BIO4HUMAN

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Contents

List of acronyms

Acronym	Full meaning
BSF	Black Soldier Fly
DG ECHO	Directorate-General for European Civil Protection and Humanitarian Aid Operations
DRC	Democratic Republic of Congo
EPR	Extended Producer Responsibility obligations
EU	European Union
HO	Humanitarian Organizations
INGO	International Non-Government Organisation
JI	Joint Initiative
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
MERS	Minimum Environmental Requirements
NFI	Non-food item
NGO	Non-Government Organisation
PLA	Polylactic acid
PPWR	EU Packaging and Packaging Waste Regulation
R&D	Research & Development
RUTF	Ready-to-use therapeutic food
S-LCA	Social Life Cycle Assessment
UN	United Nations
UNEP	United Nations Environment Programme Guidelines
UNICEF	United Nations Children's Fund
WASH	Water, sanitation and hygiene
WHO	World Health Organisation
WREC	Waste Management and Measuring, Reverse Logistics, Environmentally Sustainable Procurement and Transport, and Circular Economy

1. Executive Summary

The humanitarian sector's operations generate significant volumes of solid waste, including packaging, medical supplies, and single-use products. Very often, this happens in contexts where the waste management infrastructure is minimal or non-existent. Global solid waste generation reached approximately 2.24 billion tonnes in 2020, corresponding to an average of 0.79 kilograms per person per day, according to the World Bank. The United Nations Environment Programme (UNEP) reports that

around 11.2 billion tonnes of solid waste are collected annually worldwide, with the degradation of its organic fraction accounting for roughly 5% of global greenhouse gas emissions. Projections indicate that, driven by population growth and increasing urbanisation, total annual waste generation could rise by 73%, reaching 3.88 billion tonnes by 2050.[1] In the "Humanitarian sector needs assessment report" (D3.3.) most needs assessment respondents found it difficult to distinguish between humanitarian and general waste, as all of them end up mixed together in the same places once they enter the waste stream and start to decay. Packaging baseline from 2023 developed by the Joint Initiative (JI)[2] represents the only study, found by the consortium, providing comprehensive global data on packaging quantities within the humanitarian sector. The assessment compiled data from humanitarian organisations (HOs) covering the procurement of 6.77 million metric tons of goods in 2021, including 6.73 million metric tons of food and 36,000 metric tons of non-food items (NFIs). Based on this dataset, JI estimated that these volumes required approximately 33,000 metric tons of primary packaging and 35,600 metric tons of secondary packaging.

One of the surveys, conducted under this project, with humanitarian organizations asking about types of waste produced by them showed that out of 13 types, the main declared were: organic, packaging, sanitation, construction and plastic. Available quantitative research on both the volume and composition of waste specifically for humanitarian waste is still limited. During interviews with stakeholders the most often mentioned type of humanitarian items and packaging in the research locations was, not surprisingly, plastic. Although, according to the available secondary data analysis by quantity it is not necessarily the type of waste in the region that has the biggest volume (biggest being organic waste),[3] nor it is the main humanitarian packaging material (main being cardboard)[4] it is the one that all stakeholders were mentioning as it is ubiquitous, has significant impact, stays in the environment and does not disappear. As a result, communities that are already affected by crises bear further consequences, as waste can negatively influence human health, degrade the environment, damage agricultural soil, kill livestock, pollute and block waterways.

The use of bio-based solutions – products being wholly or partly derived from materials of biological origin, as well as technologies that convert organic waste into

[1] World Bank. (2021). Bridging the gap in solid waste management: Governance requirements for results (p.5). © World Bank, Washington, DC. Retrieved from http://hdl.handle.net/10986/35703. License: CC BY 3.0 IGO.

[2] Joint Initiative for Sustainable Humanitarian Assistance Packaging Waste Management. (2023). Packaging Baseline Assessment Based on Humanitarian Emergency Responses 2021-May 2023. Retrieved from https://reliefweb.int/report/world/joint-initiative-sustainable-humanitarianassistance-packaging-waste-management-packaging-baseline-assessment-based-humanitarianemergency-responses-2021-may-2023.

[3] UNEP. (2018). Africa Waste Management Outlook (p. 26). United Nations Environment Programme. Retrieved from https://www.unep.org/ietc/resources/publication/africa-waste-management-outlook

[4] https://reliefweb.int/report/world/joint-initiative-sustainable-humanitarian-assistance-packaging-waste-management-packaging-baseline-assessment-based-humanitarian-emergency-responses-2021-may-2023

useful resources – can help mitigate this impact. However, the adoption of bio-based solution depends not only on technical feasibility, but also knowledge, awareness, economic viability, acceptance from communities, regulatory compliance, and alignment with the global humanitarian and donor standards.

This brief presents findings and recommendations from the Bio4HUMAN research project, which assessed the potential for the application of 10 bio-based solutions in the humanitarian context. The research included humanitarian needs assessment regarding types of waste contribution and waste management, identification of the best available innovative bio-based solutions, environmental life cycle assessment (LCA), life cycle costing (LCC), social life cycle assessment (S-LCA), governance analysis, stakeholders and community engagement in the Democratic Republic of Congo (DRC) and South Sudan. To do so, the project consortium combined the expertise of bio-based industry actors, circular and bioeconomy experts, academic institutions, and humanitarian organisations.

Core message: Bio-based solutions can support the reduction of the environmental footprint of humanitarian operations, particularly plastic waste, but their effectiveness depends on adaptation of products to context specific conditions including biodegradability conditions of proposed solutions, financing mechanisms, donor priorities and system-level conditions – especially country level end-of-life infrastructure adaptation to the products' biodegradability conditions, procurement rules, and regulatory support. Without coordinated action across these areas, with all actors involved (community, government, humanitarian organisations, EU institutions, bio-based sectors' representatives), their impact will remain limited.

Key Policy Messages:

1. **Introduction of bio-based packaging would have a minor impact on total humanitarian kit costs.** Replacing conventional packaging with bio-based alternatives results in only marginal increases in total humanitarian kit costs, as packaging represents a small share of overall expenditure. This creates a clear opportunity for donors and humanitarian organisations to integrate sustainability criteria into procurement without significantly increasing budgets. There were also products for which no increase was recorded comparing to conventional options. For further information, please see chapter on Life Cycle Costing in "Socio-economic and governance aspects analysis report" (D6.1.).
2. **Community acceptance is conditional on context and experience.** Communities are generally supportive of reducing non-biodegradable waste, but acceptance depends on familiarity, usability, cost, and alignment with existing practices. Solutions with proven track records (e.g. biogas, Black Soldier Fly (BSF) systems) show higher acceptance, while newer materials require piloting, demonstrations, and adaptation to local needs. For further information please see "Community engagement summary report" (D6.2). Technologies like biogas and BSF have both proven track record of implementation and community's demand in both South Sudan and the DRC.

3. **Environmental benefits depend on manufacturing and end-of-life management.**
   Bio-based and biodegradable products do not automatically deliver environmental benefits in contexts without waste collection, composting, or treatment infrastructure. Investments in waste management systems, composting solutions, and community awareness are essential to ensure that bio-based materials perform better than conventional plastics in practice. In humanitarian context it is highly unlikely for ideal end-of-life conditions; while designing or choosing a solution it is important to cross check the overall waste management context and adapt. Overall manufacturing impact for bio-based products can be at times higher than fossil-based products. The bioeconomy sector is still under development; therefore, it is possible that the manufacturing impacts of those products are reduced over the years. The correct solid waste management and fit for context solutions will allow the bio-based product to become a «better solution».
4. **Regulatory and policy frameworks either do not exist or are not enforced in the assessed countries.** Neither the DRC nor South Sudan currently has dedicated regulations for bio-based materials or compostable packaging. In practice, humanitarian and donor standards often function as the *de facto* regulatory framework for humanitarian actors, positioning donor policy as a powerful force for change.
5. **Incentives combined with donor-driven standards are critical to enable the environment for adoption and scaling.** While bio-based alternatives may have sometimes limited impact on unit-level costs, their adoption requires upfront investment in production capacity, waste management infrastructure, and market development. In both the DRC and South Sudan, limited access to finance for local enterprises, combined with constrained humanitarian budgeting and procurement structures, limits the potential for scaling. Targeted financial mechanisms—such as donor incentives, blended finance, tax exemptions, and support for local production—will be essential to bridge the gap between pilot implementation and sustainable market development.
6. **Procurement systems are the key leverage point.** Humanitarian procurement rules, donor requirements, and approved supplier lists largely determine what products can be used in operations. Without integrating bio-based alternatives into global procurement frameworks, cluster standards, and donor guidelines, adoption at field level will remain extremely limited — regardless of local demand or availability.
7. **The humanitarian sector remains unexplored as a market by the bio-based industry.** The bio-based sector does not currently target humanitarian operations as a potential market, while humanitarian sector lacks awareness of available solutions and potential. Bridging this gap requires continued global dialogue between these sectors, as well as dedicated pilot programmes and cross sectoral platforms to demonstrate feasibility, meeting required standards and impact. Bio-based packaging substitutions and

solutions could use HOs as a niche entry points before wholesale market replacement.

2. Why This Matters

Solid Waste Management in Humanitarian Settings

A substantial volume of solid waste is being generate each year as a result of humanitarian assistance. Global solid waste generation reached approximately 2.24 billion tonnes in 2020, corresponding to an average of 0.79 kilograms per person per day, according to the World Bank. UNEP reports that around 11.2 billion tonnes of solid waste are collected annually worldwide, with the degradation of its organic fraction accounting for roughly 5% of global greenhouse gas emissions. Projections indicate that, driven by population growth and increasing urbanisation, total annual waste generation could rise by 73%, reaching 3.88 billion tonnes by 2050.[5]

In the "Humanitarian sector needs assessment report" (D3.3), most needs assessment respondents found it difficult to distinguish between humanitarian and general waste, as all of them end up mixed together in the same places once they enter the waste stream and start to decay. Packaging baseline from 2023 developed by the Joint Initiative (JI)[6] represents the only study, found by the consortium, providing comprehensive global data on packaging quantities within the humanitarian sector. The assessment compiled data from humanitarian organisations covering the procurement of 6.77 million metric tons of goods in 2021, including 6.73 million metric tons of food and 36,000 metric tons of NFIs. Based on this dataset, JI estimated that these volumes required approximately 33,000 metric tons of primary packaging and 35,600 metric tons of secondary packaging. This can range from packaging of relief items, single-use medical supplies, ready-to-use therapeutic food (RUTF) sachets, plastic bottles, sanitary pads, and logistics materials such as adhesive tape and protective wrapping.

In contexts with little or no formal waste management infrastructure, such as the DRC and South Sudan, this waste frequently accumulates in communities, agricultural land, and waterways, where it is typically managed through open dumping or uncontrolled burning. This creates serious environmental and public health risks, including pollution, soil degradation, and harm to livestock and water systems.

[5] World Bank. (2021). Bridging the gap in solid waste management: Governance requirements for results (p.5). © World Bank, Washington, DC. Retrieved from http://hdl.handle.net/10986/35703. License: CC BY 3.0 IGO.

[6] Joint Initiative for Sustainable Humanitarian Assistance Packaging Waste Management. (2023). Packaging Baseline Assessment Based on Humanitarian Emergency Responses 2021-May 2023. Retrieved from https://reliefweb.int/report/world/joint-initiative-sustainable-humanitarianassistance-packaging-waste-management-packaging-baseline-assessment-based-humanitarianemergency-responses-2021-may-2023.

The international humanitarian sector is increasingly recognising the environmental impact of its operations. Since the launch of the *Climate and Environment Charter for Humanitarian Organizations* in 2021,[7] more than 400 organizations (together with donors, relevant government agencies and foundations) have committed to reducing their environmental footprint. Moreover, the Waste Management and Measuring, Reverse Logistics, Environmentally Sustainable Procurement and Transport, and Circular Economy (WREC) survey conducted in 2022 confirmed that 82% of humanitarian organizations were assessing the environmental impacts of their logistics, while 44% identified green procurement as the most relevant area for reducing those impacts.[8] At the policy level, the Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG ECHO) has introduced Minimum Environmental Requirements (MERS, 2022), [9] making environmental impact assessment and mitigation mandatory for EU-funded actions. More recent developments (2023–2025) further indicate a shift from voluntary commitments toward more structured and enforceable approaches. Initiatives such as the Common Donor Priority Actions for Greening Humanitarian Assistance (2025)[10], the continued operationalisation of DG ECHO's Minimum Environmental Requirements (MERS), the Environmental Mainstreaming in Humanitarian Action: Lessons Learned report (2025)[11], and expanded implementation guidance under the Climate and Environment Charter for Humanitarian Organizations[12] reflect growing expectations for standardisation, particularly in procurement, environmental impact assessment, and supply chain management.

Despite this progress, **solid waste management remains a critical gap**. It falls outside the traditional mandates of most humanitarian actors and is often underfunded and under-prioritised. As a result, it has been identified as a key gap in humanitarian water, sanitation and hygiene (WASH) programming, including as one of four major cross-cutting problem areas highlighted in the 2021 Global WASH Gap Analysis.[13] At the same time, it is often overlooked, and the funding for it is not adequate. A 2023 WREC survey found that only 28% of humanitarian organizations have a solid waste management planning framework in place, and just 9% have mechanisms to measure waste volumes. This highlights that the gap is not only infrastructural, but also in basic organisational preparedness.

[7] Climate and Environment Charter for Humanitarian Organizations. (2021). *Climate and Environment Charter for Humanitarian Organizations*. Retrieved from https://www.climate-charter.org
[8] WREC. (2022). *Baseline Survey Results on Environmental Sustainability in Humanitarian Supply Chains*. Retrieved from https://logcluster.org/en/document/wrec-baseline-survey-results
[9] European Commission, Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG ECHO). (2022). *Minimum Environmental Requirements (MERS) for EU-funded humanitarian assistance*. Retrieved from https://civil-protection-humanitarian-aid.ec.europa.eu
[10] European Commission, DG ECHO et al. (2025). *Common Donor Priority Actions for Greening Humanitarian Assistance*. Retrieved from https://civil-protection-humanitarian-aid.ec.europa.eu
[11] DG ECHO. (2025). *Environmental Mainstreaming in Humanitarian Action: Lessons Learned*. Retrieved from https://www.environnementhumanitaire.org
[12] Climate and Environment Charter for Humanitarian Organizations. (2024–2025). *Implementation guidance and priority actions*. Retrieved from https://www.climate-charter.org
[13] Oxfam, Global WASH Cluster, and Elrha. (2021). *WASH Gap Analysis: Key findings and discussion note*.

Why Bio-Based Solutions are Being Considered

Bio-based solutions are gaining attention in humanitarian programmes in response to the growing volume of waste generated and the limited capacity for sustainable waste management in humanitarian contexts. Conventional plastic products frequently accumulate in the environment for long periods due to the absence of effective collection, recycling, or disposal systems, leading to long-term environmental and public health impacts.

Bio-based approaches offer two complementary pathways. First, **bio-based products,** such as biodegradable packaging, compostable sachets, and polylactic acid (PLA) bottles, can reduce the accumulation of persistent plastic waste. Second, **bio-based technologies**, including biogas digesters and BSF systems, can convert organic waste into useful resources such as cooking fuel, animal feed, and fertiliser substitutes, contributing to both waste management and local livelihoods.

However, the adoption of these solutions is not straightforward. Their performance depends heavily on local conditions, including waste management infrastructure, market availability, regulatory frameworks, and community acceptance. At present, there is **limited evidence on how bio-based solutions perform in real humanitarian settings**, particularly in low-infrastructure environments.

In the "Hotspot analysis of the current and innovative solutions" (D5.2), the consortium also examined geographical availability by analysing the impact of local energy mixes in the DRC and South Sudan, with the aim of identifying both the benefits and constraints associated with it. It has also incorporated considerations related to waste collection at the end-of-life stage, alongside an illustrative criticality assessment that compares a bio-based material with its fossil-based counterpart.

The Bio4HUMAN project was designed to address limited bio-based solutions in humanitarian settings evidence gap by assessing the environmental, economic, social, and governance dimensions of bio-based solutions scoped by the project in the DRC and South Sudan, to inform policy and practice.

Who Should Read This Brief

This brief is intended for four key audiences: First, **EU and international policymakers** who shape and decide on humanitarian funding priorities, environmental policy frameworks and the strategical development paths of the bioeconomy sectors; then, **humanitarian organisations and donors, responsible** for programming and procurement decisions at global and country levels. The third group includes **national and local policymakers** in countries that are recipients of humanitarian assistance, whose regulatory frameworks and policy choices influence the feasibility and sustainability of the deployment of bio-based solutions. Finally, the last group composes of individual actors in the **bio-based sector**, including businesses, producers, innovators, and researchers, who have the potential to ideate, develop, adapt, and supply solutions for humanitarian contexts.

3. What the Research Shows in the DRC and South Sudan

The Bio4HUMAN project has been examining ten different bio-based options to meet the following criteria: environmental LCA, LCC, S-LCA, governance and community engagement in South Sudan and the DRC. The results of these assessments are described below.

3.1 Stakeholder Perspectives and Acceptance

The community engagement study, based on interviews and discussions with 77 different stakeholders (community, humanitarian actors (donors, non-government organisations (NGOs), UN agencies), academia, businesses, national and local governments) across the two countries, shows that the level of acceptance of bio-based solutions depends on how well those solutions are known, understood, fit into community practice and economics, as well as what are considered high priority issues by the questioned community. The study focused on humanitarian use, but often stakeholders were considering the bio-based solution in much broader sense, giving examples of an individual consumer and general market context. Generally, all stakeholders were supportive of the idea to eliminate non-biodegradable waste, and they were recognizing significant waste problem in their respective countries.

Prior experience matters more than theoretical explanation. Solutions with existing operational precedents (e.g. biogas and BSF) had the strongest engagement from stakeholders. In South Sudan, Kaku Sanitation Services runs a commercial bio-digester business across seven or more locations; in the DRC, multiple BSF units operate through cooperatives, research partnerships, and enterprises. At the same time, for solutions that were less familiar to stakeholders, such as mycelium packaging and biodegradable laminating film, participants highlighted that the abstract descriptions thereof are insufficient. They expressed a clear preference for physical samples, demonstrations, and pilot programmes before their implementation.

Knowledge and understanding of the solutions are crucial for the community buy-in. Most of the stakeholders were supportive of integrating presented examples of bio-based solutions, but many raised questions and concerns around different aspects – safety, economy, functionality, availability, durability, knowledge of usage and disposal of presented solutions. Piloting could prove the theoretical feasibility of the proposed solutions and support managing some of the concerns and misconceptions. Awareness, knowledge sharing and building the local capacities are the crucial aspects to introduce any of the proposed solutions.

Proposed bio-based solutions may not match community preferences. This aspect is very context- and item-specific, and proper testing and feedback analysis is needed for each item. One of the examples are sanitary pads. While there is a clear need for better menstrual hygiene products for communities in South Sudan and the DRC, many of the stakeholders interviewed preferred reusable sanitary pads due to economic reasons over the disposable biodegradable sanitary pads that were

proposed. Likewise, many stakeholders evaluated PLA bottles having in mind general consumer market. This understanding generated concerns that were not applicable to humanitarian use cases.

Targeted applications offer more realistic entry points than attempting to replace entire markets with bio-based alternatives. Many humanitarian stakeholders indicated that while certain solutions addressed their specific operational needs, they saw little opportunity to widely adopt them due to lack of familiarity with them**.** Examples of promising niche applications include compostable RUTF (sachets used to keep food for children to prevent and treat malnutrition) sachets eliminating the ineffective return systems; PLA bottles providing a means to package single-use medical liquids that are currently being incinerated; mycelium protective material providing protection for IT/electronic/fragile equipment during transportation; and biodegradable bags providing health facility waste pit liners.

Established trusted channels are important to successful introduction. In many humanitarian contexts, religious leaders and churches can serve as trusted communication channels; moreover, in the DRC specifically it was found that community health workers (RECOs) often bridge technical and community knowledge - they are trusted by communities and adoption of certain health-related solutions could be facilitated by them.

3.2 Economic and Operational Feasibility

The LCC assessment compared bio-based alternatives against conventional items and packaging across four humanitarian kit types (WASH, NFI, Food, Agriculture) for both South Sudan and the DRC.

Perceived cost barriers are often higher than actual costs. Price competitiveness was cited as the most common barrier across all solutions and all stakeholder groups. The pricing topic has multiple dimensions related to the type of item, production location, taxation, import costs, market availability, etc. and would require further investigation. Many stakeholders, particularly those representing (community, HOs, and donors), were referring to this barrier, assuming that biobased solutions must be more expensive. Price benchmarks referenced by consulted producers often represented estimated import prices rather than local production prices.

Bio-based packaging often has minimal impact on total kit costs. Replacing conventional packaging with bio-based alternatives typically results in **less than a 10% increase in total kit costs**. This is because total kit costs are generally driven by the items themselves (tents, kitchen sets, food commodities) whereas packaging accounts for only a relatively minor portion of total kit costs. Conversely, item-level replacements (e.g. sanitary pads, mosquito/fishing nets, RUTF sachets) can result in more substantial cost increases.

Procurement systems require adaptation to facilitate bio-based solutions. The range of products used in humanitarian operations is primarily shaped by

procurement regulations, donor criteria, and pre-approved supplier lists. Many responders used existing procurement system as a barrier. Now bio-based alternatives are not incorporated into overarching HOs procurement systems, cluster standards, and donor policies, therefore their uptake in field operations remains very limited.

Local production potential remains untested. Several stakeholders in both countries stated that local/regional production may potentially greatly decrease cost per unit, however, this remains an untested hypothesis. Conducting a separate local production feasibility and cost-benefit analysis are needed to assess whether the apparent price differential is a true barrier or an unfounded assumption based on inadequate data. It is possible that prices will lower with time, once more demand is noticed by the producers. It is important to consider also more broad and ethical aspect of costs, as on one hand higher prices will mean less people are reached by projects. However, in the long run, taking into consideration costs of externalities (pollution, climate change, agricultural soil degradation, and negative health implications), bio-solutions might cost less overall. Local production can also create a shift in impact - from economic considerations to ethical ones - while the use of raw materials may compete between packaging production and food supply.

Decision-making tools can support procurement choices and key policy changes recommendations for HOs. The project developed a "Roadmap for policymakers" (D5.2) that draws on LCA evidence as well as an LCC tool to enable humanitarian actors to compare alternative kit configurations under different scenarios, supporting more informed procurement decisions. However, the tool is intended for comparative analysis rather than precise cost estimation.

3.3 Social and Governance Conditions

The S-LCA shows that **bio-based solutions do not automatically generate positive social outcomes**. Their impact depends on how they are designed, implemented, and governed.

Social benefits are not guaranteed. While humanitarian organisations generally operate under strong social standards — including health and safety, accountability, and community engagement, these standards do not consistently extend to waste management and end-of-life practices. At the same time, the social performance of bio-based product suppliers is often poorly documented, particularly in relation to labour conditions, local job creation, and contributions to poverty reduction. This lack of transparency limits the ability to assess their full social impact.

Social outcomes depend on implementation choices. The social value of bio-based solutions is shaped by governance arrangements, supply chain transparency, and the level of community involvement in decision-making. Approaches that prioritise local production, inclusive participation, and clear accountability mechanisms are more likely to generate positive outcomes. Environmentally sustainable solutions do not inherently deliver social benefits without these enabling conditions.

Women are key stakeholders and beneficiaries. Many of the assessed solutions have direct implications for women's roles and livelihoods. For example, biogas systems can reduce reliance on firewood collection, which is often carried out by women and can expose them to safety risks. BSF systems can support income-generating activities, including through women-led cooperatives, while agricultural inputs such as fertiliser benefit women farmers. In nutrition programmes, women are typically the primary caregivers, making them central users of products such as RUTF. Implementation strategies that work through women's existing networks and address their specific needs are more likely to be successful.

3.4 Regulatory and Institutional Environment

The governance study analysed the regulatory environments in South Sudan and the DRC through desk reviews and interviews with representatives of national and local governments in both countries. Interviews were held with officials representing the Ministry of Environment, National Revenue Authority and the Juba City Council in South Sudan, as well as Provincial Authorities in the DRC.

The analysis shows that **regulatory and institutional conditions remain a major constraint to the adoption and scaling of bio-based solutions** in both the DRC and South Sudan.

Regulatory frameworks are limited or weakly enforced. Neither country has dedicated regulatory frameworks for bio-based solutions. In the DRC, basic waste management legislation exists, but enforcement, including the 2017 national decree banning plastic bags, remains inconsistent. Additionally, certification systems for compostable packaging do not exist, nor do specific regulations for BSF or biogas technologies. In South Sudan, environmental and waste management legislation remains in its early stages with limited enforcement, and with key legal instruments still in draft form. An update to the National Environment Bill incorporating circular economy provisions was reported to be prepared by the national level Ministry of Environment and currently under review by the Ministry of Justice.

Donor and humanitarian standards operate as the de facto regulatory framework in these countries. In the absence of strong national legislation, the Sphere Handbook, Core Humanitarian Standard, and DG ECHO's MERS set the operational expectations for waste management in humanitarian settings. Procurement rules established by donors, cluster guidelines and WHO/UNICEF standards further determine which products can enter humanitarian supply chains. However, these standards remain nonbinding, inconsistently applied across actors, and often disconnected from national regulatory structures, limiting long-term accountability and sustainability.

Political will exists, particularly at local level. In both countries, local and provincial authorities expressed their willingness to assist with pilot initiatives, including facilitating access to land, assisting with project approvals and support enabling regulations. In South Sudan, the Juba City Council offered recommendations on locations suitable for pilot projects, including the Konyo-Konyo Market, (one of the biggest markets in the capital) and the University of Juba. Additionally, the Ministry

of Environment mentioned concrete waste streams that could be used to produce biogas (for example, to use slaughterhouse waste from abattoirs located near main cattle markets) and highlighted the importance of segregating waste as a pre-requisite. At local level, political support would need to be operationalised through formal approvals, integration into municipal plans, allocation of land and resources, and enforcement of waste segregation requirements. Continued engagement, institutional ownership, and coordination with national authorities would be essential to move from pilots to sustained implementation.

Tax structures can undermine local production. Now, all the solutions proposed under Bio4HUMAN's research are not produced locally in the DRC nor South Soudan. Tax-exempt status is granted to humanitarian organisations that import goods while locally produced goods are fully taxed. According to the National Revenue Authority in South Sudan, this creates a structural disadvantage for domestic producers of bio-based solutions, making locally manufactured alternatives less competitive than imported products. While intended to facilitate humanitarian response, this framework has the unintended effect of constraining local manufacturing, value chain development, and longer-term sustainability.

Together, these factors highlight that scaling bio-based solutions depends less on technological readiness and more on enabling policy, regulatory, and institutional conditions

3.5 Cross-Cutting Lessons Across Both Countries

Despite differences in political, economic, and infrastructure conditions, several consistent patterns emerged across both the DRC and South Sudan:

- **End-of-life infrastructure is a critical constraint.** Neither country has functioning commercial or industrial composting infrastructure. As a result, biodegradable materials may offer little than expected environmental advantage relative to non-biodegradable plastic materials.
- While such materials still degrade faster and do not generate microplastics, they can effectively become waste if disposal systems are absent. This highlights that material substitution alone is insufficient without corresponding waste management infrastructure.
- **Economic barriers work differently across adoption pathways.** Cost sensitivity among consumers is high at the household level, limiting the uptake of the bio-based alternatives in the day-to-day activities. In contrast institutional applications (humanitarian medical supplies, humanitarian logistical support), are less constrained by price, as procurement decisions are influenced by donor policies and organisational priorities making these applications more immediate and feasible entry points for adoption.
- **Reuse practices shape acceptance.** In both countries, the reuse culture exists due to economic necessity rather than environmental awareness. People keep and reuse plastic bottles, bags and other forms of packaging because

they cannot afford new ones, not because of environmental benefits. Thus, designs for alternatives that remove reuse value will likely face resistance unless those design elements provide other types of benefit.

- **Local context determines feasibility.** What is a barrier to one setting may not be relevant to another. For example, concerns about the safety of biogas are more prominent in areas without prior experience using gas for cooking while feedstock-related concerns — such as competition with food crops used for materials like PLA — depend on local agricultural practices. This underscores the need for **context-specific design and implementation rather than one-size-fits-all solutions**.

4. What These Findings Mean for Policy and Practice

4.1 European Union and International Policy Gaps

EU policy frameworks, including the European Green Deal, the Circular Economy Action Plan, and the Bioeconomy Strategy, primarily target regulated economic systems and do not explicitly address the operational constraints of humanitarian settings or regions with limited waste management infrastructure. While these frameworks acknowledge global sustainability challenges, they provide limited guidance applicable to crisis-affected or low-capacity contexts. The forthcoming EU Packaging and Packaging Waste Regulation (PPWR) establishes definitions, standards, and EPR obligations for compostable and biodegradable packaging that will increasingly shape what EU-based manufacturers supply to humanitarian operations, but the regulation assumes waste management infrastructure that does not exist in humanitarian contexts.

DG ECHO has taken steps toward incorporating environmental factors into its humanitarian programming through the MERS, which include cross-cutting requirements on waste management and supply chain sustainability, as well as sector-specific provisions. At the same time, a disconnect between the level of aspiration set forth in these requirements and the resources available to meet them in the humanitarian context remains.

There is no provision within the EU humanitarian regulations at present for bio-based or circular economy solutions in humanitarian supply chains. Many humanitarian grant applicants prioritize low costs solutions out of concern that donors may reject their proposals. Clear donor guidance could help overcome this concern as well as a general reluctance toward change and innovation. This represents a missed opportunity to align the EU's environmental and humanitarian agendas – using humanitarian operations as real-world environments to validate bio-based innovations while reducing the environmental footprint of EU-funded aid. Such alignment would support evidence-based policy refinement, strengthen accountability across supply chains, and reduce the environmental footprint of EU-funded humanitarian assistance without compromising humanitarian principles.

4.2 Humanitarian System Gaps

Solid waste management falls outside of typical mandates for most humanitarian clusters. The WASH Cluster has primary responsibility for managing water supply and sanitation needs, and solid waste management competes with water supply and sanitation for attention and resources. The Logistics Clusters manage packaging waste but are driven by a mandate to deliver goods efficiently, not environmentally.

Biobased products have been incorporated into few humanitarian organisations' approved supplier lists. Purchasing decisions of bigger humanitarian actors are restricted by their internal procurement rules that require all purchases to be made from preapproved suppliers and that items need to meet specific standards and certifications. Even though alternative biobased products may exist – and may even be competitive on cost terms – they cannot be purchased until they have first been included on such lists.

United Nations agencies, humanitarian clusters (both at global and national level), and core pipelines play a central role in shaping the procurement decisions and policies across humanitarian operations. The UN agencies frequently act as lead buyers through global frameworks, long-term agreements, and core pipelines that consolidate demand for key relief items such as medical supplies, WASH commodities, shelter materials and RUTF sachets. While this centralisation enables quality assurance and rapid deployment, it also reinforces standardised product specifications and supplier rosters that prioritise reliability, cost, and speed of delivery over environmental performance. Core pipelines are typically optimised for conventional products that are already widely tested and approved, leaving limited flexibility to introduce alternative bio-based solutions without prior validation at global level. As a result, unless bio-based products are integrated into UN-managed procurement frameworks, pipeline specifications, or cluster-endorsed standards, field-level actors have little scope to deviate from established purchasing patterns, even where sustainable alternatives may be locally available or contextually appropriate. Without such upstream changes, field-level actors and clusters have limited scope to adopt bio-based solutions, regardless of local availability.

Cluster standards do not yet systematically address biodegradable or compostable alternatives. While some sector-specific progress exists – such as the WASH Cluster in the DRC established standards for reusable sanitary pads, and the Nutrition Cluster has clearly defined procedures for evaluating RUTF packaging, no equivalent standard bodies have evaluated or created comparable standards for bio-based packaging materials, compostable bags or PLA bottles. The lack of such standards hinders field-level procurement from selecting bio-based options. Developing limited technical guidance or inclusion criteria at cluster level could provide a practical entry point for incorporating bio-based solutions without overburdening existing coordination structures.

4.3 National and Local Policy Gaps

In the DRC, the most significant policy gap is that of enforcement. There was a decree on banning plastics in 2017 which is not enforced. One reason is that viable substitutes are not available at scale. Another is that large-scale plastic importers have considerable political influence and therefore do not want the authorities to enforce the law. A respondent expressed the situation succinctly: “There is no replacement product which will meet demand, so the Ministry is seeking an alternative.” Therefore, enforcement and developing markets need to occur concurrently.

In South Sudan, the main policy gaps are very basic regulatory frameworks. While environmental regulations are still in draft status, there are no applicable standards for bio-based products, biodegradable packaging, or waste treatment technologies. On the other hand, while the regulatory environment may hinder the development of bio-based products, it provides fewer obstacles to the entry of these types of products to the market.

In addition to the regulatory environments, the tax structures of both countries create structural impediments to the creation of local bio-based alternatives. In South Sudan, the difference between completely exempted taxation of humanitarian imports, versus taxing all locally produced products at full rates, makes it difficult to economically justify creating a bio-based value chain within each country. While designed to facilitate humanitarian response, this fiscal framework discourages potential local manufacturing, weakens incentives for private-sector investment, and limits prospects for sustainable, locally anchored solutions.

4.4 Market and Cross-Sector Coordination Gaps

The bio-based sector does not currently recognise humanitarian operations as a potential market for its products and technologies. In most cases during the Bio4HUMAN scoping exercise for bio-based solutions, the providers were for the first time alerted to the potential humanitarian applications of their products and technologies. Equally, the humanitarian sector lacks awareness of what bio-based solutions exist, their technical performance, cost structures, and how they could be integrated into existing supply chains or become part of local manufacturing and/or local operations. This mutual lack of visibility limits meaningful engagement between the two sectors.

This knowledge gap operates in both directions and is reinforced by the absence of formal coordination mechanisms. Bio-based manufacturers typically design products for industrialised market conditions (industrial composting infrastructure, controlled supply chains, consistent storage conditions) without accounting for the realities of humanitarian logistics, i.e. rough transport, unventilated warehousing, extreme temperatures, and the complete absence of end-of-life infrastructure. Humanitarian organisations, for their part, are unfamiliar with bio-based material

properties, composting requirements, and other technical matters. In the absence of intermediaries, shared platforms, or structured dialogue, opportunities for mutual learning and product adaptation remain limited. The projects such as Bio4HUMAN serve well the purpose of bridging this gap.

While there is local production potential in both countries (i.e., local raw materials are readily available; local labour forces are unemployed; various respondents have the necessary technical expertise), no costing studies have been done regarding the production costs associated with any type of solution. Since such data do not yet exist, the local economic feasibility of establishing a bio-based value chain in either country continues to remain theoretical rather than proven. This perpetuates a cycle in which local production potential is recognised but not realised, and opportunities for sustainable market development remain untapped.

5. Recommendations

These recommendations were generated based on the findings of the Bio4HUMAN research in both the DRC and South Sudan. Although the specific context of humanitarian crises will differ greatly, there will likely be similarities in the structural features observed in these two countries; specifically, regulatory voids, barriers to purchasing, asymmetry of knowledge, and the dependency of environmental benefits at end of life to how materials are disposed of.

5.1 Recommendations for EU and International Policymakers

Strengthen the operationalization of solid waste management within humanitarian funding mechanisms. DG ECHO's mandatory Minimum Environmental Requirements and Recommendations (2023)[14], already include substantive waste management provisions. The WASH-and Nutrition specific requirements further specify environmental recommendations. DG ECHO has indicated willingness to co-fund the implementation of environmental requirements. At the same time, some infrastructure-related provisions, such as establishing compliant waste disposal facilities, in many contexts require investment that goes beyond standard project budgets. Clearer guidance on implementation responsibilities, access to appropriate funding instruments, and the provision of technical support would be required to translate existing requirements into consistent operational practice. Expanding the funding tools available to support waste management infrastructure, composting systems, and bio-based procurement would further help achieving operational practice.

[14] European Commission, Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG ECHO). (2022). *Minimum Environmental Requirements and Recommendations for EU-funded humanitarian assistance*. Retrieved from https://ec.europa.eu/echo/files/policies/environment/minimum_environmental_requirements_recommendations.pdf

Integrate humanitarian applications into EU bioeconomy and circular economy strategies. Strategies developed for the EU bioeconomy and circular economy should explicitly reference humanitarian applications as an emerging market for bio-based products and technologies. Recognizing humanitarian supply chains as a viable and expanding market may encourage EU-based manufactures to deliver products designed for low-infrastructure contexts. In parallel, humanitarian supply chains could serve as real-world testing environments, generating evidence to inform both products' innovations & development and future EU bioeconomy policies, while reducing the environmental footprint of EU-funded humanitarian assistance.

Provide financial assistance for R&D&I addressing unanswered technical issues that arose out of the Bio4HUMAN research, such as: the retention of insecticides in biodegradable fibres used for mosquito netting, the chemical compatibility of PLA with medical liquids, and health safety during sanitation pad use – issues that need to be tested in a laboratory setting as well as through product development, as opposed to solely relying on field consultations. Dedicated research and development (R&D) support - potentially through EU research programmes or public–private partnerships - would reduce technical uncertainty, support standard setting, and enable the safe integration of bio-based solutions into humanitarian supply chains, rather than relying solely on field consultations or ad-hoc pilots.

5.2 Recommendations for Humanitarian Actors and Donors

Programmatically integrate waste management considerations into program designs from inception, including considerations related to material selection, anticipated waste stream generation, and end-of-life management, instead of considering waste as an afterthought. Waste reduction opportunities exist across many sectors: WASH, Nutrition, Health, Shelter, and Logistics all create waste that can be minimized through innovative approaches, purposeful design and budgeting stages. Systematically embedding waste considerations into programme design processes, donor proposal requirements, and sector guidance would strengthen accountability, reduce downstream environmental impacts, and improve operational efficiency without compromising humanitarian objectives.

Prioritise low-risk entry points for bio-based solutions. Adoption should begin with applications that fit within existing procurement systems and do not require changes in user behaviour or additional infrastructure. Institutional and logistics uses, where procurement is centrally controlled, offer more immediate opportunities to test and scale bio-based alternatives. These initial applications can generate operational evidence and build organisational familiarity with bio-based materials, creating a starting point for broader adoption over time.

Add bio-based alternatives to approved vendor lists and cluster procurement standards. Without this action, field-level procurement teams will lack access to bio-based options regardless of their potential innovativeness, value or performance. Donors should review approved vendor lists to identify opportunities

for the inclusion of bio-based alternatives. In parallel, humanitarian clusters should develop clear technical specifications for bio-based packaging materials.

Use the evidence-based tools to support procurement decisions. Decision-making tools, such as the Bio4HUMAN LCC tool, can support comparison of alternative product configurations and help integrate environmental considerations into procurement processes.

Differentiate approaches by organisational scale and influence. Smaller-to-medium-sized humanitarian organisations can realistically initiate substituting bio-based packaging materials (adhesive tape, film, bags) within their existing supply chain arrangements. Larger international NGOs (INGOs) and UN agencies that possess greater procurement influence can focus on piloting bio-based items (RUTF sachets, PLA bottles for institutional use) and incorporating environmental criteria into tender specifications as more feasible and impactful ways to reduce waste. This combined approach can accelerate system-wide change.

5.3 Recommendations for National and Local Policymakers

General recommendations:

Remove regulatory and administrative barriers to market entry. This could include financial incentives, investing in supporting infrastructure, and enhancing access to markets. Tax exempts for new bio-based products and services should be consistent and transparent and unnecessary bureaucratic hurdles (e.g., redundant licenses, informal taxes) need to be removed for early-stage businesses. Supporting access to anchor buyers, including municipalities and humanitarian actors, could further improve market predictability and viability.

Strengthen institutional capacity for implementation and oversight. Allocate dedicated resources for standardization, monitoring and enforcement, training of regulatory authorities, technical support to local governments. Capacity building should extend to municipalities responsible for waste management and procurement.

Invest in enabling infrastructure for waste management. Prioritise public investment in infrastructure critical to bio-based supply chains, including reliable energy access, organic waste collection and sorting systems, local processing and storage facilities. This is particularly important in regions with limited waste management capacity.

Strengthening accountability, through formal mandates, reporting requirements, and coordination between national, local, humanitarian, and private actors - is essential to ensure that environmental and waste-management responsibilities are consistently implemented and sustained over time.

Support education and awareness as pre-conditions to the adoption of new technologies. Stakeholders in both countries agreed that communities are unable to assess whether a given solution is effective without a basic understanding of how

it functions. Environmental education programs in schools, educational messages via the radio, and hands-on demonstrations of technologies at pilot sites are necessary for building public trust and establishing a foundation for successful implementation. Education on the proper source separation of organic wastes is also needed to ensure confidence that resulting bio-based products deliver genuine environmentally benefits. **Engage local authorities as pilot hosts**. Local governments in both countries expressed a willingness to provide land, political backing, and project coordination for pilot initiatives. This commitment to supporting pilot projects should be formally established through partnerships that clearly define roles, responsibilities, and long-term sustainability pathways. The partnership agreements may well serve this purpose.

DRC-specific recommendations:

Enforce existing plastic ban legislation with simultaneous support for local bio-based producers. The implementation of the 2017 decree banning plastic bags will be ineffective unless viable alternatives are available at scale. This requires the simultaneous establishment of enforcement mechanisms and support systems for local manufacturers, i.e., providing capital support to manufacturers, tax exemptions, technical training and other capacity building mechanisms – concurrent with enforcing the plastic bag ban.

Develop technology-specific regulatory frameworks for BSF, biogas, and compostable packaging. These frameworks should build on existing draft legislation (such as AALI's proposed BSF law) and leverage established g institutional relationships with the relevant authorities for product certification.

South Sudan-specific recommendations:

Advance and strengthen the National Environment Bill currently under review, ensuring it includes provisions for bio-based materials, waste segregation standards, and extended producer responsibility. The circular economy language in the bill provides a foundation that should be maintained and enhanced further during the legislative process. Clear designation of responsible authorities and pathways for enforcement will be essential to move the framework beyond policy intent and into practical application.

Address the tax asymmetry between humanitarian imports and local production. Current structure of taxation, whereby humanitarian imports are exempt from all taxes while domestic producers pay the full amount of taxes, creates a structural disadvantage to domestic producers of bio-based materials. Options to address this issue include expanding agricultural tax exemptions to bio-based input costs, creating a special tax exemption category for environmental innovations, or allowing humanitarian organisations to "pass through" their tax-free status when purchasing materials produced locally. Such measures would support domestic value-chain development while maintaining humanitarian access and accountability.

5.4 Recommendations for Bio-Based Sector Actors

Recognise the humanitarian sector as a viable market. Humanitarian operations process millions of units of packaging and distribute hundreds of thousands of essential goods and waste management solutions. Engaging with this sector can open new market opportunities currently dominated by conventional approaches.

Design products for humanitarian operating conditions. Bio-based solutions must be adapted to low-infrastructure environments, including long-distance transport, extreme temperatures, limited storage conditions, and the absence of industrial waste treatment systems. Products that rely on controlled conditions or specialised infrastructure are unlikely to be viable in humanitarian settings.

Engage proactively with humanitarian procurement systems rather than expecting the humanitarian sector to find and adopt bio-based products independently. This could involve attending technical working groups and humanitarian cluster coordination meetings; sending product samples to humanitarian organisations for testing in operational environments; and developing relationships with the donor agency procurement teams and approved supplier lists.

Develop local production partnerships. In both the DRC and South Sudan, stakeholders reported that raw materials and labour are available, and that there is entrepreneurial interest for local production of several bio-based solutions. Local production can create employment, foster community ownership, and align with the growing emphasis on localization in humanitarian programming. However, developing local production capabilities will require investments in technology transfer, workforce training, and the establishment of robust quality control systems.

Ensure cost competitiveness and clear value propositions. In price-sensitive humanitarian markets, even modest price premiums create adoption barriers, especially for consumer-facing products. Therefore, cost reduction should remain a priority; and may be achieved through economies of scale, local production, and alternative (non-food) feedstocks. Where price parity cannot be achieved, the value proposition must be clearly articulated in terms that resonate with humanitarian procurement logic: waste reduction, simplified logistics, and compliance with donor environmental requirements.

6. Priority Actions for the Next 2-3 Years

The following recommendations are the most immediate and impactful steps toward improving the use of bio-based products and technologies in humanitarian solid waste management based upon the data developed by Bio4HUMAN.

For policymakers and donors:

- Fund integrated pilot projects in humanitarian locations (such as the DRC and South Sudan), which includes both bio-based product and bio – based

technologies introduction with composting infrastructure and community education — this can provide additional evidence that is currently missing.
- Commission cost-benefit and feasibility studies to evaluate the potential for local manufacturing of selected bio-based solutions in humanitarian contexts.
- Integrate bio-based product specifications into the humanitarian cluster procurement standards and procurement frameworks to allow their use at scale.

For humanitarian organisations:

- Conduct field trials of bio-based alternatives that represent direct product swaps within existing procurement systems, prioritizing institutional and logistics applications where adoption barriers are lowest.
- Replicate and scale the Bio4HUMAN assessment approach (including the Life Cycle Cost Tool and community outreach/engagement process) in different humanitarian settings so there is enough comparable evidence collected to support making decisions regarding future bio-based product purchases and installations of bio-based technologies.
- Develop a cross-sector working group (comprised of representatives from the humanitarian logistics, bio-based industries, academia and others) that maintains communication among its members and coordinates planning for pilots.

For bio-based sector actors:

- Develop bio-based products and technologies that are specifically designed for use in humanitarian environments (i.e., for transportation over poor roads, for use in extremely hot or cold climates, and for composting in areas that lack industrial composting capabilities); focus initially on product and technological development where demand has been identified in previous research.
- Provide free samples of products and access to technical documentation to humanitarian logistics and WASH Clusters for field testing purposes.
- Invest time and resources to answer remaining technical questions identified in this research, such as insecticide retention in biodegradable fibres and durability of materials stored and transported in tropical conditions.

For researchers and the broader community:

- Conduct laboratory and applied research to assess the performance characteristics of bio-based products when used under typical field conditions (e.g. temperature ranges, humidity levels, exposure to transportation stressors).
- Monitor and evaluate pilot programs over time to determine whether the implementation continues after initial adoption.
- Maintain and support open channels of communication among all stakeholders involved (policy makers, humanitarian workers, manufacturers

and suppliers of bio-based products) to share results of this research and facilitate further discussion and collaboration.