be multiplied, the best practices and the suggested bio-based solutions have been presented in the table below.

Table 6 Identified existing solutions to be multiplied

SC stage	Identified existing solutions to be multiplied	Best practices	Identified bio–based solutions
Identification of needs	• Home composting, **anaerobic digesters** as small and very small units or as pilot projects • Collection by local community units	**BP2** Safe disposal techniques **BP11** Bio-Based Solutions **BP14** Local recycling activities **BP15** Household reuse practices **BP30** Community-led efforts	**(1)**Packaging utilizing Notpla Seaweed; **(3)**Sustainable film concept for medical and food packaging; **(6)**Sway Polybags; **(7)**Wood Foams utilising the Fibrease® and Papira®; **(8)**High barrier and compostable packaging materials for food contact applications; **(9)**PLA bottles for water; **(21)**Black soldier fly; **(22)**Small-Scale Residue Utilization Pathways (SSRUP) - Black Soldier Fly technology;
Conceptualization and planning	local organic waste collection and management systems	**BP3** Waste quantification and estimation methods **BP11** Bio-Based Solutions	**(1)**Packaging utilizing Notpla Seaweed; **(9)**PLA bottles for water;
Procurement – sourcing / purchasing of products and services	• Segregation and municipal collection systems • Structured contracts for recyclers and transporters • Activities related to planning of tendering processes, preparing specifications establishing contacts, managing orders and establishing cooperation between entities	**BP8** Green procurement **BP9** Reverse logistics **BP20** Coordination initiatives **BP31** Collaborative projects in joint planning **BP38** Private sector engagement	**(1)**Packaging utilizing Notpla Seaweed / Zero Waste Paper;
Goods in warehouses destination	• Storage and repacking management • ICRS software • Periodic waste collection • multi-stakeholder coordination	**BP2** Safe disposal techniques **BP16** Human Organisations-led initiatives **BP29** Digital tools implementation **BP31** Collaborative projects in joint planning **BP36** Innovative technologies for SWM	**(1)**Packaging utilizing Notpla Seaweed / Zero Waste Paper; **(2)**MYCO 4Pack and SafePads; **(3)**Sustainable film concept for medical and food packaging; **(4)**LAM'ON – Biodegradable laminating film; **(5)**Monta Biopack® – self-adhesive tape / monta Klebebandwerk; **(6)**Sway Polybags; **(7)**Wood Foams utilising the Fibrease® and Papira®; **(8)**High barrier and compostable packaging materials for food contact applications; **(9)**PLA bottles for water; **(16)**Bio4Pack Waste Bag (TIPA); **(17)**Single use compostable HaPPE apron; **(18)**Biodegradable containers;

Custom clearance	• Partnerships with customs agents to streamline clearance. Real-time customs clearance status tracking tools • Shared freight and customs clearance for outbound logistics • Reverse logistic • Local municipality SW units	**BP9** Reverse logistics **BP31** Collaborative projects in joint planning	**(1)**Packaging utilizing Notpla Seaweed / Zero Waste Paper; **(2)**MYCO 4Pack and SafePads; **(3)**Sustainable film concept for medical and food packaging; **(5)**Monta Biopack® – self-adhesive tape / monta Klebebandwerk; **(6)**Sway Polybags; **(7)**Wood Foams utilising the Fibrease® and Papira®; **(8)**High barrier and compostable packaging materials for food contact applications; Domestic biogas Technologies; **(24)**Single Stage Biogas Digester;
Transport to the destination country	• Reverse logistics • Logistics for waste transportation • Optimisation of transport routes	**BP9** Reverse logistics **BP16** Human Organisations-led initiatives **BP29** Digital tools implementation **BP31** Collaborative projects in joint planning **BP38** Private sector engagement	**(2)**MYCO 4Pack and SafePads; **(7)**Wood Foams utilising the Fibrease® and Papira®;
Transport to the final destinations	• Community-managed waste transport initiatives, Informal transportation tools • Maximising vehicle utilisation; shared delivery services. Smart fleet management technologies; route planning apps • Community fundraising, local participation, Private vehicles used for waste transport, optimized vehicle usage • Reverse logistic	**BP9** Reverse logistics **BP29** Digital tools implementation **BP30** Community-led efforts **BP31** Collaborative projects in joint planning	the same as in the case of **Transport to the destination country**

Storage at the final destination	• Labelling and storage for waste segregation. Designated storage sites • Landfill improvements (e.g., Fukuoka method), green circular practices • Community-based waste management (including composting, anaerobic digesters and biogas production) • Reuse and reverse logistic	**BP2** Safe disposal techniques **BP9** Reverse logistics **BP16** Human Organisations-led initiatives **BP30** Community-led efforts **BP31** Collaborative projects in joint planning **BP35** Community reuse practices	**(2)**MYCO 4Pack and SafePads; **(3)**Sustainable film concept for medical and food packaging; **(4)**LAM'ON – Biodegradable laminating film; **(5)**Monta Biopack® – self-adhesive tape / monta Klebebandwerk; **(6)**Sway Polybags; **(7)**Wood Foams utilising the Fibrease® and Papira®; **(8)**High barrier and compostable packaging materials for food contact applications; **(9)**PLA bottles for water; **(10)**Anandi 100% Compostable Sanitary Pads + Aakar Mini –Factories; **(11)**NATY Incontinence Pads; **(12)**KINGSPAN Bio based insulation in buildings; **(13)**Product lines made from bioPUR; **(14)**Eco-friendly insulation with natural sheep's wool; **(15)**Biodegradable shelter; **(16)**Bio4Pack Waste Bag (TIPA); **(17)**Single use compostable HaPPE apron; **(18)**Biodegradable containers; **(19)**Monofilament fishing nets; **(20)**Biodegradable and compostable mulching spray; **(21)**Black Soldier Fly (BSF) opportunities; **(22)**Small-Scale Residue Utilization Pathways (SSRUP)- Black Soldier Fly technology; **(23)**Modular micro AD system – Qube Renewables; **(24)**Single Stage Biogas Digester; **(25)**Micro Biogas Digester; **(26)**Domestic biogas technologies; **(27)**Biogas production from (bio) organic waste;
Operational logistic at final destination	• Waste sorting and composting at community collection sites landfill improvements (e.g., Fukuoka method) • Increased collaboration in emergencies • Reverse logistics	**BP2** Safe disposal techniques **BP6** Waste hierarchy approach **BP9** Reverse logistics **BP11** Bio-Based Solutions **BP31** Collaborative projects in joint planning **BP35** Community reuse practices	the same as in the case of **Storage at the final destination**

5. Identification of gaps for Solid Waste Management in Humanitarian Contexts

The main approach is to identify gaps in SWM systems in humanitarian contexts, understood as a difference between "current state" (Chapter 3) and "desire state" (Chapter 4), focusing on the potential for implementing bio-based products, technologies, solutions and systems.

As defined in Chapter 4, "Desire state of SWM in HA is the goal or target, reflecting an effective, sustainable, and environmentally friendly SWM practices humanitarian settings". To assure identification of the full spectrum of gaps in SWM in HAs it was an elaborated comprehensive study from two major points of view: a) basic SWM needs and related challenges; b) SWM needs and challenges at each stage of supply chain in HAs. Key findings reveal deficiencies in infrastructure, financial resources, policy frameworks, and community engagement, among other dimensions along the SC stages.

5.1 Basic SWM needs and challenges in HA's

The gap analysis considers the following challenges crucial to SWM in humanitarian contexts, identified in WP3 and crossed in WP4 along the HA SC (Task 4.2.2):

- Challenges in Waste Management Infrastructure (G1);
- Limited Adoption of Advanced Technologies (G2);
- Underrepresentation of Intermediate Stages (G3);
- Insufficient Financial Resources (G4);
- Shortage of Human Resources (G5);
- Weak Policy Framework and Enforcement (G6);
- Lack of Strategic Planning (G7);
- Insufficient Data and Inconsistent Monitoring (G8);
- Limited Awareness and Education on SWM (G9);
- Lack of Coordination among Facilities (G10);
- Challenges in Sustainable Procurement and Planning (G11);
- Inadequate Waste Management at the End of the Supply Chain (G12);

Six dimensions were defined and consulted with HOs (PIN and PAH) based on the project's objectives, stakeholder inputs, and the unique challenges faced in SWM in the humanitarian context. These dimensions form the foundation of the gap analysis.

1) Resource availability;
2) Technology for SWM in humanitarian contexts;
3) Supply chain and operational efficiency;
4) Stakeholder engagement;
5) Environmental sustainability and policy alignment;
6) Community needs and impact assessment.

Rating Scale: Each dimension is rated on a 5-point scale (maximum scores for each challenge is 30 per gap)

- 5 = Critical Gap: Severe deficiency, requires immediate action.
- 4 = Significant Gap: Major deficiency, needs focused efforts.

- 3 = Moderate Gap: Noticeable gap, moderate improvements needed.
- 2 = Minor Gap: Small Gap, minor adjustments required.
- 1 = Minimal Gap: Close to full compliance or implementation.

Table 7 Prioritization of gaps in SWM

#	Challenges in SWM	Current Conditions	Desired state	Gap	Rating (1–5)
1	Infrastructure	Limited collection centres	Collection points with full SW processing	Need to establish more collection points and processing facilities.	22
2	Advanced technologies	Limited access to technology	Technology adequate to the type of SW and access to media	High costs and lack of expertise in bio-based solutions.	20
3	Intermediate stage representation	Customs, transport and warehouses not properly supported	Provided collecting and segregations tools and equipment	Most of the intermediate stage are public or business services with not support at SWM	18
4	Financial Resources	Sporadic funding from donors	Dedicated financial resources to SWM	Partial funding from NGOs, but unsustainable in the long term.	24
5	Human resources	Insufficient workforce	Dedicated training and bio-based education	Local staff require more training to handle bio-based technologies.	21
6	Policy Framework	Policies exist but not enforced	SWM monitoring and enforcement in place	National policies are weakly enforced, especially in rural areas.	23
7	Strategic Planning	No strategic approach and limited SWM rules enforcement	Designed road maps, policies, programmes & enforcement	SWM activities are reactive rather than proactive.	21
8	Data and Monitoring	Fragmented and not properly processed data	SWM data collection and waste tracking systems	No unified system for tracking waste generation along SC and recycling rates.	20
9	Awareness and education	All stakeholders' low awareness and lack of professional education	Bio-based professionals, society aware of SWM, health & environmental consequences	Limited stakeholders' education and access to professional schools, communities unaware of sustainable SWM practices.	22
10	Coordination	Actors work in silos	Good cohesive collaboration among stakeholders	Limited collaboration between NGOs, governments, and private sector, limited synergy.	24
11	Procurement and Planning	Focus on speed over sustainability	Procurement of HA, goods & services by HOs, SWM oriented	Decisions prioritize cost and availability; environmental concerns are often overlooked.	21
12	SWM at the end of SC	Lack or very limited waste collection and segregation	Bio-based products, packaging and technologies, local NGOs and entities involve in SWM	Lack of access to investment resources, limited scope of bio-based products and technologies	22

The gaps with the highest total scores are "Insufficient Financial Resources" and "Lack of Coordination among Facilities", both scoring 24 points. These gaps highlight their significant impact on operations due to limited resources, high financial dependency, and insufficient relationships between facilities throughout the SC. Following closely is "Weak Policy Framework and Reinforcement" with 23 points,

emphasizing coordination challenges and the need to involve local governments and institutions to strengthen policy alignment and enforcement.

Dimension wise, “Supply Chain Efficiency” and “Environmental Sustainability and Policy Alignment” emerge as the most critical categories, both with total scores of 46. This indicates that inefficiencies in the SC and misalignment in policies are major obstacles affecting the organization’s performance.

Full presentation of the gaps evaluation and ranking are presented in Annex 2.

5.2 SWM needs and challenges at each stage of SC in HA’s

Gap analysis for Humanitarian Actions SWM at each stage of the SC consist of a detailed study of the management aspects and the techniques, technologies and solutions used and desired to manage SW that is generated at each stage of the SC. The identification process was done by literature review (Annex 3), interviews with humanitarian SC leaders (Annex 4) and data collection from humanitarian operations (Annex 5).

SWM techniques, technologies and systems were analysed for the following supply stages: Identification of needs, Conceptualization and planning, Procurement – sourcing/ purchasing of products and services, Goods in warehouses destination, Custom clearance, Transport to the destination country, Transport to the final destinations, Storage at the final destination, and Operational logistic at final destination.

Rating Scale: Each dimension is rated on a 5-point scale (maximum scores for each challenge is 30 per gap)

- 5 = Critical Gap: Severe deficiency, requires immediate action.
- 4 = Significant Gap: Major deficiency, needs focused efforts.
- 3 = Moderate Gap: Noticeable gap, moderate improvements needed.
- 2 = Minor Gap: Small Gap, minor adjustments required.
- 1 = Minimal Gap: Clouse to full compliance or implementation.

Table 8: Identified gaps in SWM supply chains

#	Supply chain stage	Current state	Desire state	Gaps	Rate 1-5
1	Identification of needs	Reuse, recycling, combustion, managed by local community	Identification of SWM systems and solutions at future HA	Staff and tools for SWM aspects identification	**3**
2	Conceptualization and planning	Segregation and collection by local waste management unit	Detailed programme for SWM along SC	SWM specific requirements in Terms of Reference for humanitarian services	**3**
3	Sourcing/ purchasing of products	Reuse, segregation by local units	Products should be from close destination in recyclable packaging not burden to environment	Permanent source of goods and services recognition, clear donors’ regulations on goods and packaging requirements	**3**

4	Goods collection in warehouses and repacking	ICRS software, collection, reuse, repair, municipal collection and treatment	Adequate storage to avoid damage and sustainable repackaging	Selection of adequate warehouses and its permanent monitoring at SWM aspects	**4**
5	Custom clearance	Reverse logistic, local municipal SW units	Organized by professional partners no time consuming and limited reloading	Limited capacity to change formal requirements and admin. burden and monitor SWM	**4**
6	Transport to the destination country	Reverse logistic, waste manage by local units or transported to destination	Direct transport from warehouse or good and reliable local transport with full collection of waste	Limited access to vehicles relevant to the transported goods and weather conditions to avoid waste scattering along the roads	**4**
7	Transport to the final destinations	Reverse logistic, waste manage by local units or transported to destination	Transport adequate to climate and roads conditions with good SWM awareness	SW very difficult to manage and monitor mostly in new HA's surroundings	**4**
8	Storage at the final destinations	Temporary waste storage facilities and periodic waste removal, municipal composting, anaerobic digesters and biogas production, segregation, labelled containers, reuse, repair	Well organized waste storage, segregation, composting and biogas production, reuse containers, most equipment suitable for RRR	SW is a very serious problem for short term HA's and not peaceful surroundings. Still space for improvement for long term HAs with friendly local authorities and society	**4**
9	Distribution	Waste segregation, recycling and compaction. Designated storage places at community level	Waste segregation, recycling and compaction. Designated storage places at community level	Not very common good quality waste storage facilities and not properly constructed and protected to avoid wastes scattering around, stopping soil and water pollution	**3**

6. Bridging the gaps/areas for improvements

Bridging the SWM gaps provides guidance on waste management governance to national and local authorities as well as practitioners[10]:

- ✓ Creating the right institutional structure for effective waste management;
- ✓ Policy, planning & legal frameworks to achieve urban and national SW goals;
- ✓ Financing to ensure investment and sustained operational funds and to provide incentives for change;
- ✓ Organizational models for service delivery in a local context;
- ✓ Including stakeholders and the informal sector in planning and service delivery;

[10] https://www.worldbank.org/en/topic/urbandevelopment/publication/bridging-the-gap-in-solid-waste-management

- ✓ Policy instruments to advance along the waste hierarchy and towards circular economy.

6.1 Bridging the gaps in SW treatment

In order to at least partially address SW distributed along the SC, as well as those that are outside the collection system, when analysing available technologies that will be recommended for use in HA, considerable attention should be paid to:

a) The scalability of the available solutions, and their minimisation to the level of containers or autonomous operating units;
b) The mobility of the proposed solutions (transport from place to place - i.e. self-propelled units attached to other means of transport or as semi-trailers for TIR);
c) Independent power supply (power generator included or possibility of power supply from easily assembled renewable sources) and own access to other necessary utilities such as; water, sewage tanks, technological additives, etc.;
d) The final products after disposal are easy to store, long term storage regardless of temperature and humidity, easy to transport and usually for local or at most regional use. Limited quantities of products do not create the conditions for developing distant and stable markets.

Table 9: Baseline conditions to carry out effective and large-scale disposal of SW

Condition	Rationale
Concentration of waste in a given location or the ability to concentrate waste in a chosen location and the associated continuity of waste generation	We have to meet this condition in order to invest, this is done by waste collectors from residents and companies and waste treatment plants as well as landfills
Technical and technological capacity to separate waste into homogeneous groups	When developing new sorting and separation solutions and technologies, attention should be paid to the scale and type of possible contamination of a given group of waste. Any contamination poses a serious challenge to the selection of optimal solutions and often even prevents the use of unique and dedicated technologies, making it necessary to classify a given, even valuable group of waste as one that must be sent to landfill. It is necessary to pay attention to maintaining the homogeneity of a given group of waste and taking measures to limit or even exclude its contamination. A waste group should be understood as a type of waste intended for joint disposal or further type of treatment.
Availability of public infrastructure at the waste concentration site	Electricity, water, sewage treatment plants, access roads, paved yards, covered and at least netted storage areas, etc. In this respect, the analysis should identify the nearest municipal waste treatment facilities and their technical and technological advancement.
Human resources availability and education system	In this respect, it does not necessarily have to be highly qualified engineering staff but so-called middle personnel with the potential for further education on the job.
Market for products arising after disposal or using waste as a raw material for the manufacture of new products	In the case of an outlet, it is not enough that such a market exists, but also its accessibility (distance from the place of production, identified customers or the possibility of setting up a distribution system in a given market), its absorptive capacity, as well as the requirements related to the introduction of a given product into identified markets and related studies, certificates, permits, etc.

6.3 Actions supporting SWM in HAa

Based on the identified gaps for each stage of HAs SC, we have developed set of actions to be implemented, to address each gap. Most of the actions were identified during data and information collection (Investigation Lines) and from the reports and consultation with other consortium members, especially with HOs PIN and PAH.

The actions were selected for each dimension and for each stage of SC, which made it possible to accurately define the spectrum of key activities that should be considered first if humanitarian actors encounter a problem described as a Gap. However, it should be kept in mind that such a dedicated selection does not exclude complementary and supplementary activities described in other Gaps, without which implementation of key supporting actions may not be possible.

Table 10: Necessary actions to bridge the SWM gaps

G1: Challenges in Waste Management Infrastructure
1.1: *Improve waste collection systems* – Expand household and centralized collection points with adequate equipment (e.g., handcarts, trucks) and regular schedules (e.g., twice weekly), tailored to local infrastructure and climate.
1.2: *Strengthen local SWM systems* – Invest in urban waste collection infrastructure, establish safe landfills, and support private sector and informal waste pickers to enhance recycling and reuse capacities.
1.3: *Invest in sanitary landfills* – Construct and maintain sanitary landfills with liners, leachate collection, and methane capture to replace open dumping, prioritizing high-waste urban areas.
1.4: *Promote waste-to-resource models* – Invest in technologies like composting, anaerobic digestion, and landfill gas recovery to convert waste into energy, fertilizers, and materials, fostering livelihoods and circular economies.
G2: Limited Adoption of Advanced Technologies
2.1: *Enhance waste data collection and monitoring* – Prioritize accurate waste measurement and reporting through standardized methods (e.g., waste audits, procurement-based estimates, IoT sensors, drones) to improve planning and resource allocation.
2.2: *Implement advanced tools for customs and logistics* – Use advanced technologies (e.g., routing systems, automated tracking) in customs clearance, transport, and warehouse management to optimize SWM and reduce waste.
2.3: *Promote bio-based solutions* - Scale up bio-based solutions like composting and biogas by involving local suppliers and building infrastructure, ensuring performance in harsh conditions.
2.4: *Incorporate eco-design principles* - Use eco-design to reduce plastic usage and enhance recyclability and reuse, tailoring solutions to humanitarian aid product needs.
2.5: *Design context-specific innovations* - Develop waste management innovations that account for local infrastructure, regulations, and community practices to ensure sustainability and effectiveness.
G3: Underrepresentation of Intermediate Stages
3.1: *Strengthen waste segregation systems* – Promote segregation at the source into organic, inorganic, and special waste categories using simple systems (e.g., color-coded bins) to enhance material recovery and safe disposal, starting at households and facilities.
3.2: *Develop recycling infrastructure* – Build recycling systems and material recovery facilities (MRFs) in humanitarian settings, leveraging the informal sector while regulating recyclable exports.

3.3: *Implement tailored waste treatment methods* – Adopt specific disposal methods for different waste types, such as composting or anaerobic digestion for organic waste, recycling for plastics and metals, and incineration or specialized facilities for hazardous waste (e.g., medical or chemical).
G4: Insufficient Financial Resources
4.1: *Increase funding for SWM* – Advocate for more donor funding for SWM, including greening efforts, and establish sustainable financing models (e.g., gate fees, private sector investment, polluter-pays principles) to support systems.
4.2: *Create income opportunities through SWM* – Link waste collection with income-generating activities for affected persons, collaborating with private enterprises and extending beyond project cycles.
G5: Shortage of Human Resources
5.1: *Build SWM capacity* – Provide training and exchange programs for governments, businesses, HOs, and communities to enhance expertise in segregation, recycling, and safe disposal techniques.
5.2: Provide external experts and at job training opportunities – When implementing new technical and technological solutions it is a need to provide external experts to assure new units construction and proper operation and train local staff to operate new technologies after HA.
G6: Weak Policy Framework and Enforcement
6.1: *Enhance SWM policy enforcement* – Strengthen national SWM policies with clear roles, responsibilities, and enforcement mechanisms, supported by coordination platforms among agencies and HOs.
6.2: *Align with waste management standards* – Ensure SWM practices comply with standards like the Climate Charter, Sphere, CHS, and donor requirements (e.g., DG ECHO's MERS) to minimize environmental impact.
6.3: *Minimize branded packaging* - Reduce the use of humanitarian organization logos on aid supplies to decrease distinguishable waste and align with trends in aid delivery.
6.4: *Establish specialized environmental NGOs- support* creating organizations focused on environmental control to address waste management gaps overlooked by general humanitarian NGOs.
G7: Lack of Strategic Planning
7.1: *Adopt sustainable SWM models* – Implement integrated SWM, circular economy principles, and green procurement practices to reduce waste and enhance sustainability, tailored to local contexts.
7.2: *Utilize waste management guidance* – Use published resources like the "Waste or Material Characterization Exercise Guidance" (WREC, June 2024) to understand waste streams, develop solid waste management (SWM) plans, and allocate resources effectively.
7.4: *Prioritize SWM across humanitarian sectors* – Integrate SWM into all humanitarian sectors (beyond WASH) with dedicated policies, planning frameworks, and trained personnel to elevate its priority.
7.5: *Adopt waste hierarchy practices* - Prioritize waste prevention and reduction at the source (e.g., green procurement, bulk packaging), followed by reuse, recycling, and safe disposal to aim for zero-waste systems.
7.6: *Foster collaboration between HO teams* - Encourage cooperation between needs identification and planning teams within humanitarian organizations to minimize downstream waste in the supply chain.
7.7: *Mitigate SWM risks* - Address health, environmental, and social risks (e.g., child exposure, pollution) through targeted strategies like segregation and safe disposal systems.
G8: Insufficient Data and Inconsistent Monitoring
8.1: *Enhance waste data collection and monitoring* – Prioritize accurate waste measurement and reporting through standardized methods (e.g., waste audits, procurement-based estimates, IoT sensors, drones) to improve planning and resource allocation.

8.2: *Leverage digital tools for SWM* – Implement tools like IoT sensors, GPS tracking, GIS mapping, and waste mapping platforms (e.g., WREC's facilities mapping) to monitor waste streams, optimize collection, and inform strategies.
G9: Limited Awareness and Education on SWM
9.1: *Raise awareness among stakeholders* – Educate aid beneficiaries, staff, communities, and local suppliers on proper waste disposal, sustainable practices, and environmental impacts to improve participation and responsibility.
9.2: *Engage communities in SWM* – Launch campaigns via radio, local leaders, and schools to raise awareness, change behaviours, and encourage household-level waste segregation and responsibility.
G10: Lack of Coordination among Facilities
10.1: *Establish stakeholder coordination platforms* – Creates joint committees to unite SWM stakeholders for better coordination.
10.2: *Collaborate with local stakeholders* – Partners with local authorities, suppliers, and informal actors to align efforts.
G11: Challenges in Sustainable Procurement and Planning
11.1: *Integrate sustainability into supply chain stages* – Enhances all supply chain stages with sustainability criteria.
11.2: *Optimize humanitarian supply chains* – Plans procurement to minimize waste and prioritize local sourcing.
11.3: *Define sustainability criteria for procurement* – Establishes strict guidelines for sustainable purchasing.
11.4: *Develop local supplier capacity data base* - Build databases and train local suppliers to meet international environmental standards, supporting sustainable procurement and reducing reliance on external sources.
G12: Inadequate Waste Management at the End of the Supply Chain
12.1: *Promote reverse logistics* – Encourages returning or reselling packaging waste to reduce disposal burdens.
12.2: *Replace physical aid with cash or vouchers* – Reduces packaging waste at the end by shifting to non-physical aid.
12.3: *Introduce sustainable packaging alternatives* – Replaces plastic with eco-friendly options to ease end-stage management.

6.4 Supporting actions at each stage of SC

The table below outlines a SC framework for HAs with a focus on SWM at each stage. It is structured into 9 stages, from "identification of needs" to "distribution". The aim is to support sustainability and efficiency in HA delivery by highlighting specific challenges and proposing supporting actions that could help closing each gap. The framework seeks to minimize environmental impact and improve waste handling throughout the SC process.

Table 11: Necessary actions to bridge the SC gaps

#	Sc stage	Gaps	Supporting actions
1	Identification of needs	Staff and tools for SWM aspects identification	✓ Dedicated staff with SWM knowledge ✓ Environmental NGOs to be identified ✓ ICT tools to collect and process SW data
2	Conceptualization and planning	SWM specific requirements in Terms of Reference for humanitarian services	✓ Define sustainability criteria for procurement ✓ When applicable replace physical aid with cash and vouchers
3	Sourcing/ purchasing of products	Permanent source of goods and services recognition, clear donors'	✓ Goods and services delivery guidance and standards ✓ Sustainable packaging and repackaging standards

		regulations on goods and packaging requirements	✓ Goods sampling at testing at source and delivery location
4	Goods collection in warehouses and repacking	Selection of adequate warehouses and its permanent monitoring at SWM aspects	✓ Warehouses with standardize storage facilities ✓ Modular and standard packaging units to limit repacking
5	Custom clearance	Limited capacity to change formal requirements and admin. burden and monitor SWM	✓ Cooperation with other experienced partners or specialized entities
6	Transport to the destination country	Limited access to vehicles relevant to the transported goods and weather conditions to avoid waste scattering along the roads	✓ Cooperation with professional transport entities ✓ Education and guidance to transport companies' staff on SWM ✓ Provide equipment to assure SW collection, segregation, reverse logistic or transport to HA location
7	Transport to the final destinations	SW very difficult to manage and monitor mostly in new HA's surroundings	✓ Education and guidance to transport companies' staff ✓ Equipment to assure SW collection, segregation and transport to HA location
8	Storage at the final destinations	SW is a very serious problem for short term HA's and not peaceful surroundings. Still space for improvement for long term HAs with friendly local authorities and society	✓ Open space or transport vehicle as short-term storage need to be protected to avoid organic good to be spoiled ✓ Cooperation with local authorities and business entities ✓
9	Distribution	Not very common good quality waste storage facilities and not properly constructed and protected to avoid wastes scattering around, stopping soil and water pollution	✓ Identification of local community storage facility ✓ Assure facilities to collect and segregate HA related waste ✓ Support local authorities in waste collection from households and collective feeding or dwelling locations

6.5 Recommendations for SWM in HA

It seems obvious that maintaining the uninterrupted SC in humanitarian operations is a crucial factor in providing effective aid, where the primary goal is saving lives. In that context, sustainability might seem the secondary issue. Environmental impact and sustainability criteria are not always considered as a key aspect in the procurement phase. However, it appears that the more can be done throughout the SC in context of SWM, especially at the first stages, the less amounts of waste are then left at the destination countries to be dealt with.

Throughout the research, the Bio4HUMAN project has identified several aspects (Recommendations) that can be introduced to improve the environmental impact of the HAs at different stages. They can be considered as strengthening or supporting actions to the introduction of the innovative bio-based solutions, whose identification was the primary goal of the Bio4HUMAN project.

The recommendations have been gathered under 12 categories, on the basis of SWM needs and challenges in Has presented in chapter 5.1:

- Infrastructure (G1);
- Advanced Technologies (G2);
- Intermediate Stages Representation (G3);
- Financial Resources (G4);
- Human Resources (G5);

- Policy Framework (G6);
- Strategic Planning (G7);
- Data and Monitoring (G8);
- Awareness and Education (G9);
- Coordination (G10);
- Procurement and Planning (G11);
- SWM at the End of the Supply Chain (G12).

Table 12: Recommendations for SWM in HA

(G1) Infrastructure
Develop SWM Infrastructure: Invest in sanitary landfills with liners, leachate collection, methane capture, collection systems, waste segregation and material recovery settings, recycling, and disposal systems (e.g., bins, trucks, sanitary landfills) to replace open dumping and burning, particularly in urban and camp settings.
(G2) Advanced technologies
Focus on new technologies: innovation approaches on bio-based technologies, ICT, at any SC stage. **Adopt complete innovations:** Design waste management innovations that consider the entire waste ecosystem, including local infrastructure, regulations, and community practices, to ensure sustainability and effectiveness. **Adopt eco-design principles:** Use eco-design to reduce plastic usage and promote recyclability and reuse, tailoring these solutions to the specific needs of humanitarian aid products. **Innovate with accessible tools:** Innovative tools (e.g., for planning or waste reduction) ensuring they are practical and available in the target regions.
(G3) Intermediate stage representation
Intermediate stages innovation: SWM innovation approaches in warehouses, transport and customs clearance. **Development of SWM documentation** with ICT support, including advanced routing systems for optimized waste transport.
(G4) Financial Resources
Increase funding mechanisms: Advocate for increased donor funding for SWM, including specific allocations for greening efforts, and establish sustainable financing models like higher gate fees or private sector investment to support national and HO SWM systems. **Secure innovative financing**: Apply principles like polluter-pays and lifecycle costing to fund SWM, encouraging private sector investment and donor support for sustainable infrastructure and operations. **Implement cash replacement**: Replacing physical non-food item distributions with cash or voucher systems is recommended as an efficient and effective way to deliver aid, reducing branded packaging waste while supporting local markets.
(G5) Human resources
Build technical capacity: Provide training and exchange programs for government, businesses, HOs, and communities to improve SWM expertise, focusing on segregation, recycling, and safe disposal techniques. Support establishment of professional technology and business schools. **Presentation of best practice** at all SC stages to encourage local stakeholders for participating in SWM system as a business opportunity. **Education/Awareness/Knowledge:** Educating the local population, the refugees, and the humanitarian workers in the SC stages on waste handling, separation, and its disposal.
(G6) Policy Framework
Enhance policy enforcement: Strengthen national SWM policies with clear roles, responsibilities, and enforcement mechanisms, supported by coordination platforms among government agencies and humanitarian actors.

Adopt sustainable SWM models: Implement integrated SWM, circular economy principles, and green procurement to reduce waste and enhance sustainability, tailoring approaches to local contexts and needs.
Implement waste management standards: Humanitarian organizations should align with standards like the Climate Charter, Sphere, CHS, and donor requirements (e.g., DG ECHO's MERS) to systematically manage waste and minimize environmental impact.

(G7) Strategic Planning

Prioritize SWM in HOs: Integrate SWM into all humanitarian sectors (beyond WASH) with dedicated policies, planning frameworks, and trained personnel to elevate its priority and ensure accountability.
Promote sustainable SWM models: Integrate SWM hierarchy, circular economy principles, and green procurement into HO policies, focusing on waste reduction, resource efficiency, and eco-friendly materials.
Leverage opportunities: Prioritize waste prevention and minimization, establish formal reuse and recycling systems, and develop waste-to-resource models (e.g., composting, biogas) with stakeholder collaboration and private sector funding.
Identification of needs stage should be analysed in detail: There was lack of information regarding Identification of Needs related to all provided columns of SC stages analysis.
Mitigate risks: Address health, environmental, and social risks through targeted waste management strategies such as segregation and safe disposal.

(G8) Data and Monitoring

Improve data collection and monitoring: Develop standardized methods for measuring and reporting waste (e.g., waste audits, characterization exercises) to support planning and resource allocation.
Enhance digitalization and data use: Implement tools like IoT sensors, GPS tracking, and waste mapping (e.g., WREC's facilities mapping[11] to monitor waste streams, optimize collection, and inform SWM strategies.
Need to analyze in detail at operational logistic at final destination stage. In most analyze cases it was no information related with: Implementing entity, Key SWM supporting elements, Tools and technologies used in HAs.
Digital tools implementation: Use of IoT sensors in Zaatari camp and GPS-enabled vehicles in Kabul optimize waste collection, while platforms like Banyan Nation (India) connect collectors and recyclers efficiently.

(G9) Awareness and education

Raise awareness and capacity: Educate communities and HOs on SWM benefits and practices (e.g., composting, reuse) to increase participation, alongside building local government and private sector capacity.
Increase community engagement: Launch sensitization campaigns in radio, local leaders, and schools to raise awareness, change behaviours, and encourage waste segregation and responsibility at the household level.
Develop change of mindset: Educate local suppliers and NGO staff about the environmental impact of non-sustainable practices to foster a more responsible approach to waste management
Use published guidance: Humanitarian organizations should utilize available guides[12] to better understand and manage waste, develop SWM plans, and allocate resources effectively.

(G10) Coordination

Strengthen stakeholder collaboration: Establish coordination platforms involving governments, HOs, private sector, informal waste pickers, and academia to pool resources, share knowledge, and align efforts.
Enhance collaboration between HO: Encourage cooperation between the "identification of needs" team and the "planning team" within NGOs to minimize downstream waste in the SC.

[11] https://logie.logcluster.org/?op=wrec
[12] "Waste or Material Characterization Exercise Guidance" (published June 2024 by WREC)

Promote reverse logistics: Encourage returning, donating or reselling packaging waste to suppliers or local entities to keep materials in circulation and reduce disposal burdens. **Engage local stakeholders:** Collaborate with qualified local suppliers and recyclers, building their capacity to meet international standards, and integrate informal sector efforts into formal SWM systems.
(G11) Procurement and Planning
Focus on upstream solutions: Address waste and sustainability issues at the earliest stages of the SC (e.g., needs identification and planning) to mitigate downstream challenges. **Promote sustainable procurement:** Train HOs on green procurement practices, screen suppliers for environmental standards, and conduct life-cycle assessments to reduce waste from relief items, favouring local sourcing where feasible. **Prioritize local procurement:** Purchase products from local suppliers whenever possible to reduce waste and support local economies, shifting to regional or international suppliers only when necessary due to availability or cost constraints. **Incorporate sustainable criteria early:** Integrate sustainability into the initial stages of the SC (e.g., product selection and packaging) since later stages are harder to control, especially in challenging environments. **Adopt waste hierarchy practices:** Prioritize waste prevention and reduction at the source (e.g., through green procurement and bulk packaging), followed by reuse, recycling, and safe disposal to transition toward zero-waste systems.
(G12) SWM at the end of SC
Bio-Based Solutions: Local practices like; composting organic waste into fertilizer, producing biogas, and transforming waste into briquettes or animal feed (e.g., by NGOs and local actors in the DRC and South Sudan) offer sustainable waste management options. **Strengthen local systems:** Invest or support investment in urban and at HA location waste collection infrastructure, establish safe landfills, and support private sector and informal waste pickers to enhance recycling and reuse capacities. **Enhance waste quantification:** Implement standardized methodologies (e.g., WREC's waste audits) and allocate resources for consistent data collection to better categorize and quantify humanitarian and general waste. **Support implementation of specific waste treatment methods:** Different types of waste require tailored disposal methods, such as composting or anaerobic digestion for organic waste, recycling programs for plastics and metals, and incineration or specialized facilities for hazardous waste like medical or chemical waste. **Support creation of specialized environmental NGOs:** Establish organizations focused specifically on environmental control to address waste management issues that general NGOs overlook.

6.6 Implementation

Practical implementation of each of the listed actions, as well as numerous actions simultaneously in HOs, is a very serious challenge for several key reasons, such as: time and location discrepancies between the place of HA and donors, suppliers, supporters of the action, and in addition the very location of the HA often severely hampered by climatic conditions, lack of basic security or limitations in access to basic utilities. Despite so many variables and unexpected constraints appearing during humanitarian action, many solutions for SWM, if well planned and implemented at the stage of needs identification and planning, can significantly reduce the side effects of such actions, which are very often poorly or not managed waste.

As a rule, the implementation of waste management solutions should take into account environmental concerns, the protection of the climate and the absence of harmful effects on the health of residents of the region affected by the HA. Where investment activities will be involved, requiring adequate infrastructure, financial outlays and competent staff, the report on bio-based solutions also describes the challenges that humanitarian organizations or any investor will have to face to address the topic of SWM on a wider scale.

Challenges to be addressed when investing in bio–based solutions in humanitarian settings:

- **Economic viability:** difficulty in creating sustainable business models, limited markets for end products, competition non-sustainable alternatives;
- **Operational challenges:** integrating new solutions into existing practices, ensuring consistent waste separation at source, managing odors and pests associated with organic waste processing;
- **Knowledge gaps:** lack of local expertise in bio-based techniques, limited data on long-term effectiveness of SWM practices in humanitarian contexts;
- **Logistical issues:** difficulties in transporting necessary equipment or materials to the location, challenges in establishing reliable SC, managing periodical and seasonal variations in waste composition and volume;
- **Social and cultural barriers:** resistance to waste handling or separating, lack of community buy-in or participation, cultural taboos related to waste or waste products;
- **Regulatory hurdles:** navigating complex or unclear regulations in host countries obtaining necessary permits for waste processing activities.

6.7 Continuous improvement techniques

To monitor and evaluate progress in the implementation of new solutions, it is first necessary to introduce the collection of a wide spectrum of data and its adequate processing. The broad list of proposed actions also includes several necessary IT solutions for the products themselves (IoT) or transport and logistics, but also standardization and preparation of personnel both from humanitarian organizations and local communities affected by such actions. Considering the scope of the action and its duration (long-term actions predominate), it would be advisable to systematically implement procedures, processes and investments in the subsequent stages/years of their implementation, which reduce or eliminate the scope of risks resulting from improper waste management.

To better illustrate the issues that should be addressed for good monitoring of ongoing changes and correct planning of subsequent implementations, below is a list of key questions, the answers to which should be reviewed and analyzed annually and form the basis for decisions on further actions.

1. What type of activities take place at each stage of HA's SC, considering operational logistics, tools and techniques provided by supporting logistics?

2. What groups and amounts of SW are produced at each stage of SC, in connection to operational and supporting logistics used for its implementation?
3. What can be done by HOs, along with the SC supporting entities, to improve and finally ensure SWM, including related data collection?
4. What should be changed in the management of SC in the short, medium and long term to enable the concentration and segregation of waste in a selected location?
5. What can be the new systemic solutions - mainly organizational and logistic - optimizing the current SC and SWM?
6. What kind of solutions and technologies are used for SWM and which one of them has the biggest potential for improvement?
7. Is there a market for the products created/produced after disposal or using SW as a raw material to produce new products?

Additionally, when it is a need for investment in bio-based solutions, the expectations of the humanitarian sector, are (D4.1.): sustainable to the stage of SC, type of waste and location, address environmental, economic, and social factors, utilize local resources, adaptable to local conditions, have the possibility of empowering local communities, and provide long-term benefits without unintended negative consequences.

6.8 Communication and collaboration among team members and stakeholders

Effective SWM in HAs requires significant communication and collaboration among HOs, team members, and diverse stakeholders across the SC. This chapter outlines a simplified communication and dissemination plan to ensure that action plans are effectively shared with all partners, fostering coordinated efforts, raising awareness, and building capacity to address waste management challenges. The plan emphasizes stakeholder engagement, streamlined information flow, and tailored dissemination strategies to align with local contexts and operational needs.

Table 13: Key objectives and principles of the Communication and Dissemination Plan

Key Objectives	
Enhance Stakeholder Coordination	Facilitate collaboration among HOs, governments, private sector actors, informal waste pickers, local communities, and other partners to pool resources and align efforts.
Raise Awareness	Educate all SC actors — HO staff, beneficiaries, local suppliers, and communities — on SWM practices, benefits, and responsibilities to improve participation and reduce environmental risks.
Strengthen Organizational Integration	Ensure SWM action plans are embedded within HOs operational frameworks and communicated across all SC stages, from needs identification to final distribution.
Support Local Engagement	Leverage local knowledge, capacities, and market actors to tailor communication strategies and enhance the relevance of SWM initiatives.

Key Principles	
Clarity and Simplicity	Use accessible language and formats to ensure all partners, regardless of technical expertise, can understand and act on the plans.
Context-Specific Adaptation	Tailor communication methods to local socio-cultural, logistical, and crisis-specific factors.
Inclusivity	Engage all relevant actors, including often-overlooked groups like informal waste pickers and local communities.
Two-Way Communication	Encourage feedback to refine action plans and address gaps collaboratively.

Table 14: Communication and Dissemination Plan

Stage	Action	Description
1. Stakeholder Identification	Establish a stakeholder mapping exercise at the onset of each humanitarian operation, using coordination platforms, to assign responsibilities and communication channels.	**HOs and Internal Teams:** Responsible for integrating SWM into policies and operations, training staff, and monitoring progress. **Local Authorities:** Enforce SWM policies and collaborate on infrastructure development. **Private Sector and Suppliers:** Adopt sustainable packaging and participate in reverse logistics. **Informal Sector:** Support recycling and waste collection efforts. **Communities and Beneficiaries:** Participate in waste segregation and reuse practices. **Donors and Academia:** Fund initiatives and provide research or innovative solutions.
2. Communication Channels and Tools	Select communication channels based on local infrastructure and stakeholder preferences, ensuring redundancy (e.g., radio + workshops) in crisis-affected areas.	**Coordination Platforms:** Create joint committees or platforms (e.g., Juba stakeholder committee,) for regular meetings among HOs, governments, and private actors to share updates and align strategies. **Training Workshops:** Conduct in-person or virtual sessions for HO staff, local suppliers, and community leaders on SWM practices, leveraging existing guidelines like WREC's Waste Characterization Exercise. **Sensitization Campaigns:** Use radio, local leaders, and schools to raise community awareness, focusing on segregation and health benefits. **Digital Tools:** Where possible, deploy accessible technologies like WREC's facilities mapping or mobile apps to share real-time waste data and plans with stakeholders who have connectivity. **Printed Materials:** Distribute simple guides or posters in local languages outlining action plans (e.g., waste hierarchy) for areas with limited digital access.
3. Key Messages	Develop message templates that can be customized per context, ensuring alignment with best practices like the waste hierarchy and green procurement	**For HOs:** Integrate SWM into all SC stages and collaborate with local partners to reduce waste and meet donor standards. **For Local Authorities:** Strengthen policy enforcement and coordinate with HOs to build sustainable SWM systems.

		For Suppliers: Adopt eco-friendly packaging and engage in reverse logistics to support circular economies. **For Communities:** Segregate waste at the source and reuse materials to protect health and the environment. **For Donors:** Increase funding for SWM to enable innovative and sustainable solutions.
4. Timeline	Assign a communication lead within each HO to oversee the timeline and ensure consistent messaging	**Pre-Operation Phase (Needs Identification & Planning):** Share SWM goals and initial plans with HOs and planning teams to prioritize upstream waste reduction. **Procurement Phase:** Communicate sustainable procurement criteria to suppliers and HOs via tenders and workshops. **Implementation Phase:** Launch awareness campaigns and activate coordination platforms as aid distribution begins. **Ongoing Operations:** Provide monthly updates via digital tools or meetings, incorporating feedback and waste data. **Post-Operation Phase:** Disseminate lessons learned and best practices to stakeholders for future operations.
5. Monitoring and Feedback	Train personnel on data collection and establish a feedback loop to address gaps, such as those in intermediate supply chain stages	**Data Sharing:** Use standardized waste audits to report progress to stakeholders, fostering transparency. **Feedback Channels:** Set up suggestion boxes, community forums, or digital surveys (where feasible) to gather input from partners and beneficiaries. **Adjustment Process:** Review feedback quarterly during coordination meetings to refine action plans.

This communication and dissemination plan provides a practical framework to bridge gaps in collaboration and awareness among humanitarian actors and stakeholders. By leveraging existing recommendations and best practices, it ensures that SWM action plans are not only communicated effectively but also adapted to the unique challenges of HSC . Implementing this plan will require commitment from HOs, flexibility to local contexts, and ongoing refinement based on stakeholder feedback.

7. Conclusions

The "Gap Analysis Report" provides a comprehensive framework for addressing SWM challenges within humanitarian contexts, with actionable insights. The conclusions drawn from this report are shown below.

7.1 Current state of SWM in HA

SWM in HSC is currently underdeveloped, marked by data deficiencies, a focus on operational efficiency over sustainability, and limited technological adoption. Addressing these challenges requires a holistic approach that integrates

environmental considerations into every stage of the supply chain, fosters collaboration across teams and sectors, and adapts solutions to the realities of humanitarian contexts. The current state can be characterized by following:

1. Limited data regarding SWM across supply chain stages - This lack of documentation suggests that SWM is not systematically monitored or prioritized, limiting the ability to develop evidence-based strategies for waste reduction and management.
2. Waste generated from logistic is crucial – There is a need for greater collaboration between needs identification and planning teams to mitigate downstream waste impacts.
3. Prioritization of aid delivery over sustainability - The operational efficiency over environmental responsibility reflects a broader HOs mindset, where waste management is seen as a secondary issue
4. Planning and Procurement challenges and opportunities – Planning and Procurement stages does not generate lots of waste itself but has critical influence on next stages. The early-stages decisions could have a crucial role in reducing overall waste.
5. Technological and logistical gaps – There are number areas of HA interventions in which advanced technology and tools are being used. However, those tools along with bio-based solutions are not explored enough or used on a larger scale. It is followed by logistical challenges, including changing regulations and poor infrastructure, which impacts the effective waste management.

7.2 Desired state of SWM in HA

The desired state of SWM in HSC is a holistic, sustainable ecosystem where waste is minimized, resources are reused, and environmental impacts are mitigated across all stages. It addresses current shortcomings through ecodesign, infrastructure, advanced technologies, stakeholder collaboration, and sufficient funding. By integrating best practices and innovative bio-based solutions, this vision aligns humanitarian objectives with environmental security, ensuring aid delivery enhances rather than degrades the ecosystems of crisis-affected regions. The desired state seeks to address current deficiencies while introducing innovative bio-based solutions and best practices to improve SWM system across all 9 supply chain stages. Those are key conclusions on what the desired state should be based upon:

- **Design for recycling, repair, and reuse**
- **Sufficient and adequate waste management systems and infrastructure**
- **Effective SW Treatment and disposal methods**
- **Sustainable SC and procurement optimization**
- **Stakeholder collaboration and capacity building**
- **Sufficient funding**
- **Integration of innovative bio-based solutions**

7.3 Identification of gaps for SWM in humanitarian contexts

Based on the performed research **12 crucial gaps** were identified and prioritized by assessing **with 6 dimensions.**
The analysis showed that **the most critical gaps are related to "Insufficient financial resources" and "Lack of coordination among facilities".** These gaps highlight their significant impact on operations due to limited resources, high financial dependency, and insufficient relationships between facilities throughout the supply chain. **Following is "Weak policy framework and reinforcement"** which highlights coordination challenges and the need to involve local governments and institutions to strengthen policy alignment and enforcement.

Dimension wise, **“Supply chain efficiency” and “Environmental sustainability” emerge as the most critical categories.** This indicates that inefficiencies in the supply chain and misalignment in policies are major obstacles affecting the environmental performance.

7.4 SWM needs and challenges at each stage of SC in HA’S

Regarding **the gaps in supply chain stages**, the analysis revealed a pattern of **moderate to significant gaps (ratings of 3–4) across all supply chain stages.** The most **critical deficiencies visible in intermediate and final stages (e.g., warehousing, transport, and storage).** These gaps are driven by limited infrastructure, inadequate technology adoption, and insufficient planning and monitoring capacity tailored to SWM. The current state heavily relies on informal and localized solutions, while the desired state demands systematic, sustainable, and bio-based approaches integrated throughout the supply chain. Addressing these gaps requires targeted investments in infrastructure, training, and policy alignment to enhance SWM effectiveness and reduce environmental impact in humanitarian operations.

7.5 Bridging the gaps/areas for improvements

The below mentioned points identify what has to be done in order to address the gaps and bridge them to increase the possibility of reaching the desired state:
Bridging the gaps in SW treatment

- Effective SW treatment in humanitarian settings requires technologies and solutions that are scalable, mobile, and independent of extensive infrastructure.
- There is a need to prioritize containerized or autonomous waste treatment units that can be easily transported and deployed, with independent power supplies to operate in crisis-affected areas with limited resources.
- The final products of waste disposal—such as compost, biogas, or recyclable materials—should be designed for local or regional use, ensuring easy storage and transport without reliance on distant markets.

Actions supporting SWM in Humanitarian Actions

- Improving waste management infrastructure (e.g., expanding collection points and constructing sanitary landfills) and adopting advanced bio-based

technologies (e.g., composting, anaerobic digestion) are crucial for sustainable SWM.

- Financial and human resource constraints can be mitigated by securing donor funding, implementing income-generating waste-to-resource models, and providing targeted training for local staff and communities.
- Policy enforcement must be strengthened through clear roles and coordination platforms
- Data collection must be supported by using tools like IoT sensors and waste audits is essential for informed decision-making.
- Community awareness campaigns and stakeholder collaboration platforms are also critical to ensure buy-in and operational success.
- Tailored interventions at each of the nine stages of supply chain are essential to minimize waste generation and enhance management.

Supporting actions at each stage of the supply chain

- There is a need for dedicated SWM staff and ICT tools during needs identification to embed sustainability early, alongside sustainable procurement criteria at the sourcing stage.
- Warehousing and transport stages require standardized storage facilities, modular packaging, and cooperation with professional entities to reduce waste scattering and enable reverse logistics.
- At the final distribution stage, collaboration with local authorities and communities is vital to establish segregated waste collection systems.
- The stage-specific actions emphasize upstream planning and downstream coordination, ensuring that SWM is integrated throughout the supply chain rather than addressed reactively at the endpoint.
- Prioritizing SWM at the initial stages of the supply chain (e.g., needs identification and planning) can substantially reduce downstream waste, aligning with the Bio4HUMAN project's mission to deploy bio-based solutions for sustainable humanitarian aid.