D5.1 Data collection from partners: state-of-the art and innovative solutions

Due date: 30/06/2025

Responsible partner: ITENE

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*R — Document, report; DMP — Data Management Plan; DATA — data sets, microdata, etc; DEC —Websites, patent filings, videos, etc.

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Document history

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Publishable summary

The main purpose Bio4HUMAN's T5.1 was to set the basis for the future Life Cycle Assessment that is carried out in *T5.2 Hotspot analysis of the current and innovative solutions*. In this sense the goal and scope of the systems, functional unit and the inventory data of the bio-based solutions listed in Deliverable 4.1 are included in this *report*. This deliverable is divided into two sections: the basic settings of Life Cycle Assessment and the Life Cycle inventory of the innovative bio-based solutions.

In the first section the basic settings such as Goal & Scope are explained, including the reference scenario, the selected solutions and the correspondent substitution in the current benchmark. The reference scenario was based on the most common types of aid in the two countries (Democratic Republic of Congo and South Sudan) and the waste identified in the Bio4HUMAN *Deliverable 3.3 Humanitarian sector need assessment report*. In this sense, **four types of humanitarian aid kits were established as reference scenario:** Food basket, Agriculture, Water Sanitation and Hygiene (WASH) kit and Non-Food Items (NFI). In this deliverable bio-based solutions for the construction sector have also been considered, as suggested by PIN and PAH, for the replicability of the solutions in other regions with different climate conditions where insultations materials are looked-for.

With regards to the reference scenario for the **End-of-Life options**, in D3.3, it is stated that an estimated 10% of waste—such as plastics, cartons, and metals (e.g., steel from packaging)—is formally collected, primarily in urban centres of humanitarian settings. Therefore, most of the waste is either openly dumped or ends up in unmanaged landfills with little to no environmental controls. Waste management remains highly limited due to infrastructural and institutional constraints. The inventory data of the reference scenario, for the kits and the End-of-Life options are included in the Annex 1.

The second part of the report **focuses on the bio-based solutions that were identified in D4.1 and are intended to substitute the reference scenario**. The objective of this report is to collect the inventory data, in terms of inputs (materials, ancillary materials, energy) and outputs (products, co-products, waste emissions) of the solutions that were provided in WP4 Scoping exercise. For achieving this goal, the different partners involved in this task (ITENE, WeLOOP, AIMPLAS, and UC) compiled the information provided by the companies, and where not available, the data gaps were covered by the existent bibliography.

This report is the basis for the *Task 5.2 Hotspot analysis of the current and innovative solutions,* where the bio-based solutions will be analysed in terms of potential environmental impacts.

BIO4HUMAN

List of acronyms

Acronym	Description
AD	Anaerobic Digestion
BSF	Black Soldier Fly
E-LCA	Environmental Life Cycle Assessment
DRC	Democratic Republic of Congo
FAO	Food and Agriculture Organization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LDPE	Low Density Polyethylene
NFI	Non-Food Items
Non-GMO	Non-Genetically Modified
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
PE	Polyethylene
PET	Polyethylene terephthalate
PHB	Polyhydroxybutyrate
PP	Polypropylene
PS	Polystyrene
R&D	Research and Development
RTUF	Ready To-Take Therapeutic food
SSRUP	Small Scale Residue Utilization Pathways
TRL	Technology Readiness Level
USAID	United States Agency for International Development
UNFPA	United Nations Population Fund
UNICEF	United Nations children's fund
UNHCR	United Nations High Commissioner for Refugees
WASH	Water Sanitation and Hygiene
WFP	World Food Programme
WHO	World Health Organization

1. Bio4HUMAN Introduction

In humanitarian actions the generated solid waste can accumulate quickly and in large amounts, which has clear potential impacts on public health, livelihood and the environment.

According to the June 2022 questionnaire developed by French independent think tank - *Groupe URD and disseminated among humanitarian organizations in Europe*, the highest concern for the sector constitutes packaging, followed by e-waste, followed by organic waste, sanitation, construction, and medical waste. September 2022 GLC-led WREC project Baseline survey called *Sustainable Supply Chains*[1] states that the most common packaged products used or distributed by humanitarian organizations are plastic packaging (44%), followed by paper and cardboard (43%).

In this context, bio-based solutions and compostable materials are an answer to the problem of solid waste, as they eliminate it by being treated at its end-of-life with technologies such as composting or anaerobic digestion, among others. The assistance to analyse bio-based solutions that can fit into humanitarian context is done through the Bio4HUMAN project.

The general objective of the project is to "*Identify bio-based solutions for waste management and reduction applicable to humanitarian sector*". In this regard, Bio4HUMAN is assessing the scope to which bio-based innovative technological solutions and bio-based products identified in WP4, *"D4.2 List of bio-based solutions"*, have the potential to be applied under the humanitarian context, with the simultaneous reduction of negative effect on the environment. Hence, Life Cycle Assessment (LCA) methodology will be applied to examine the potential of the proposed solutions with regards to reducing the environmental impact.

In this sense, WP5 objective is "to *carry out the Environmental Life Cycle Assessment (E-LCA) of the innovative bio-based solutions identified in WP4*". This deliverable is framed within the first task of this WP5, *Definition of goal and scope and data collection for innovative solutions.*

The objectives of this task, and thus, also of this deliverable, are:

- To define the goal and scope of the systems to be assessed
- To develop a template for data collection
- To collect data for the current and innovative bio-based waste management solutions by the partners based on their expertise

[1] https://logcluster.org/document/wrec-baseline-survey-results?language=es

2. Life Cycle Assessment Settings

The Life Cycle Assessment (abbreviated as LCA) methodology is used in the Bio4HUMAN project in accordance with the ISO standards on LCA **(ISO 14040:2006**-Environmental management - Life cycle assessment - Principles and framework and **ISO 14044:2006**- Environmental management - Life cycle assessment - Requirements and guidelines).

The methodology that will be implemented follows the standards UNE-EN ISO 14040:2006[2] and UNE-EN ISO 14044:2006[3]. In accordance with this standardization, LCA is divided into four stages, which are represented in *Figure 2*, and are the following:

- **Goal and scope definition**: Defines the objective (the reason for the LCA and the intended implementation) and the plan used of the study (the audience to which the study is going to be disseminated), as well as the scope in line with the system boundaries, the functional unit, the flows within the life cycle, the quality required for the data, and the technological parameters.
- **Life Cycle Inventory (LCI)**: Is the stage of LCA where the inputs and outputs data of all the stages of the product system both are collected and evaluated.
- **Life Cycle Impact Assessment (LCIA)**: In this stage, the LCI is turned into environmental indicators of potential impacts. This assessment covers impacts on the environment, human health, and natural resource availability.
- **Interpretation:** Finally, the interpretation phase will provide the conclusions of the processes, which are entirely affected by the scope and goals that are defined in the first step of LCA.

[2] **ISO 14040:2006**-Environmental management - Life cycle assessment - Principles and framework
[3] **ISO 14044:2006**- Environmental management - Life cycle assessment - Requirements and guidelines

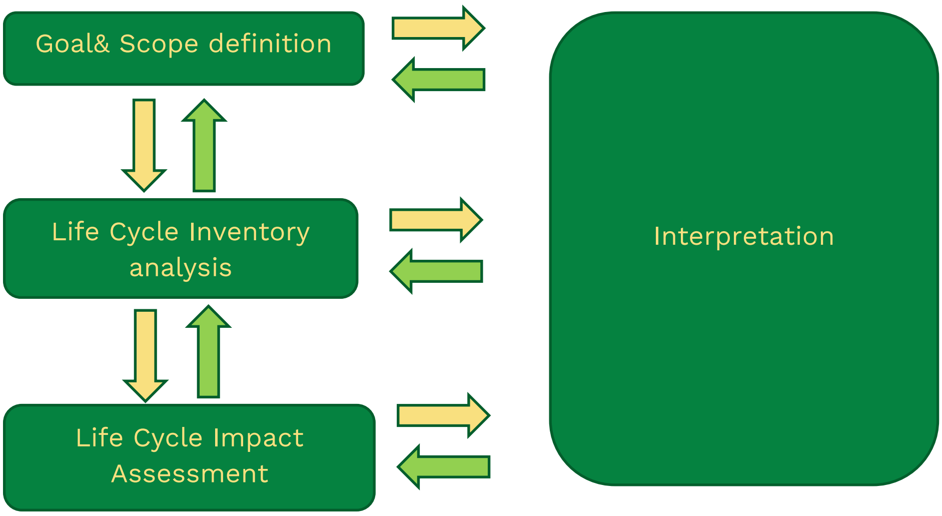

Figure 1. LCA stages according to ISO 14040

As shown in *Figure* **2**, the LCA of a product should include all inputs and outputs of the processes involved throughout its life cycle: the extraction of raw materials, the processing of materials needed for the manufacture of components, the use of the product, and finally its recycling and/or final disposal. Transport, storage, distribution and other intermediate activities between life cycle phases are also included when they are sufficiently relevant. This type of life cycle is commonly referred to as 'cradle-to-grave'.

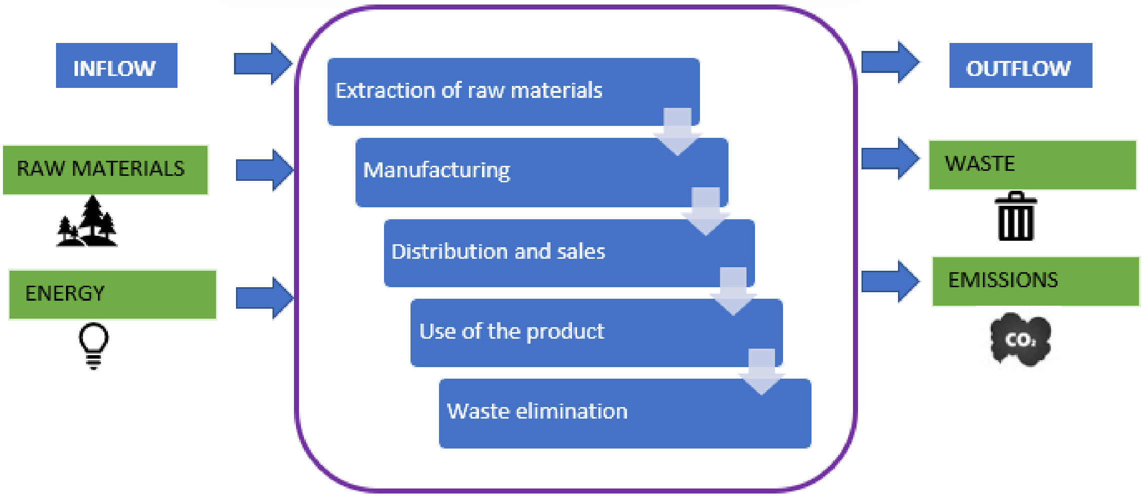

Figure 2. Life Cycle Concept

In view of the stages that make up the life cycle, it is common to encounter different scopes in the development of a LCA, the most common being, as shown in Figure 3:

- **From gate to gate**: only the activities (production process) of the organization to which it applies are considered.
- **From gate to grave:** the company's production process, use phase and waste management phase of the product are considered.

- **From cradle to gate:** from the extraction of raw materials to the company's production process.
- **From cradle to grave:** from the extraction of raw materials to the final disposal of waste (recycling or other).
- **From cradle to cradle** considers the complete life cycle of the product, from the packaging of the raw materials until the product, after being out of use, is reintroduced into the same or another production process. This scope follows the circular approach, meaning that, the end of one product's life becomes the beginning of another product.

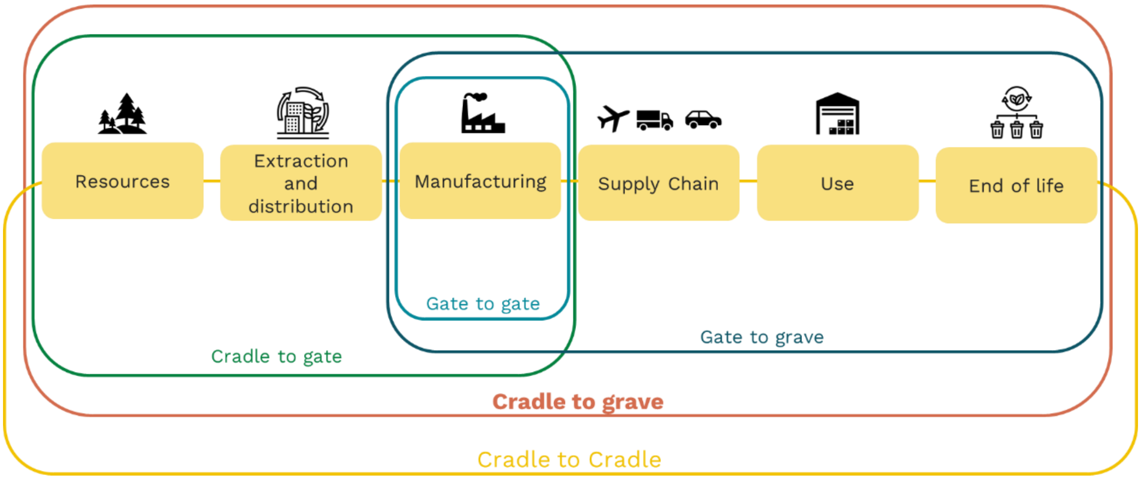

Figure 3. Possible scopes of LCA

In Bio4HUMAN the scope selected for the LCA is **cradle-to-grave**, therefore considering all the stages from the extraction of raw materials to the end-of-life. This scope will allow to analyse the end-of-life of the bio-based solutions versus the end of life of the benchmark solutions.

2.1 Goal and scope in Bio4HUMAN

The definition of the goal and scope is a critical phase that guides the entire procedure of Life Cycle Assessment. Therefore, it must be carried out with rigor and precision.

2.1.1 Goal

In the Bio4HUMAN project, the main goals are:

- To assess and **compare the environmental impact of innovative bio-based solutions against current practices in the context of solid waste management in humanitarian settings**. This comparison is made by defining sustainable scenarios that consider the environmental benefits associated with the integration of bio-based solutions.
- To reduce solid waste by the incorporation of bio-based products and technologies in humanitarian context.

The study also explores how geographical factors influence the adoption and effectiveness of regionalized solutions in different types of communities, specifically in **Democratic Republic of the Congo (DRC) and South Sudan**. In this sense, the solutions for construction sector included in this deliverable are also analysed for replicability in other regions with different climate conditions (i.e. cold weather). More information on the feasibility of the solutions regarding availability of local resources, socio-economic (i.e., level of knowledge of the local people for the implementation, social acceptance) and governance aspects are deeply analysed in WP6 *Socio-economic and governance aspects evaluation*.

Relation with WP4

For meeting the goals of Bio4HUMAN project and for the purpose of Life Cycle Assessment**, WP4. Scoping exercise is the basis for the subsequent work packages of the project**. The solutions scoped and presented in D4.1 are diverse:

- The **list of bio-based solutions** includes products that: a) utilise renewable raw materials, b) combine bio-based feedstock and waste, c) utilise bioplastics, d) combine bio-based feedstock with recycled materials, and e) utilise polysaccharides obtained from renewable sources. Most of the products are compostable and/or biodegradable.
- On the **technology side**, there are solutions that are: a) able to utilize fibrous and non-fibrous feedstock, including vegetable waste and animal excrements, and b) offer the possibility of recycling plastic waste. The technologies are mostly suitable for rural and remote areas, with some of them adaptable also to the needs of urban communities.

All of the 81 solutions were initially analysed by the PRO CIVIS, as the leader of T.4.2.1., and then clustered into following seven categories based on the features of applicability and functionality: 1) Multi-purpose packaging products, 2) Packaging products for food and drinks, 3) Hygiene products, 4) Construction related products, 5) Other products potentially applicable in the context of humanitarian interventions, 6) Small-scale technologies, and 7) Large-scale technologies.

After internal consultations (within the scope of the consortium) and **external consultations** (with the participation of humanitarian stakeholders), **the final list of 27 bio-based solutions** potentially applicable to humanitarian context and helping in the process of solid waste management was presented in D.4.1.

For the external consultations it should be highlighted the **workshop** organised by Enspire Science, that was held on the 5th of February 2025, **Evaluating the application potential of bio-based solutions for humanitarian sector actors.** This workshop was focused on presenting the bio-based solutions identified in Bio4HUMAN's WP4 so far and requesting input from various humanitarian organisations on their application potential.

- This workshop proved crucial in helping WP4 investigation line leaders establish the final list of bio-based solutions applicable to the humanitarian context and helping in the process of solid waste management.
- With this workshop the list was reduced from 31 to 27 solutions.
- In order to better ensure that the organisations registering for this workshop were indeed only humanitarian organisations, the dissemination for this workshop was done by Bio4HUMAN's humanitarian partners, PIN and PAH, via a targeted email campaign to their networks as well as social media posts on their respective social networks.
- 16 humanitarian organizations registered to participate in this session, of which 9 attended the workshop on February 5th. The attending organizations were Action Contre La Faim (France), United Nations World Food Program (representative from Italy), Danish Refugee Council (representatives from Georgia and Bangladesh) , Logistics Cluster (representative from Italy), Médecins Sans Frontières (Switzerland), Hulo (France) , International Committee of the Red Cross (Switzerland) and People in Need (PIN) and Polish Humanitarian Action (PAH).

The bio-based list of solutions was reduced from 31 top 27. after the 5th of February workshop. These 27 solutions were the ones that moved on the next phase, which is the revision by the LCA experts (WeLOOP, ITENE, AIMPLAS and UC) in *WP5. LCA of innovative bio-based solutions*. Some of the solutions were grouped whenever they were very similar (as for technologies at the end-of-life), and other solutions were discarded after no data was received and no information in external databases was found. The methodology followed in this reduction of the list is indicated in Figure **4**.

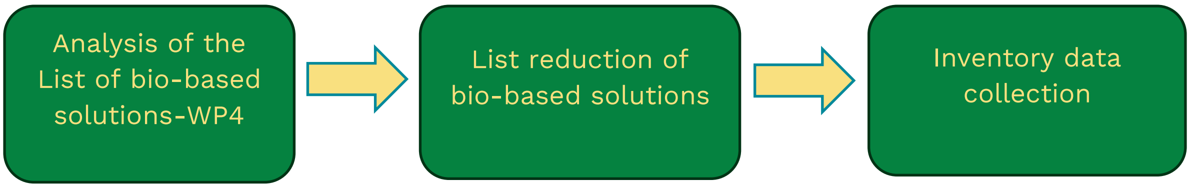

Figure 4. Methodology followed within Task 5.1

The solutions that were taken out of the initial list and the reason behind it are included in *Table **1***.

Table 1.Solutions taken from the initial list of WP4

Solutions that are not included in LCA	
Item	**Description**
Packaging utilizing seaweed coating	The function of this solution is to substitute fossil-based packaging from a canteen to contain food. Therefore, for Bio4HUMAN this applicability is not contemplated.
Sustainable film concept for medical and food packaging	The blister is not made with PLA, it is recycled PP. The tubular film is what is made from PLA. As Bio4HUMAN is selecting bio-based solutions, this solution was discarded because it has two components of different origin, one fossil based and the other one bio-based. Therefore, at its end of life two different technologies would have to be applied: plastic recycling and composting. As our target is to reduce waste, specially of fossil origin, it was finally discarded.
Bags made from seaweed	No information was shared by the owner of the solution.
Wood foams	This solution serves to protect fragile items like medical equipment or electronics that are not part of the scope
High barrier and compostable packaging materials for food contact applications	This solution was not intended for the function of contain Ready-To-Use Therapeutic Food (RTFU). Therefore, it was substituted by the compostable pouch.
Starch-based biopolymer active, intelligent food packaging	Currently this solution is not available on the market beyond small-scale trials at R&D level, which will have a high cost of production. Moreover, this solution mostly directed to food chain (fruits, vegetables, meat), which is almost non-existent in humanitarian setting. The social acceptance seems difficult since there may be cultural barriers, based on PIN perspective. In addition, this solution does not help to tackle the Solid Waste Management problem
Incontinence Pads	This solution is very similar to the sanitary pads which are included in this deliverable.
Biodegradable containers	This solution came from a patent that was analysed, where no information could be extracted. However, there are similar solutions on the market such as the biodegradable bags from renewable sources that are included in this report.
Biodegradable and compostable mulching spray	The information on this solution was not shared by the owner and the analysis would require creating a very complex LCA model to without data available.
Polystyrene consuming- lesser mealworm	TRL to low, as it is at R&D scale. Very complex to control and not cause major health problems (i.e.. Pest). Also, for this solution, a big stream of expanded polystyrene should be available, which will require installations for sorting plastic waste.
Bioremediation technology	This technology is not used to treat a waste stream, but to decontaminate soils.
Biodegradable shelter	The solution appears to be promising; however, there has been no response from the solution owner regarding its composition after various attempts of contact**.**

For collecting the information on the solutions a template was developed by WeLOOP that was used as basis for the inclusion of the data collected in this deliverable (Annex 2 and Annex 3). The LCA partners collected information on innovative bio-based solutions depending on their expertise, as stated in *Table* ***2***.

Table 2. Partner in charge of the data collection of the different innovative bio-based solutions

Classification per reference kit	Solutions	Partner in charge of the data collection
Food basket	PLA bottle for water	ITENE
Food basket	PLA bottle for oil	
Tertiary packaging in all kits	Adhesive tape	
Tertiary packaging in all kits	Biodegradable laminating film	
Primary packaging in Food basket	Compostable Sacket for RTUF	
Construction kit	Foams for insulation	WeLOOP
Construction kit	Wool Insulation material	
Construction kit	Bio-based insulation	
Primary packaging in all kits	Disposable bag from renewable resources	AIMPLAS
Packaging for fragile goods	Mycelium protective material	
WASH kit	Sanitary pads	
Non-food item kit	Monofilaments fishing nets/Mosquito net	
End of life solutions	Anaerobic digester technologies	University of Cantabria
End of life solutions /Agriculture kit	Black Soldier Fly (BSF)	

2.1.2 Scope

Figure 5 illustrates the processes involved throughout the life cycle of humanitarian aid providing a comprehensive view of the cycle, from the initial sourcing of materials to their final disposal at the locations where the aid is delivered. In this sense, this reflects the “**Cradle-to-Grave**” scope.

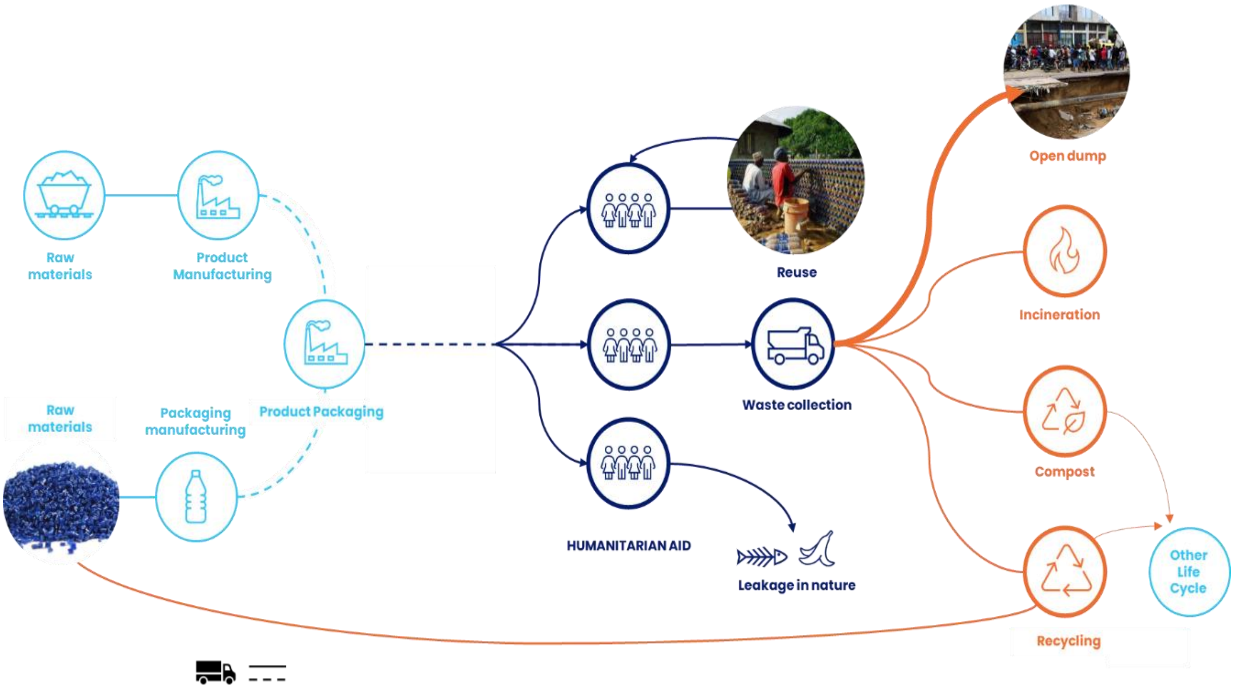

Figure 5. Life Cycle of humanitarian aid- Scope of LCA of Bio4HUMAN project (WeLOOP)

2.2 Reference scenario

For the reference scenario, WeLOOP, with the help of PIN and PAH, established four types of humanitarian aid:

- Food basket[4] (*Table **3***)
- Agriculture kit (*Table **4***),
- WASH kit (*Table **5***)
- Non-food items (*Table **6***).
- Construction material

These kits and their compositions are the basis for the comparison with the innovative bio-based solutions. In this section, the information selected as baseline for the analysis is detailed to be compared with the bio-based solutions proposed in WP4.

2.2.1 Choice of the Kits

The reference scenario was based on the most common types of aid in the two countries (DCR and South Sudan) and the waste identified in the Bio4HUMAN Deliverable 3.3[5].

The types of waste generated by humanitarian operations, identified in Bio4HUMAN Deliverable 3.3, include organic, plastic, sanitation, construction, household, cardboard, and paper waste. Plastic waste mainly comes from RUTF sachets,

[4] https://www.wfp.org/stories/wfp-food-basket
[5] Resources - bio4human

Polyethylene Terephthalate (PET) bottles, Polypropylene (PP) woven bags, jerricans, and tarpaulins; cardboard originates from primary and secondary packaging boxes; and construction waste from materials like plasterboard and bricks. Additionally, USAID launched the Joint Initiative for Sustainable Humanitarian Assistance Packaging Waste Management, which identified similar sources of plastic and cardboard waste in its 2021 baseline assessment[6]. It also detailed packaging types (primary, secondary, tertiary) used for Water Sanitation and Hygiene (WASH) and Non-Food Items (NFI) items and provided a streamlined LCA[7] of World Food Programme food packaging as source of waste.

Reports from various organisations, such as OCHA's Humanitarian Action website[8,9] and USAID's FY2023 Annual Report[10], outline the types of crises and aid delivered across sectors including WASH, Shelter and NFI, Education, Health, Food Security, and Nutrition. Monthly emergency fact sheets for DRC[11] and South Sudan[12] highlight similar sectors, with agriculture, food assistance, nutrition, health, shelter, and WASH identified as waste-generating. Based on these reports, the main waste-generative sectors considered for the reference scenario are Food, Agriculture, WASH and NFI. Education and Health were excluded as they fall outside the project scope, since Bio4human tackles bio-based solutions for reducing solid waste. These same sectors were also highlighted in the Groupe URD's review[13] on the environmental footprint of humanitarian assistance. The waste types and associated products are included in the reference scenario with the sectors selected.

2.2.2 Composition of the kits

In this section it is described the composition of the kits: food, agriculture, WASH and NFI, as well as the construction material.

Food basket

The composition of the Food basket is an average composition based on documentation from the Food Security Cluster[14] and WFP[15], for the two countries (DRC and South Sudan), which indicates that a standard food basket typically includes cereals, pulses, vegetable oil, and iodized salt. The quantities were further refined using a joint report[16] from UNHCR, UNICEF, WFP, and WHO. According to country reports, in 2023, WFP assisted 5.6 million people in South Sudan[17] by distributing 190,000 metric tons of food and reached 5.3 million people in the DRC[18] with 97,000 metric tons of food in 2022.

[6] Packaging Baseline Assessment Based on Humanitarian Emergency Responses in 2021 | Shelter Cluster
[7] Streamlined Life Cycle Assessment of the World Food Programme Food Packaging | Logistics Cluster Website
[8] DRC : République Démocratique du Congo Plan de Réponse Humanitaire 2024 | Humanitarian Action
[9] South Sudan : South Sudan Humanitarian Response Plan 2024 | Humanitarian Action
[10] Bureau for Humanitarian Assistance - Annual Report for Fiscal Year (FY) 2023 - World | ReliefWeb
[11] Democratic Republic of the Congo - Complex Emergency Fact Sheet #9, Fiscal Year (FY) 2024 - Democratic Republic of the Congo | ReliefWeb
[12] South Sudan - Complex Emergency Fact Sheet #3, Fiscal Year (FY) 2024 - South Sudan | ReliefWeb
[13] Environmental footprint of humanitarian assistance-scoping review - World | ReliefWeb
[14] FSAC Minimum Food Basket Transfer Value Guidelines – Food security cluster
[15] What is a food basket? | World Food Programme (2025)
[16] Food and nutrition needs in emergencies - UNHCR, UNICEF, WFP and WHO (2004)
[17] Annual Country Reports - South Sudan | World Food Programme
[18] Annual Country Reports - Democratic Republic of the Congo | World Food Programme

Ready-to-Use Therapeutic Food (RUTF) was also included in this food basket, as it is a r source of metallized sachet waste. RUTF is primarily used to treat severe acute malnutrition[19] in children under five, and for pregnant ad breastfeeding mothers. It is composed of powdered milk, peanuts, butter, vegetable oil, sugar, and a premix of vitamins and minerals. Each sachet provides 500 kilocalories along with essential micronutrients[20]. For a family with 2 children under five years old, the quantity of sachets would be 2 (children) x 7 (days/week) x 4 (weeks/month).

Packaging data for the Food basket were sourced from WFP[21]. The table below summarizes the composition of the Food basket for a family of 7 with 2 children under 5 that it is used as the reference scenario.

Table 3. Food basket composition

Food basket composition			
Item		**Quantity for 1 family for 1 month**	
Wheat flour		60kg	
Rice		29kg	
Vegetable oil		6L	
Pulses (like beans)		14kg	
Salt		1kg	
Sugar		6kg	
RUTF		7 sachets per week per child[22] = 2*7*4 = 56 sachets of 92 g = 5.15kg	
Item	**Primary packaging**	**Secondary packaging**	**Tertiary packaging**
Solids	PE bag	PP woven bag	Tape and Wooden Euro pallet
Liquid	HDPE jerry cans	Cardboard	Tape and Wooden Euro pallet
RTUF	Metallized Sackets	Cardboard	Tape film, tape and Wooden Euro pallet

Agriculture Kit

The composition of the agriculture kit was defined based on the crop, vegetable, and fishing kits described in reports from the Food and Agriculture Organization (FAO) of the United Nations for both the DRC[23] and South Sudan[24]. In 2022, FAO supported over 760,210 people in DRC through agricultural assistance, contributing to improved food security and in South Sudan, FAO planned to assist over 1 million farmers with the distribution of 10,000 tons of seeds[25].

Fertilizer was also included in the kit, with the type and quantity determined based on data from a Food Security and Agriculture Cluster report[26]. To identify relevant

[19] https://www.wfp.org/specialized-nutritious-food
[20] Saving lives with RUTF (ready-to-use therapeutic food) | UNICEF Supply Division
[21] Specifications Index - WFP
[22] Optimal_quantity_of_RUTF_for_the_treatment_of_severe_wasting_and_or_nutritional_oedema_r535872.pdf
[23] Democratic Republic of the Congo: Humanitarian Response Plan 2024 - FAO
[24] South Sudan: Humanitarian Needs and Response Plan 2024 - FAO
[25] Interactive map, Agricultural aid is humanitarian aid - FAO
[26] Guideline on Food Security and Agriculture Cluster Response Packages (May 2024) - Afghanistan | ReliefWeb

seed varieties, an additional source[27] from the South Sudan Ministry of Agriculture and Food Security was consulted.

*Table **4*** presents the composition of the agriculture kit considered for the reference scenario

Table 4. Agriculture kit composition

Agriculture kit composition			
Item		**Quantity for 1 family**	
Crop seeds		5kg per types of seeds	
Vegetable seeds		50g per types of seeds	
Hoe		1 unit	
Rake		1 unit	
Spools of twine		2 units	
Filament		1 unit	
Box of hook		2 units	
Fertilizer DAP/urea		50 kg	
Item	**Primary packaging**	**Secondary packaging**	**Tertiary packaging**
Seeds	PE bag	PP woven bag	PE film and Wooden Euro pallet
Objects	Cardboard	/	PE film and Wooden Euro pallet

WASH Kit

The composition of the WASH kit was established based on guidance from a UNICEF report[28], as well as resources provided by Oxfam[29] and UNFPA[30]. Information on packaging and item specifications was sourced from the UNICEF supply catalogue[31] and the UNHCR WASH kit specifications report[32]. The previously mentioned Joint Initiative report[33] was also consulted to obtain complementary data on packaging.

Additional sources were used to determine the composition of menstrual hygiene products[34] and adhesive tape[35] included in the kit.

*Table **5*** presents the composition of the WASH kit considered for the reference scenario.

[27] Main crops grown in South Sudan – Ministry of Agriculture and Food Security South Sudan
[28] UNICEF-WASH-Dignity-Kit-Guidance.pdf
[29] Hygiene Kits | Oxfam WASH Resources
[30] What is in a UNFPA Dignity Kit? - USA for UNFPA
[31] UNICEF Supply Catalogue
[32] UNHCR WASH equipment specifications | UNHCR
[33] Joint Initiative for Sustainable Humanitarian Assistance Packaging Waste Management: Packaging Baseline Assessment based on Humanitarian Emergency Responses in 2021 (May 2023) - World | ReliefWeb
[34] Toward eco-friendly menstrual products: a comparative life cycle assessment of sanitary pads made from bamboo pulp vs. a conventional one | Environmental Science and Pollution Research (2025)
[35] Wanslin PVC Tape

Table 5.WASH kit composition

WASH kit composition			
Item		**Quantity for 1 family**	
Water container without logo (3)		2	
Bucket with lid (3)		1	
Soap toilet bar wrapped (1)		12	
Water purification tablets (50 tablets /unit) (2)		6	
Torch handheld self-powered (2)		1	
Child potty		1	
Multipurpose cloth (1)		2	
Reusable menstrual pads set (1)		2	
Female disposable sanitary pads with wings (1)		2	
Whistle (3)		1	
Female underwear set (1)		1	
Laundry detergent (3)		1	
Guidance on kit use (1)		1	
Item	**Primary packaging**	**Secondary packaging**	**Tertiary packaging**
(1)	PE bag	Cardboard	PE film and Wooden Euro pallet
(2)	Cardboard	Cardboard	PE film and Wooden Euro pallet
(3)	/	Cardboard	PE film and Wooden Euro pallet

NFI Kit

The composition of the Non-Food Item (NFI) kit was determined using a report[36] from the Global Shelter Cluster, which provided details on the items included and their respective quantities. For material and packaging specifications, reference was made to two UNHCR reports: one[37] describing the global NFI kit and another[38] focused specifically on the kitchen set.

Table ***6*** presents the composition of the NFI kit used in the reference scenario.

Table 6. Non-Food Item kit composition

Non-Food Item kit			
Item		**Quantity for 1 family**	
Plastic sheet / tarpaulin (1)		2	
Sleeping mat (1)		3	
Blankets (1)		3	
Jerrycans (3)		2	
Kitchen set (2)		1	
Solar lamp (2)		1	
Mosquito net (1)		2	
Item	**Primary packaging**	**Secondary packaging**	**Tertiary packaging**

[36] Shelter and NFI Cluster Sudan - Standard NFI kit Composition | Shelter Cluster
[37] UNHCR Core Relief Items Catalogue | Shelter Cluster
[38] Kitchen set | UNHCR

(1)	PE bag	Cardboard	PE film and Wooden Euro pallet
(2)	Cardboard	Cardboard	PE film and Wooden Euro pallet
(3)	/	Cardboard	PE film and Wooden Euro pallet

Construction

Construction solutions involving thermal insultation products were retained due to their potential relevance in humanitarian contexts where thermal insulation is a significant concern. This is not the case for South Sudan and DRC, where the Bio4HUMAN D3.3 surveys identified plasterboard and bricks as the primary construction-related waste materials.

However, in countries with colder climates, thermal insulation can be more relevant, justifying the inclusion of these solutions. For the reference scenario, **mineral wool** was selected, as it is the most widely used thermal insulation material globally[39].

2.2.3 Logistics

The logistics for delivering humanitarian aid to countries such as DRC and South Sudan are highly complex, primarily due to the length and fragmentation of supply chains. Aid kits are often sourced from international suppliers and assembled in global or regional logistics hubs such as Nairobi, Mombasa, or Kampala, which serve as key entry points for humanitarian operations in East and Central Africa[40]. From there, transporting aid into DRC and South Sudan typically involves multimodal logistics, combining sea freight, overland trucking, and in some cases, air transport—especially during the rainy season when roads become impassable[41] Both countries face significant infrastructure constraints: South Sudan is landlocked and heavily reliant on border access through neighbouring countries[42], while DRC has limited functional port capacity and vast interior regions difficult to access[43]. Customs delays, insecurity, and bureaucratic hurdles further disrupt supply chains. Indeed, ongoing insecurity has also triggered civil unrest, looting, and disruption of humanitarian supply chains[44]. Once inside the country, poor road conditions, remote target areas, and volatile security environments complicate last-mile delivery.

Food Aid can also be supplied locally. In fact, in both South Sudan and the DRC, local food supply chains play a critical role in humanitarian operations by improving delivery speed and supporting local economies. In South Sudan, aid agencies such as the World Food Programme (WFP) use river barges to transport food commodities like sorghum from regional markets when roads are inaccessible due to flooding, and complement this with last-mile delivery using trucks and motorcycles[45]. Local production supported by the Food and Agriculture Organization (FAO) in towns like

[39] All 9 Types Of Insulation Explained (Materials, R-Values, Applications)
[40] UNICEF Supply Annual Report 2022
[41] Logistics Cluster - 2023 Annual Report
[42] South Sudan Humanitarian Needs Overview 2021
[43] Logistic cluster Democratic Republic of Congo Logistics Infrastructure
[44] WFP- https://reliefweb.int/report/democratic-republic-congo/wfp-democratic-republic-congo-drc-eastern-drc-emergency-situation-report-2025-2
[45] Food security cluster - https://fscluster.org/fr/south-sudan-rep/document/wfp-situation-report-278

Wau provides staples such as cowpeas for both local markets and humanitarian food baskets[46]. In the DRC, WFP partners with smallholder farmers[47] in provinces to source maize and beans, which are distributed via road networks to crisis-affected areas—shortening supply chains and bolstering local livelihoods.

Figure 6 shows how the humanitarian aid supply chain depends on the locations of the suppliers. The transportation methods used to cover the different distances depend on whether the suppliers are local, regional or international. When suppliers are local, aid delivery typically requires only one mode of transport; such as a truck—**unless** the destination is in an area that cannot be reached by road or air alone. In contrast, if the suppliers are regional or international, multiple modes of transport are usually necessary. This may include a combination of ships, planes, and various types of trucks or vehicles to ensure the aid reaches its final destination.

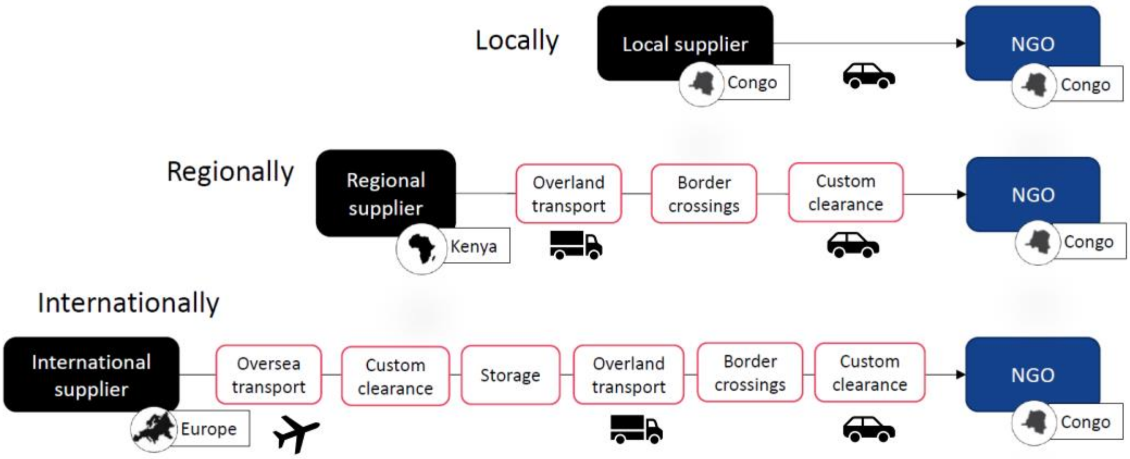

Figure 6. Humanitarian Logistic Supply Chain. (PIN and PAH)

Average origins of imports of South Soudan and the DRC were assessed for products of the kits using import statistics from **https://www.trademap.org/**. Based on those origins of imports, the most plausible routes of transport were defined using different tools to collect, harbours, sea distances, truck distances etc. (**Fluent cargo**, **Sea distance**, Google maps). Detailed inventories for the modelling can be found in Annex 1.

2.2.4 End of Life

From Bio4HUMAN D3.3, we know that an estimated 10% of waste—such as plastics, cartons, and metals (e.g., steel from packaging)—is formally collected, primarily in urban centres. Concerning waste management, the two countries studied, South Sudan[48],[49] and DRC[50], are similar. As described, in the D3.3, since it cannot be distinguished between the humanitarian waste and general waste once it enters

[46] FAO - https://openknowledge.fao.org/server/api/core/bitstreams/6169665b-8a47-4093-bdc7-82bfc79c6dbd/content
[47] WFP - https://www.wfp.org/countries/democratic-republic-congo
[48] Current Status of Municipal Solid Waste Management in Juba City, South Sudan (2020)
[49] Official Launching of "Solid Waste Management Master Plan in Juba City 2021-2030" (2022)
[50] Environmental and economic performances of municipal solid waste management strategies based on LCA method: A case study of kinshasa (2023)

waste streams, it makes almost impossible to state what pertains only to the humanitarian sector.

Waste management remains highly limited due to infrastructural and institutional constraints. Most of the waste is either openly dumped or ends up in unmanaged landfills with little to no environmental controls. In rural and conflict-affected areas, where most humanitarian interventions take place, formal waste management systems are virtually non-existent. As a result, materials from aid operations are often burned in open pits or discarded in the local environment, contributing to pollution and health risks. Recycling activities are minimal, informal, and focused mostly on high-value materials like scrap metal, while plastic and cardboard are rarely recovered at scale. The following pie chart in Figure 7, gives an idea of the scenarios considered for the end-of-life in those two countries.

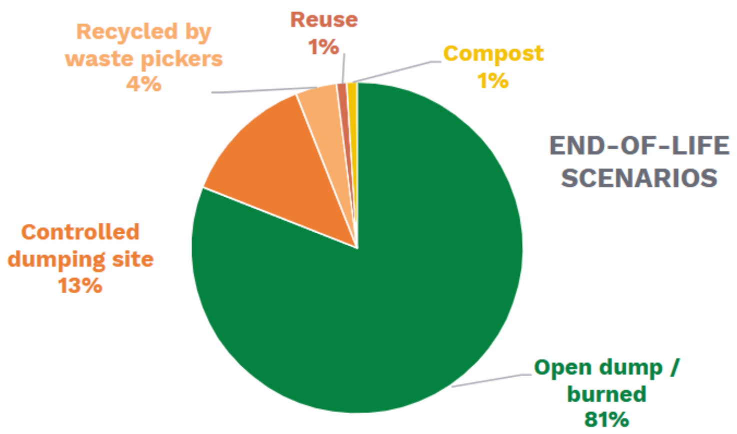

Figure 7. End-of-life scenarios considered for reference scenarios in DRC and South Sudan

Detailed inventories for the modelling of the end-of-life can be found in the Annex 1.

2.2.5 Functional Unit: Reference Scenario

In line with Life Cycle Assessment (LCA) principles, a clearly defined functional unit is essential to ensure comparability and consistency between the reference scenario and the bio-based alternatives. The functional unit chosen for this study is: "**The delivery and end-of-life management of one humanitarian aid kit to a beneficiary household, fulfilling the same functional performance in terms of utility, durability, and hygiene, under field conditions in South Sudan or the Democratic Republic of Congo**."

The functional unit is defined per type of humanitarian kit (Food, WASH, Agriculture, or NFI). Each kit contains a specific list of items as described in the reference scenario (see Section 2.1), with the assumption that the quantity and quality of aid items remain constant between the conventional and bio-based solutions. It encompasses the full life cycle of the kit, including sourcing, packaging (all levels), transport from international hubs to remote areas, and end-of-life treatment.

Additionally, some assessments may be conducted at material level when relevant for decision making context.

2.3 Solutions Selected and Substitution

In this section are first included the description of the different bio-based solutions that will undergo the LCA, and then the reference scenario of the substitution.

2.3.1 Description of the solutions

In this section is included a brief description of the innovative bio-based solutions that will undergo Life Cycle Assessment, and that were first included in the *D4.1.1 List of bio-based solutions*. Please take into consideration that no brands are given in this deliverable since the inventories that have been considered are generic.

2.3.1.1 Multipurpose packaging products

The solutions included in the "Multipurpose packaging products" are intended to cover the functionality of fastening or protection elements in all the kits (Transport packaging).

Mycelium protective material

This innovative bio-based solution consists of a combination of protective mailers made from mycelium and waste from the woodworking or agricultural industry. The function is to offer product protection while it is transported. The technology could be transferred to African locations. It is a 100% biodegradable material, according to ASTM D5988-18 (aerobic degradation in soil at 21 ± 2 ºC for 104 days)[51].

Adhesive tape

This self-adhesive tape is made from about 90% renewable resources, featuring a bio-based PLA film with natural rubber adhesive. It offers strong adhesion, low elongation, and easy hand treatability. Designed for sealing biodegradable bags, films, and sustainable packaging, it´s also suitable for sealing medium to heavy cardboard boxes and manual dispensers. The tape is certified as home compostable and biodegradable.

Biodegradable laminating film

This packaging features a 100% biodegradable laminating film made from renewable resources like corn. It's toxic-free, printable and water-resistant, offering protective packaging. Compatible with standard laminators, it ensures product safety during handling and distribution. It is 100% certified as industrial compostable.

[51] Technical data sheet for Myco material. Online: Myco-Technical_data_sheet-202505_EN

2.3.1.2 Food and drinks packaging products
The products included in this section are intended to substitute primary packaging items from the Food basket.

PLA bottle for water or for oil

This packaging solution consists of 100% plant-based water bottles made from sugar cane and non-GMO materials, including the cap and label. Available in various capacities, they offer a durable, sustainable alternative for bottled water and oil. The bottles are industrially compostable.

Compostable Pouch for RUTF

This solution is made from PLA, cellulose metallized and cellophane. This compostable pouch can be used to contain Ready-to-Use Therapeutic food (RUTF). This solution is fully biodegradable and compostable in natural conditions; therefore, it can be considered as home compostable.

2.3.1.3 Hygiene products
In this section are included the sanitary pads from the WASH kit that intend to substitute the conventional ones.

Sanitary pads

The sanitary pads are made from jute, bagasse, banana fibre, and water hyacinth, using agricultural plant waste materials. In a composting environment, they biodegrade within 180 days and can be used in agriculture. They are manufactured in simple factories with the potential to be transferred to humanitarian destinations. They are 100% home compostable and certified.

2.3.1.4 Construction related products
In this section are included the solutions from the construction sector that are included for replicability in other regions.

Foams for insulation

To reduce CO_2 emissions in buildings, innovative thermal insulation with 65-75% renewable material has been considered, including windows with thermal and acoustic performance, and insulation foams for roofs, walls, and floors, offering thermal efficiency. This material is recyclable.

Wool Insulation material

This solution consists of 100% natural sheep wool insulation that is renewable. It's suitable for roofs, walls, floors, and more, providing high insulation even when wet, moisture control, heat stability, and air purification. It also resists fire, mould, and condensation. It is reusable and biodegradable.

Hemp: Bio-based insulation

These products are made from hemp, a fast-growing bio-based material, with high bio-based content and thermal performance. It has been tested according to the

NCS 16785- Bio-based content certification scheme. This solution helps to reduce the carbon footprint of buildings. It is reusable and recyclable.

2.3.1.5 Other products potentially applicable in the context of humanitarian interventions

Disposable bag from renewable sources

This item is an alternative to disposable bags, made from renewable resources and available in various sizes. They can be disposed of with organic waste and break down within a maximum of 180 days under composting conditions, DIN EN 13432 Compostable certified[52].

Monofilaments fishing nets/Mosquito net

Monofilaments fishing/mosquito nets use bioplastic (PLA) formulations. It replaces conventional thermoplastics, reducing environmental impact, and integrates by-products for local valorisation. They are biodegradable.

2.3.1.6 Small-scale technologies

Anaerobic Digester technologies

The anaerobic biodigester technologies included in the deliverable D4.1 were screened into the List of biobased solutions of D4.2 that is summarized in Table 6. Anaerobic reactors were selected because they are versatile to accept different types of organic waste[53], including fibrous agricultural waste, food waste, low-risk organic waste, kitchen, garden residues, and animal or domestic manure. The influence of these differences on the effect of waste composition, on the energy efficiency of the technology, and the expected emissions to air, are compared with literature [54], as well as the operation conditions of the reactors[55].

Table ***7*** compares the fundamental reactor and operation variables of the technology to be accounted for during LCA modelling. From WP4, this list was reduced to four specific reactor types: Modular micro-AD system – Qube

[52] Bio4Pack compostable certificate for Waste bags. Online: https://www.bio4pack.com/wp-content/uploads/2025/01/7P0333_en-S1.pdf

[53] PacWatePlus. (2022). Factsheet: Small-scale anaerobic digestion (WET). https://pacwasteplus.org/regional-project/organics-management/

[54] Mengistu M. G., Simane B., Eshete G., Workneh T. S., (2016). "The environmental benefits of domestic biogas technology in rural Ethiopia ". *Biomass and Energy,* 90, 131-138. Dio: 10.1016/j.biombioe.2016.04.002

[55] Uzorka A., Wonyanya M. (2025). " Design and performance evaluation of small-scale biogas digesters using locally available materials in rural Uganda", *Renewable Energy,* 246, 122994. Doi: 10.1016/j.renene.2025.122994

Renewables[56], single stage biogas digester[57], micro biogas digesters[58] and domestic biogas technologies[59].

To facilitate the data collection in D5.1 for LCA modelling, they can be grouped as a single biogas digester, based on their similar operation and construction characteristics. The main differences lie on the size, cost and particular innovations that can be analysed as different scenarios upon sensitivity analyses for adaptation to the Bio4HUMAN case studies. The variations in in scale (processing capacity) depend on the amount of waste to be converted to biogas or biomethane.

[56] QUBE renewables. (2023). dryQUBE. accessed on June 20th, 2025. https://www.quberenewables.co.uk/dryqube

[57] DIVAGRI. (2020). Biogas Digester. accessed on June 23th, 2025. https://divagri.org/single-stage-solar-supported-biogas-digester/

[58] Preparation action on smart Rural Areas in the 21th century. (2022). Micro-Biogas Digesters. accessed on June 22th, 2025. https://www.smartrural21.eu/smart-solution/micro-biogas-digester/

[59] Nzila C., Dewulf J., Spanjers H., Tuigong D., Kiriamiti H., Langenhove H. V. (2012). "Multi criteria sustainability assessment of biogas production in Kenya ". *Applied Energy*, 93, 496-506. doi: 10.1016/j.apenergy.2011.12.020

Table 7. Characteristics of the four types of anaerobic digestion technologies.

Waste-to-energy technologies				
Aspect	**Modular micro-AD system Renewables**	**Single Stage Biogas Digester**	**Micro-biogas Digester**	**Domestic biogas technology**
Type of digester	Fixed, on the ground	Fixed dome	Fixed dome or portable	Floating drum
Type of technology	Dry, needs irrigation with liquid digestate	Wet	Wet	Wet
Type of feedstock	High lignocellulose agricultural crops (straw bagasse, wheat&rape)	All kinds of **organic** waste	All kinds of **organic** waste, scaling-down	Fibrous and non-fibrous **organic** (e.g., animal manure, vegetable waste
Stages	single	Single	Single	Single
Cost	Medium to high	Low (local materials, labor)	Very low	Low to medium
Operating conditions	No additional heating; 60-90 days	45-55ºC; 15-25 days	20-40ºC; 20-25 days	35-55ºC; 20-30 days
Digestate treatment	Fertilizer	Fertilizer	Fertilizer	Ferilizer
Construction materials/spare parts	Modular bought, 2 weeks installation	Locally sourced (stones, cement, wood, iron rods, PVC, copper pipes)	DIY concrete (2 mixers), 3 days; Portable: plastic	Brick, concrete, with 2.5mm steel sheets on the sides and the top
Labour construction	About 11 people	1 supervisor, 2 workers (18-62 days construction)	10-15 volunteers (construction); portable: 1 person, 2 days	1 supervisor, 2 workers (18-62 days)
Maintainance	Easy after careful familiarization	Easy after careful familiarization	Easy after careful familiarization	Easy after careful familiarization
Training	Standard Operating procedure to understand process, simple & careful			

Biogas upgrading	Optional: -Biogas treatment pods to clean and dry raw biogas. - Biogas storage - Biomethane upgrade for bioCNG. - Combined heat and power biogas generator (CHP). - Biogas boilers - Control system with remote access - The Qube app	combined heat and power (CHP) generator	Cooking and heating	Combined heat and power (CHP) generator if biogas upgrading unit attached, biomethane can be used for vehicles
Context	Tested in Delhi (India); Qube Renewables website	Divagri.org; the information is based on case studies from Uganda, Egypt, Kenya	Tested in Sweden and Egypt	The information is based on case studies from Kenya, Egypt, Italy

Black Soldier Fly (BSF)

This technology employs Black Soldier Fly (BSF) larvae to convert organic waste into protein-rich animal feed and organic fertilizer, thereby contributing to waste reduction and promoting sustainable agricultural practices. The Small-Scale Residue Utilization Pathways (SSRUP) – Black Soldier Fly technology originates from a project primarily funded by the European Union and has been implemented in several African countries, including Uganda, Ethiopia, and Côte d'Ivoire.

Meanwhile, the Black Soldier Fly Organic Waste Processing System is being developed under a joint initiative implemented by the ACEN Foundation in collaboration with other partners. Within the Bio4HUMAN project, both technologies[60] [61] are under consideration, and their respective characteristics are detailed in *Table **8***.

Table 8. Characteristics of the two types of BSF technologies

Black soldier fly larvae technologies		
Aspect	**Black soldiers fly organic waste processing system**	**Small-Scale Residue Utilization Pathways (SSRUP) – Black Soldier Fly technology**
Operating Process	Waste pre-processing → biowaste treatment → BSFL separation → product refinement	Features dark cage and love cage for breeding; organic waste used to attract adult BSF
Applicability	Targets all organic waste fractions: solid waste, industrial, and agricultural residues	Designed for rural and remote areas; focuses on small-scale or community-based setups
Size/Scale	Larger, fixed facility with integrated processing steps	Mobile, small-scale biorefinery; more adaptable to different locations
Ease of Installation & Maintenance	Likely more complex due to fixed infrastructure and multiple processing stages	Simpler, mobile setup; tailored for areas with limited infrastructure
Cost	Likely more complex due to fixed infrastructure and multiple processing stages	Simpler, mobile setup; tailored for areas with limited infrastructure
Environmental & Circular Economy	Strong environmental benefits: waste valorisation, compost production	Emphasizes circular bioeconomy, supports rural livelihoods and sustainable agriculture
Effectiveness	High (Technology Readiness Level 9	Promising (Technology Readiness Level 8)
Feedstock Acceptance	Wide range of feedstock (solid, industrial, agricultural waste)	Decomposing organic waste, more suitable for household and local sources

[60] ACEN. (2024). Black Soldier Fly Opportunities Explored in Uganda, Ethiopia, and Ivory Coast. accessed on June 25th, 2025. https://acenfoundation.org/project/black-soldier-fly-opportunities-explored-in-uganda-ethiopia-and-ivory-coast/

[61] DIVAGRI. (2025). Small-scale Residue Utilisation Pathways (SSRUP) Black Soldier Fly. . accessed on June 25th, 2025. https://divagri.org/biorefinery/

Operating Conditions	Requires more infrastructure and controlled processing	Designed for field conditions; tolerates low-tech environments

2.3.2 Substitution in the reference scenario

The **innovative bio-based solutions** that have been studied in section 2.3.1 **have the aim to substitute some of the items of the reference scenarios** described in section 2.2. In this sense, in Table 9 it is included the innovative bio-based solution along with the reference scenario that it is being substituted and the kit to which it belongs to.

Table 9. Reference scenario that the innovative bio-based solution will substitute

Item	Reference scenario substitution	Type of kit
PLA bottle for water	PET water bottle	Primary Packaging in Food basket
PLA bottle for oil	HDPE jerry cans	Primary Packaging in Food basket
Compostable sachet for RTUF	Metallized sachets	Primary Packaging in Food basket
Adhesive tape	PLA + natural adhesive	Tertiary packaging in all kits
Biodegradable laminating film	PE film for tertiary packaging	Tertiary packaging in all kits
Mycelium protective material	Expanded PS	Packaging for fragile goods
Disposable bag from renewable sources	PE bag	Primary packaging in all kits
Foams for insulation	Glass wool	Construction material
Wool Insulation material	Glass wool	Construction material
Bio-based insulation	Glass wool	Construction material
Sanitary pads	Female disposable sanitary pads with wings	Wash kit
Monofilaments fishing nets/Mosquito net	Mosquito net	Non-food item kit
Anaerobic Digester technologies	Energy production from other fuels (air dried wood, branches, leaves, twigs, charcoal, crop residues, dung fuel, electricity, kerosene Incineration	End of life solutions / Pulp and paper, Agriculture kit
Black Soldier Fly (BSF)	Open dump	End of life solutions/Agriculture kit

2.3.3 Functional Unit: bio-based solution

The functional unit depends on the final solution. Therefore, for Bio4HUMAN project each solution has a different functional unit, since each bio-based product has a different function.

Table ***10*** illustrates the information about the functional unit and the reference flow of the solutions.

Table 10. Functional unit and reference flow of the innovative bio- based solutions

Item	Functional Unit	Reference flow bio-based solution	Reference flow of reference scenario
PLA bottle for water	To contain 1 L of water	1L PLA bottle	1L PET bottle
PLA bottle for oil	To contain 2 L of oil	2L PLA bottle	2L PET bottle
Adhesive tape	1 m^2 of adhesive tape	50.7 gr bio-based adhesive tape	1 m2 of adhesive tape
Biodegradable laminating film	1 m^2 of film to be used as tertiary packaging	37.2 gr of bio-based film	1 m2 of film
Compostable sachet for RTUF	To contain 92 gr of RTUF	1 compostable sachet for RTUF	To contain 92 gr of RTUF
Foams for insulation	To thermally insulate 1m2 of surface with an R=1W/m2K	1m^2 bio-based polyurethane insulation	1m^2 of glasswool
Wool Insulation material	To thermally insulate 1 m^2 of surface with an R=1W/m2K	1m^2 sheep wool insulation	1m2 of glasswool
Bio-based insulation	To thermally insulate 1m^2 of surface with an R=1W/m2K	1m^2 hemp insulation	1m2 of glasswool
Sanitary pads	240 pads used to cover the needs of a menstruating person for one year	1 disposable organic pad	1 disposable nonorganic pad
Disposable bag from renewable sources	Production of 1 bio-based bad with a capacity of 19,1 litres	Capacity of 19,1 litres	Capacity of 19,1 litres
Mycellium Protective material	1kg of product produced by in 2023 by the company	1 pack (mycelium production)	1 pack (standard production)
Monofilaments fishing nets	Providing protection for one person for one year	240.8 g of mosquito net	206.4 g of mosquito net
Digester technologies	1 t waste to produce energy	1 m^3 biogas	21.6 MJ of natural gas (estimated calorific value of biogas)
Black Soldier Fly (BSF)	1 t organic waste	65 kg of matured compost and 30.94 kg of animal feed.	Conventional Fertilizer

3. Life Cycle Inventory data of innovative bio-based solutions

In this section it is included the inventory data that the partners of WP5 (ITENE, WeLOOP, AIMPLAS and UC) have collected regarding the innovative bio-based solutions.

3.1 Data collection Template

Data on environmental performance was collected for the current and innovative bio-based waste management solutions identified in T4.2 Identification of existing solutions and supply chain gaps.

The life cycle stages, from cradle to grave, consider in the data collection from the project partners, including raw material extraction, primary production, processing, packaging, and transportation, products, and co-products, wastes, and emissions.

For the collection of information two templates were elaborated by WeLOOP: one for the product data collection (Annex 2) and the second one for the treatment/process (Annex 3).

3.2 Life Cycle Inventory data of innovative Bio-based solutions

The data collection of the different innovative biobased solutions has been organized among the partners that collaborate in this task according to the description in the Grant Agreement.

- Packaging (ITENE),
- Agricultural and hygienic plastic products (AIMPLAS),
- Pulp and paper, and agricultural waste management (UC)

In this section of the report is included the inventory data of each of the innovative bio-based solutions gathered by the Partners: ITENE, WeLOOP, AIMPLAS and University of Cantabria. The data is shown depending on the classification per reference kit.

Food baskets

In this section is included the Inventory data collected for the PLA solutions for containing water and oil and the bio-based sachets for RTUF

PLA bottle

Table 11. Inventory data of the PLA bottle for water (1L capacity)

PLA bottle for water				
Material	**Weight**	**Unit**	**Data set**	**Price**
Inputs				
PLA	40/0.997/0.976	g	Polylactic acid, granulate {GLO}| market for polylactic acid, granulate | Cut-off, U	Between 0.65-0.75 €/bottle
Extrusion	Extrusion, plastic film {RoW}| extrusion, plastic film | Cut-off, U Yield: 97.6%			
Blow moulding	Blow moulding {RoW}| blow moulding | Cut-off, U Yield: 99.7%			
Outputs				
PLA bottle	40	g	-	
End of life	**Data set**			
Industrially composting	40	g	Biowaste {RoW}| treatment of biowaste, industrial composting | Cut-off, U	

PLA is only compostable industrially under specific condition of pH and temperature. No credits with composting of PLA as no fertiliser are produced because of the absence of potassium, nitrogen or phosphorus in PLA.

Table 12. Inventory data of the PLA bottle for oil (Capacity 2 L)

PLA bottle for oil				
Material	**Weight**	**Unit**	**Data set**	**Price**
Inputs				Between 0.65-0.75 €/bottle
PLA	69/0.997/0.976	g	Polylactic acid, granulate {GLO}| market for polylactic acid, granulate | Cut-off, U	
Extrusion	Extrusion, plastic film {RoW}| extrusion, plastic film | Cut-off, U Yield: 97.6%			
Blow moulding	Blow moulding {RoW}| blow moulding | Cut-off, U Yield: 99.7%			
Outputs				
PLA bottle	69	g	-	
End of life	**Data set**			
Industrially composting	69	g	Biowaste {RoW}| treatment of biowaste, industrial composting | Cut-off, U	

PLA is only compostable industrially under specific condition of pH and temperature. No credits with composting of PLA as no fertiliser are produced because of the absence of potassium, nitrogen or phosphorus in PLA.

Compostable sachets for RTUF

Table 13. Bio-based sachets for RTUF

Bio-based sachets for RTUF				
Material	**Quantity**	**Unit**	**Dataset**	**Price**
Inputs				
PLA	1.05/0.945/0.965/0.969	g	Polylactic acid, granulate {GLO}| market for polylactic acid, granulate | Cut-off, U	0.047 €/ud
PBAT	1.05/0.945/0.965/0.969	g	1,4-butanediol {GLO}| market for 1,4-butanediol | Cut-off, U	
Cellophane	0.94/0.945/0.965	g	Table 14	
Metallized cellulose	0.94/0.945/0.965	g	Table 15	
Extrusion/coextrusion PLA+PBAT	Extrusion, co-extrusion {RoW}| extrusion, co-extrusion of plastic sheets | Cut-off, U Yield: 96.9%			
Adhesive lamination of the components of the bio-based pouch	Table 16 Yield: 96.5%			
Shaping-Electricity[62]	0.000375	kWh/0.015 m2	Electricity, medium voltage {GLO}| market group for electricity, medium voltage | Cut-off, U Yield: 94.5%	
Outputs				
Bio-based sachets	4.2	g	-	
End of life				
Home compostable	4.2	g	Biowaste, garden waste {RoW}| treatment of garden biowaste, home composting in heaps | Cut-off, U	

The cellulose part has credits with the production of fertilisers during compost.

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Table 14. Cellophane production[63]

Cellophane production			
Material	**Quantity**	**Unit**	**Dataset**
Inputs			
Fibers	63.09	%	Sulfate pulp, bleached {RoW}| market for sulfate pulp, bleached | Cut-off, U
NaOH	11.67	%	Sodium hydroxide, without water, in 50% solution state {RER}| market for sodium hydroxide, without water, in 50% solution state | Cut-off, U
Carbon disulphide	22.08	%	Sulfur {GLO}| market for sulfur | Cut-off, U
Sulfuric acid	Variable	%	-
Glycerine	3.15	%	Glycerine {RoW}| market for glycerine | Cut-off, U
Cellophane extrusion	Extrusion, plastic film {RoW}| extrusion, plastic film | Cut-off, U Yield 97.6%		
Outputs			
Cellophane	0.94	g	-

63 https://www.researchgate.net/profile/Abdelhamid-Aboalasaad/publication/347096687_THE_RELATION_BETWEEN_VISCOSE_FIBERS'_CHARACTERISTICS_AND_THEIR_YARN_PROPERTIES/links/5fd7f455299bf140880f5a27/THE-RELATION-BETWEEN-VISCOSE-FIBERS-CHARACTERISTICS-AND-THEIR-YARN-PROPERTIES.pdf

Table 15. Metallized cellulose production

Metallized cellulose			
Material	**Quantity**	**Unit**	**Dataset**
Inputs			
Fibers	63.09	%	Sulfate pulp, bleached {RoW}| market for sulfate pulp, bleached | Cut-off, U
Aluminium	11.67	%	Aluminium, cast alloy {GLO}| aluminium ingot, primary, to aluminium, cast alloy market | Cut-off, U
Vapour deposition	0.015	m2	Selective coat, copper sheet, physical vapour deposition {RoW}| selective coating, copper sheet, physical vapour deposition | Cut-off, U
Output			
Metallized cellulose	0.94	g	-

Table 16. Adhesive lamination[62]

Adhesive lamination			
Material	**Quantity**	**Unit**	**Dataset**
Inputs			
Polyurethane base adhesive	0.0525*67.01%	g/0.015m2	Polyether polyols, long chain {RoW}| market for polyether polyols, long chain | Cut-off, U
	0.0525*35.00%	g/0.015m2	Methylene diphenyl diisocyanate {RoW}| market for methylene diphenyl diisocyanate | Cut-off, U
Solvent	0.07875	g/0.015m2	Ethyl acetate {GLO}| market for ethyl acetate | Cut-off, U
Electricity	9.75E-05	kWh/0.015m2	Electricity, medium voltage {GLO}| market group for electricity, medium voltage | Cut-off, U
Electricity	3.75E-04	kWh/0.015m2	Heat, central or small-scale, natural gas {GLO}| market group for heat, central or small-scale, natural gas | Cut-off, U
Outputs			
Sachet with all the layers bonded	4.2	g	-

Non-food item kit

Mosquito nets/fishing nets

In this section is included the Inventory data collected for the mosquito nets. It should be taken into account that it is modelled as generic since no data was provided apart from the density and the major component. The dimensions are supposed to be the same as for the conventional product of reference, as well as the processes for its production.

Table 17. Inventory data of the mosquito nets

Mosquito nets				
Material	**Weight**	**Unit**	**Data set**	**Price**
Inputs				
>90% PLA	1,25g/cm3*0.04608 m3[64]	g	Polylactic acid, granulate {GLO}| market for polylactic acid, granulate | Cut-off, U	9 €/kg
Weaving	Weaving, synthetic fibre {GLO}| market for weaving, synthetic fibre | Cut-off, U			
Outputs				
Mosquito net	57.6	Kg/0.04608m3		
End of life	**Data set**			
Biodegradable	Biowaste, garden waste {RoW}| treatment of garden biowaste, home composting in heaps | Cut-off, U			

[64] For the Life Cycle analysis, we would ask for the thickness, for this deliverable no more information was provided.

Construction kit

In this section are included the inventory data for the foams for insulation, sheep wool insulation and biobased insulation

Foams for insulation

Table 18. Inventory data for foams for insulation[65]

Foams for insulation			
Material	**Quantity**	**Unit**	**Dataset**
Inputs			
Linseed oil	0.447	kg	Proxy : Soybean oil, refined {GLO}| market for soybean oil, refined | Cut-off, U
Formic acid	0.14	kg	Formic acid {RoW}| market for formic acid | Cut-off, U
Hydrogen peroxide	0.444	kg	Hydrogen peroxide, without water, in 50% solution state {RoW}| market for hydrogen peroxide, without water, in 50% solution state | Cut-off, U
Tin catalyst	0.00137	kg	Tin {GLO}| market for tin | Cut-off, U
DABCO	0.00106406	kg	Proxy : Diethanolamine {GLO}| market for diethanolamine | Cut-off, U
Diethanolamine	0.00258	kg	Diethanolamine {GLO}| market for diethanolamine | Cut-off, U
Surfactant	0.00486	kg	Non-ionic surfactant {GLO}| market for non-ionic surfactant | Cut-off, U
Toluene diisocyanate	0.399	kg	Toluene diisocyanate {RoW}| market for toluene diisocyanate | Cut-off, U
Steam	1.38	MJ	Heat, from steam, in chemical industry {RoW}| market for heat, from steam, in chemical industry | Cut-off, U
Cooling duty	4.88	MJ	Cooling energy {GLO}| market for cooling energy | Cut-off, U
Water	0.14	m3	Water, deionised {RoW}| water production, deionised | Cut-off, U
Electricity	0.36	kWh	Electricity, medium voltage {RoW}| market group for electricity, medium voltage | Cut-off, U
Outputs			
Renewable Polyurethane	1	kg	**Price** : 17 euro / kg
Biogenic carbon	-0.394	kg	Carbon dioxide, biogenic
Wastewater	0.122	kg	Wastewater, average {RoW}| treatment of wastewater, average, wastewater treatment | Cut-off, U

[65] Pomeroy, R. S. (2023). "Rethinking Polyester Polyurethanes: Algae Based Renewable, Sustainable, Biodegradable and Recyclable Materials". Pays-Bas: Elsevier

End of Life			
Polyurethane credits with recycling	-0.9415	kg	Bio PU production process
Recycling process	1	kg	Proxy : Polyethylene, high density, granulate, recycled {RoW}| polyethylene production, high density, granulate, recycled | Cut-off, U
Transport	20	km	truck
Biogenic carbon	0.394	kg	Carbon dioxide, biogenic

This foam is recyclable and has credits of avoided production of fossil-based polyurethane

Bio-based insulation

Table 19. Data Inventory for bio-based insulation[66]

Bio-based insulation			
Material	**Quantity**	**Unit**	**Dataset**
Inputs			
Solar energy	29.9	MJ	Electricity, high voltage {RoW}| electricity production, solar tower power plant, 20 MW | Cut-off, U
diesel	0.0159	kg	Diesel {RoW}| market for diesel | Cut-off, U
urea N fertilizer	0.0153	kg	Inorganic nitrogen fertiliser, as N {RoW}| market for inorganic nitrogen fertiliser, as N | Cut-off, U
P2O5 fertilizer	0.0123	kg	Inorganic phosphorus fertiliser, as P2O5 {RoW}| market for inorganic phosphorus fertiliser, as P2O5 | Cut-off, U
K2O fertilizer	0.0138	kg	Inorganic potassium fertiliser, as K2O {RoW}| market for inorganic potassium fertiliser, as K2O | Cut-off, U
Lime	0.133	kg	Hydrated lime, loose {RoW}| market for hydrated lime, loose | Cut-off, S
Seed	0.0069	kg	Proxy : Linseed seed, at farm {RoW}| linseed seed production, at farm | Cut-off, U
Water	43.2	gal	Tap water {RoW}| market for tap water | Cut-off, U
Land	0.000379	ac	Occupation, grassland
Electricity	0.7312	kWh	Electricity, medium voltage {RoW}| market group for electricity, medium voltage | Cut-off, U

[66] Davis, Kara (2024), "Life cycle assessment of a hemp-based thermal insulation panel". WWU Graduate School Collection. 1295.

PE Fiber	0.0141	kg	Proxy : Textile, nonwoven polypropylene {GLO}| market for textile, nonwoven polypropylene | Cut-off, U
natural gas	0.0686	btu	Natural gas, high pressure {RoW}| natural gas production | Cut-off, U
Outputs			
Hemp insulation	1	m2	**Price** : 8 euro per m2
Biogenic carbon	-2.96	kg	Carbon dioxide, biogenic
CO_2 (emissions to air)	0.0241	kg	Carbon dioxide
NH_3 (emissions to air)	0.0023	kg	Ammonia
NO_3 (emissions to air)	0.00766	kg	Nitrate
N_2O (emissions to air)	0.000192	kg	Dinitrogen monoxide
PO_4 (emissions to surface water)	0.000123	kg	Phosphate
Cd (emissions to soil)	0.39	mg	Cadmium (II)
Cr (emissions to soil)	8.03	mg	Chromium (III)
Cu (emissions to soil)	-6.36	mg	Copper compounds
Pb (emissions to soil)	4.92	mg	Lead (II)
Ni (emissions to soil)	0.917	mg	Nickel (II)
Zn (emissions to soil)	-61.2	mg	Zinc (II)
H_2O (emissions to air)	98.1	gal	water / m3
H_2O (emissions to groundwater)	63.7	gal	waste water / m3
H_2O (emissions to surface water)	1.63	gal	waste water / m3

End of Life			
Hemp waste incineration	1.62	kg	Biowaste {GLO}| treatment of biowaste, municipal incineration | Cut-off, U
PET waste incineration	0.14	kg	Waste plastic, mixture {RoW}| treatment of waste plastic, mixture, municipal incineration | Cut-off, U
Electricity	-6.74	MJ	Electricity, medium voltage {RoW}| market group for electricity, medium voltage | Cut-off, U
Biogenic carbon	2.96	kg	Carbon dioxide, biogenic

Wool insulation material

Table 20. Inventory data for wool insulation material

Wool insulation material			
Material	**Quantity**	**Unit**	**Dataset**
Inputs			
NH4NO3	0.0623	kg	Ammonium nitrate {RER}| market for ammonium nitrate | Cut-off, U
Fertilizer	0.0103	kg	Fertilising, by broadcaster {CH}| processing | Cut-off, U
P2O5 fertilizer	0.0073	kg	Inorganic phosphorus fertiliser, as P2O5 {BE}| market for inorganic
Irrigation	0.0545	kg	Irrigation {DE}| market for | Cut-off, U
Lime	0.2905	kg	Lime {RER}| market for lime | Cut-off, U
Lime, packed	0.1053	kg	Lime, packed {Europe without Switzerland}| market for lime, packed | Cut-off, U
Animal feed - Maize	0.6587	kg	Maize grain {BR}| market for maize grain | Cut-off, U
KCl	0.0173	kg	Potassium chloride {RER}| market for potassium chloride | Cut-off, U
Shed	0.0006	kg	Shed {CH}| construction | Cut-off, U
Soda	110000	kg	Sodium chloride, powder {RER}| production | Cut-off, U
Animal feed - Soybean	0.4328	kg	Soybean meal {BR}| market for soybean meal | Cut-off, U
Tillage	0.0003	kg	Tillage, rolling {CH}| processing | Cut-off, U
Water	31.5224	L	From nature: Water, river

Electricity	0.6048	kWh	Electricity, medium voltage {RoW}| market group for electricity, medium voltage | Cut-off, U
Heat	6.068	kWh	Heat, district or industrial, natural gas {RoW}| market for heat, district or industrial, natural gas | Cut-off, U
Outputs			
Wool insulation	1	m2	Price: 10 euro per m2
biowaste	0.24	kg	Biowaste {RoW}| treatment of biowaste, industrial composting | Cut-off, U
Wastewater	37.56	L	Wastewater, average {RoW}| treatment of wastewater, average, wastewater treatment | Cut-off, U
CO2 biogenic	-1.85	kg	Carbon dioxide, biogenic
NH3 (emissions to air)	5.5E-01	kg	Ammonia
N2O (emissions to air)	4.1E-03	kg	Dinitrogen monoxide
NH4 biogenic (emissions to air)	1.4E-01	kg	Methane, biogenic
NO (emissions to air)	8.6E-04	kg	Nitrogen oxides
H2O (emissions to air)	3.2E-02	m3	Water/m3
Cd (emissions to river)	6.1E-10	kg	Cadmium
Cr (emissions to river)	1.5E-06	kg	Chromium
Cu (emissions to river)	1.2E-06	kg	Copper
Pb (emissions to river)	3.6E-09	kg	Lead
Ni (emissions to river)	2.5E-07	kg	Nickel
NO3 (emissions to groundwater)	7.9E-02	kg	Nitrate
PO4 (emissions to river)	2.0E-03	kg	Phosphate
P (emissions to river)	7.6E-04	kg	Phosphorus

H2O (emissions to groundwater)	1.8E-02	m3	Water, RoW
H2O (emissions to river)	4.5E-03	m3	Water, RoW
Zn (emissions to river)	4.0E-06	kg	Zinc
Cd (emissions to soil)	-2.5E-10	kg	Cadmium
Cr (emissions to soil)	-1.4E-06	kg	Chromium
Cu (emissions to soil)	-1.2E-06	kg	Copper
Pb (emissions to soil)	-2.9E-09	kg	Lead
Ni (emissions to soil)	-2.1E-07	kg	Nickel
Zn (emissions to soil)	-2.6E-06	kg	Zinc
End-of-Life			
Compost	1.1	kg	Biowaste, garden waste {RoW}| treatment of garden biowaste, home composting in heaps and containers| Cut-off, U
N fertiliser credits	-0.16 * 1.1 * 0.4	kg	Inorganic nitrogen fertiliser, as N {RoW}| market for inorganic nitrogen fertiliser, as N | Cut-off, U

Sheep wool contains 16% nitrogen hence producing nitrogen fertiliser during compost

WASH kit

Sanitary pads

In this section is included the inventory data of disposable organic sanitary pads depending on the country of production: United states, France and India.[67]

Table 21. Inventory for Sanitary Pads for United States (1 sanitary pad)

Sanitary Pads – US Product			
Material/Process	**Quantity**	**Unit**	**Dataset**
Inputs			
Paper	0.000475	kg	Kraft paper {RoW}|market for kraft paper | Cut-off, U
Box	0.00212	kg	Corrugated board box {RoW}|market for corrugated board box | Cut-off, U
Biopolymer	0.0005	kg	Polyester-complexed starch biopolymer {GLO}|market for polyester-complexed starch biopolymer | Cut-off, U
Organic cotton	0.004	kg	Fibre, cotton, organic {GLO}|market for fibre, cotton, organic | Cut-off, U
Glue	0.001	kg	Styrene-acrylonitrile copolymer {GLO}|market for styrene-acrylonitrile copolymer | Cut-off, U
Rayon	0.000952	kg	Fibre, viscose {GLO}|market for fibre, viscose | Cut-off, U
Process			
Assembly	0.00387	kWh	Electricity, medium voltage {US}|market group for electricity, medium voltage | Cut-off, U
Transport			
Truck	0.003	tkm	Transport, freight, lorry, unspecified {RoW}|transport, freight, lorry, all sizes, EURO6 to generic market for transport, freight, lorry, unspecified | Cut-off, U
Boat	0.039	tkm	Transport, freight, sea, container ship {GLO}| transport, freight, sea, container ship | Cut-off, U
End-of-life			
Landfill	0.0027	kg	Municipal solid waste {RoW}|treatment of municipal solid waste, sanitary landfill | Cut-off, U
Flushed	0.0002	m^3	Wastewater, from residence {RoW}|market for wastewater, from residence | Cut-off, U
Incineration	0.00054	kg	Municipal solid waste (waste scenario) {RoW}| Treatment of municipal solid waste, incineration | Cut-off, U

[67] Fourcassier, S., Douziech, M., Pérez-López, P., et Schiebinger, L. (2022). Menstrual products: A comparable Life Cycle Assessment. Cleaner Environmental Systems 7. https://doi.org/10.1016/j.cesys.2022.100096

Table 22.Inventory for Sanitary Pads for France (1 sanitary pad)

Sanitary Pads – FR Product			
Material/Process	**Quantity**	**Unit**	**Dataset**
Inputs			
Paper	0.000475	kg	Kraft paper {RoW}|market for kraft paper | Cut-off, U
Box	0.00212	kg	Corrugated board box {RoW}|market for corrugated board box | Cut-off, U
Biopolymer	0.0005	kg	Polyester-complexed starch biopolymer {GLO}|market for polyester-complexed starch biopolymer | Cut-off, U
Organic cotton	0.004	kg	Fibre, cotton, organic {GLO}|market for fibre, cotton, organic | Cut-off, U
Glue	0.001	kg	Styrene-acrylonitrile copolymer {GLO}|market for styrene-acrylonitrile copolymer | Cut-off, U
Rayon	0.000952	kg	Fibre, viscose {GLO}|market for fibre, viscose | Cut-off, U
Process			
Assembly	0.00387	kWh	Electricity, medium voltage {RER}|market group for electricity, medium voltage | Cut-off, U
Transport			
Truck	0.005	tkm	Transport, freight, lorry, unspecified {RoW}|transport, freight, lorry, all sizes, EURO6 to generic market for transport, freight, lorry, unspecified | Cut-off, U
End-of-life			
Landfill	0.0027	kg	Municipal solid waste {RoW}|treatment of municipal solid waste, sanitary landfill | Cut-off, U
Flushed	0.0002	m^3	Wastewater, from residence {RoW}|market for wastewater, from residence | Cut-off, U
Incineration	0.00054	kg	Municipal solid waste (waste scenario) {RoW}| Treatment of municipal solid waste, incineration | Cut-off, U

Table 23. Inventory for Sanitary Pads for India (1 sanitary pad)

Sanitary Pads – IN Product			
Material/Process	**Quantity**	**Unit**	**Dataset**
Inputs			
Paper	0.000475	kg	Kraft paper {RoW}|market for kraft paper | Cut-off, U
Box	0.00212	kg	Corrugated board box {RoW}|market for corrugated board box | Cut-off, U
Biopolymer	0.0005	kg	Polyester-complexed starch biopolymer {GLO}|market for polyester-complexed starch biopolymer | Cut-off, U
Organic cotton	0.009	kg	Fibre, cotton, organic {GLO}|market for fibre, cotton, organic | Cut-off, U
Process			
Assembly	0.00387	kWh	Electricity, medium voltage {IN}|market group for electricity, medium voltage | Cut-off, U
Transport			
Truck	0,0025	tkm	transport, freight, lorry, all sizes, EURO6 to generic market for transport, freight, lorry, unspecified {RoW}
Boat	0,099	tkm	Transport, freight, sea, container ship {GLO}| transport, freight, sea, container ship | Cut-off, U
End-of-life			
Landfill	0.0094	kg	Municipal solid waste {RoW}|treatment of municipal solid waste, sanitary landfill | Cut-off, U
Flushed	0.00121	m^3	Wastewater, from residence {RoW}|market for wastewater, from residence | Cut-off, U
Incineration	0.0015	kg	Municipal solid waste (waste scenario) {RoW}| Treatment of municipal solid waste, incineration | Cut-off, U

Packaging

The products included in this section can be used in the different kits: Biodegradable film, the adhesive tape and disposable bag.

Laminating biodegradable film

Table 24. Inventory data of the tertiary packaging: Laminating biodegradable film (1m2)

<table>
<tr><th colspan="5">Tertiary packaging in all kits: Laminating biodegradable film</th></tr>
<tr><th>Material</th><th>Quantity</th><th>Unit</th><th>Dataset</th><th>Price</th></tr>
<tr><td colspan="4">Input</td><td rowspan="7">Between 6-8€/kg of film</td></tr>
<tr><td>PLA</td><td>37.268 /0.976</td><td>g</td><td>Polylactic acid, granulate {GLO}| market for polylactic acid, granulate | Cut-off, U</td></tr>
<tr><td>Extrusion</td><td colspan="3">Extrusion, plastic film {RoW}| extrusion, plastic film | Cut-off, U
Yield: 97.6%</td></tr>
<tr><td colspan="4">Output</td></tr>
<tr><td>PLA</td><td>1</td><td>m2</td><td>-</td></tr>
<tr><td>End of life</td><td colspan="3">Dataset</td></tr>
<tr><td>Industrially compostable</td><td colspan="3">Biowaste {RoW}| treatment of biowaste, industrial composting | Cut-off, U</td></tr>
</table>

[68] Weight for 1m^2 of film

Adhesive tape

Table 25. Inventory data of the tertiary packaging: Adhesive tape (1m2)

Tertiary packaging in all kits: Adhesive tape				
Material	**Quantity**	**Unit**	**Dataset**	**Price**
Input				Between 1.786-1.875 €/unit. In 1 unit there is approximately 80m*0.05m= 4m2
PLA	34.7/0.94	g	Polylactic acid, granulate {GLO}| market for polylactic acid, granulate | Cut-off, U	
Natural adhesive	16/0.94	g	Seal, natural rubber based {GLO}| market for seal, natural rubber based | Cut-off, U	
Extrusion-coating Yield: 94%[62]	0.0325	kWh/m2	Heat, central or small-scale, natural gas {RER}| market group for heat, central or small-scale, natural gas | Cut-off, U	
	0.1075	kWh/m2	Electricity, medium voltage {RER}| market group for electricity, medium voltage | Cut-off, U	
Outputs				
Adhesive tape	1	m2	-	
End of life	**Quantity**	**Unit**	**Dataset**	
Home compostable	50.7	g	Biowaste, garden waste {RoW}| treatment of garden biowaste, home composting in heaps | Cut-off, U	

Mycelium protective material

The company of this solution did not provide the inventory data to be modelled in BIO4HUMAN. Therefore only LCA results are available which will be analysed in D5.2 Hotspot analysis of the current and innovative solutions.

Other products potentially applicable in the context of humanitarian interventions

Disposable bag from renewable resources

Table 26. Disposable bag from renewable resources

Disposable bag from renewable resources			
Material/Process	**Quantity**	**Unit**	**Dataset**
Inputs			
Starch-polyester	10,682	g	Polyester-complexed starch biopolymer {GLO}| market for polyester-complexed starch biopolymer | Cut-off, U
Output			
Bio-based bags	10,621	g	-
Waste (recycled polyester)	0,061	g	Fibre and fabric waste, polyester {GLO}| fibre and fabric waste, polyester, Recycled Content cut-off | Cut-off, U
Process			
Energy	0,0111	kWh	Electricity, medium voltage {GLO}| market group for electricity, medium voltage | Cut-off, U
End-of-life			
Biodegradable	10.621	g	Biowaste {RoW}| treatment of biowaste, industrial composting | Cut-off, U

End of life solutions data

The end-of-life waste treatment technologies for the organic waste of the previous kits follow in Table 27 and Table 28.

Table 27. Inventory data of BSF technology organic waste to compost [69].

Black soldier Fly technology			
Material	**Quantity**	**unit**	**Dataset**
Input			
Organic Waste	1000	kg	-
BSF egg	0.53	kg/t organic waste	-
Energy consumption	71	kWh /t organic waste	Electricity, medium voltage {GLO}| market group for electricity, medium voltage | Cut-off, U
Output			
Compost	65	Kg/t organic waste	market for compost {GLO}| compost | Cutoff, U
Dried BSF pre-pupae for animal feed replacing soybean	30.94	Kg/t organic waste	soybean meal {RoW}| market for soybean meal | Cutoff, U
C (Emission to air)	99.95	Kg/t organic waste	Carbon
N (Emission to air)	6.45	Kg/t organic waste	Nitrogen
CH4 (Emission to air)	0.35	Kg/t organic waste	Methane
NH3 (Emission to air)	2.09	Kg/t organic waste	Ammonia
N2O (Emission to air)	0.06	Kg/t organic waste	Dinitrogen monoxide
H2O (Emission to air)	795.55	Kg/t organic waste	Water

[69] Guo, H., Jiang, C., Zhang, Z., Lua, W., Wanga. H. (2020). " Material flow analysis and life cycle assessment of food waste bioconversion by black soldier fly larvae (Hermetia illucens L.) ". Science of the Total Environment. 750, 141656.

Table 28. Inventory data of biogas anaerobic digestion for waste-to-energy [70].

Biodigester technology			
Material	**Quantity**	**unit**	**Dataset**
Input			
Organic waste (farm waste)	1000	kg	-
Cow-dung (inoculate)	100	kg	manure, liquid, cattle {GLO}|market for manure, liquid, cattle | Cutoff, U
Energy consumption (thermophilic)	121	kWh/ t organic waste	Electricity, medium voltage {GLO}| market group for electricity, medium voltage | Cut-off, U
Energy consumption (mesophilic)	189	kWh/ t organic waste	Electricity, medium voltage {GLO}| market group for electricity, medium voltage | Cut-off, U
Output			
Biogas	50	m3/ t organic waste	Price: 0.20-0.36 (€/m3) 71
Liquid effluent (water and 5% of nutrition rich digestate)	943	kg/ t organic waste	Digester sludge {RoW} |market for digester sludge | Cutoff, U
CO2 (air emission)	23688	g/ t organic waste	Carbon dioxide for thermophilic digesters
CH4 (air emission)	2.17	g/ t organic waste	Methane for thermophilic digesters
N2O (air emission)	0.043	g/ t organic waste	Dinitrogen monoxide for thermophilic digesters
CO2 (air emission)	37225	g/ t organic waste	Carbon dioxide for mesophilic digesters
CH4 (air emission)	3.41	g/ t organic waste	Methane for mesophilic digesters
N2O (air emission)	0.068	g/ t organic waste	Dinitrogen monoxide for mesophilic digesters

[71] European Biogas Association, IRENA publication: Biogas cost reduction to boost sustainable transport. Accessed on June 2, 2025. https://www.europeanbiogas.eu/irena-publication-biogas-cost-reductions-boost-sustainable-transport/

Raw materials inventory: PLA and PHB

The lower carbon footprint and environmental friendliness of polylactic acid (PLA) is one of the most widely produced bioplastics in the world. There are attempts from the manufacturing industry to partially replace petrochemical plastics with PLA, which are growing every year[72]. However, its production from crops makes that in some environmental impact categories: land use, ecotoxicity, and water use, the impacts are higher than conventional fossil plastics[73].

However, PLA can also be produced from PLA waste (mechanical and chemical), and from organic waste with free sugars (fruits). As stated in *" Reprocessing and Recycling of Poly(Lactic Acid): A Review"*[74], PLA is one of the fastest-growing bioplastics on the global market, and mechanical and chemical recycling of PLA is gaining prominence as a sustainable alternative to direct biodegradation. It also mentions that the use of organic waste as a raw material for PLA is a promising way to increase production without competing with food crops.

According to a Study of Total Energies Corbion on the LCA of PLA production[75], the largest contributions to the impacts of virgin PLA are in the lactic acid and sugar production. In this study it is also stated that by switching to circular lactic acid feedstock, the impacts in some categories are significantly reduced: Climate change (-22%), particulate matter (-19%), acidification (-17%), water use (-26%).

As most of the solutions included in this report are made from PLA, it has been decided to include the inventory data of this raw material, coming from different sources: virgin PLA, mechanically recycled PLA, chemically recycled PLA and PLA from organic waste, in order to analyse the differences in the impacts in T5.2.

This data has been obtained by articles, and external consultations with experts, so it should be considered an approximation to real data. Currently the recycled PLA and PLA coming from organic waste are not included in the existent data base.

Note that PLA and lactic acid inventory data as it is included in Ecoinvent 3.11 cannot be disclaimed, since it is a pay-for database, therefore it will not be broken down in this report.

[72] A review on biodegradable polylactic acid (PLA) production from fermentative food waste - Its applications and degradation - ScienceDirect
[73] SimaPro software
[74] Reprocessing and Recycling of Poly(Lactic Acid): A Review
[75] LCA: Environmental footprint of PLA production, Total Energies Corbion 2025

Mechanically recycled PLA

The process of mechanical recycling of PLA starts with the sorting of PLA waste (usually this process is done manually), then the pretreatment step (washing and drying), grinding and extrusion.

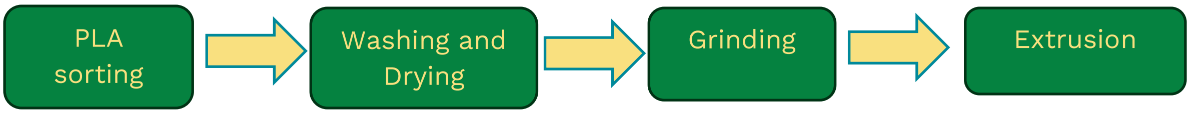

Figure 8. Flux diagram of mechanically recycling of PLA

The pretreatment includes the washing of PLA waste in order to eliminate impurities (labels, stickers, food or drink residue, dirt, etc) and then this waste has to be dried. The material is dried completely to prevent hydrolysis during the extrusion process.

The PLA once is clean and dry; PLA is ground into flakes or pellets. The flakes are melted and extruded to form new pellets that can be reused in manufacturing processes. The inventory data of the pretreatment step (washing and drying stages) is included in Table **26**, whereas the process of recycling the PLA is included in Table **27**.

Table 26. Inventory data of the pretreatment step for 1 ton of PLA waste[76]

Pretreatment of PLA waste			
Material	**Quantity**	**Unit**	**Dataset**
Input			
Transport of PLA waste to pre-treatment facility	25	km	Transport, freight, lorry, 7.5-16 metric ton, diesel, EURO 6 {RER}| market for transport, freight, lorry, 7.5-16 metric ton, diesel, EURO 6 | Cut-off, U
Diesel demand for PLA waste collection and transportation	1.98	kg	Diesel {RER}| market group for diesel | Cut-off, U
Water demand for washing	200	Kg/ton PLA	Water, deionised {Europe without Switzerland}| market for water, deionised | Cut-off, U
Washing agent (2% aq NaOH)	4	Kg/ ton PLA	Sodium hydroxide, without water, in 50% solution state {RER}| market for sodium hydroxide, without water, in 50% solution state | Cut-off, U
Thermal energy demand for drying	43	kWh/ton PLA	Heat, central or small-scale, natural gas {Europe without Switzerland}| market for heat, central or small-scale, natural gas | Cut-off, U
Elecricity for shreeding	63.53	kWh/ton PLA	Electricity, medium voltage {RER}| market group for electricity, medium voltage | Cut-off, U
Output			

[76] Valorisation of polylactic acid (PLA) waste: A comparative life cycle assessment of various solvent-based chemical recycling technologies - ScienceDirect

PLA net amount	943	Kg/ton flakes	-
Residues after sorting stage	12	kg/ ton flakes	Process-specific burdens, municipal waste incineration {Europe without Switzerland}| market for process-specific burdens, municipal waste incineration | Cut-off, U
Residues after washing stage	27	kg/ ton flakes	
Residues after shredding stage	18	kg/ ton flakes	-

Table 27. Mechanically recycling of 1 ton of PLA[77]

Mechanically recycled PLA			
Material	**Quantity**	**unit**	**Dataset**
Input			
PLA sorted	1	Ton	Assumed that recycling plant is constructed next to the sorting plant
Energy consumption: Extrusion and strand pelletizing	207	kWh/ton	Electricity, medium voltage {RER}| market group for electricity, medium voltage | Cut-off, U
Water	20	L/ton	Tap water {Europe without Switzerland}| tap water production, conventional treatment | Cut-off, U
Output			
PLA	950	Kg/ton flakes	-
Quantity of impurities from sieve exchanger	50	kg/ ton flakes	Basically paper
PLA losses during extrusion	1	%	-

According to ITENE experts on plastics recycling, PLA cannot be recycled indefinitely as it is biodegradable and therefore it loses quality. Therefore, it has been assumed that the **substitution range would be 50% PLA mechanical recycled and50% virgin PLA**. For the virgin PLA the database that would be use is provided by Ecoinvent 3.11: "Polylactic acid, granulate {GLO}| polylactic acid production, granulate | Cut-off, U".

[77] Life cycle assessment of recycling options for polylactic acid - ScienceDirect

Chemically recycled PLA

The chemical recycling process of PLA has the following stages: pretreatment of PLA waste, hydrolysis to obtain lactic acid (LA), repolymerization and purification for producing PLA (Figure 9).

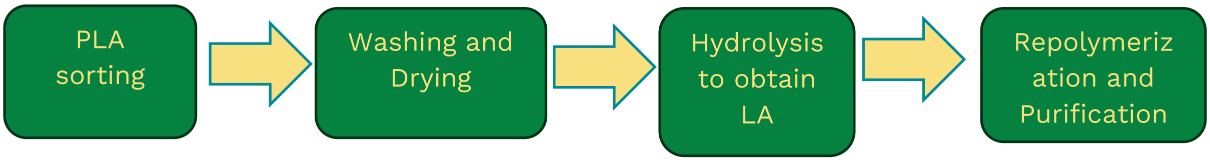

Figure 9. Flux diagram of chemically recycling of PLA

The pretreatment inventory data is already included in Table 26. For the hydrolysis, the data used was extracted from *"Valorisation of polylactic acid (PLA) waste: a comparative life cycle assessment of various solvent-based chemical recycling technologies"*[78]. The inventory data extracted from this article for the hydrolysis is included in Table 28.

Table 28. Hydrolysis stage of chemically recycling of PLA[78]

Hydrolysis stage			
Material	**Quantity**	**unit**	**Dataset**
Input			
PLA waste sorted after the pretreatment	943	Kg	-
Electricity demand for recycling	11	kWh/ton PLA	Electricity, medium voltage {RER}| market group for electricity, medium voltage | Cut-off, U
Thermal energy demand for recycling	5406	MJ/ ton PLA	Heat, central or small-scale, natural gas {RER}| market group for heat, central or small-scale, natural gas | Cut-off, U
Thermal energy demand for the entire downstream processing	15960	MJ/ ton PLA	
Solvent demand for recycling	5000	Kg/ton PLA	Water, deionised {Europe without Switzerland}| market for water, deionised | Cut-off, U
Output			
Amount of lactic acid produced	1225.18	Kg/ton PLA	-
Spent solvent for reuse	4774.82	kg/ ton PLA	Reintroduced in the process

For the Repolymerization and Purification steps, no data that allowed to obtain reliable results was available, since most of the information is at laboratory scale.

[78] Valorisation of polylactic acid (PLA) waste: A comparative life cycle assessment of various solvent-based chemical recycling technologies - ScienceDirect

In this sense, the Ecoinvent 3.11 database was used with some modifications to the PLA process that were added.

- Raw materials such as maize were erased and indicated as 0
- As stated in "Valorisation of polylactic acid (PLA) waste: A comparative life cycle assessment of various solvent-based chemical recycling technologies", For virgin PLA coming from crops the fermentation of lactic acid and its subsequent purification primarily accounts for 79% of the total energy required for PLA production.
- Therefore, the energy consumption of the PLA process from Ecoinvent 3.11, was adjusted to 21%.
- The wastewater output of the PLA production from Maize crops was also erased.

PLA obtained from organic waste

PLA is currently obtained from maize or sugarcane crops, which are rich in free sugars. However, these two sources compete with food cultivation. As stated in " *Reprocessing and Recycling of Poly(Lactic Acid): A Review*"[79], the use of organic waste as a raw material for PLA is a promising way to increase production without competing with food crops.

Therefore, after internal consultation with ITENE experts on producing Lactic acid from organic waste, and polymerization of PLA from this Lactic acid, the conclusions are as follows:

- The organic waste coming from fruits is a rich source of free sugars. Therefore, with this feedstock the production of PLA is similar to the PLA coming from maize. Other type of organic waste that does not have these free sugars, will need and additional hydrolysis step after the fermentation.
- The fermentation process will be the next step. According to ITENE experts that are working on this area, the yields of this process to obtain Lactic acid from organic waste are between 60%-80%.
- After the fermentation step, is the polymerization to produce PLA. According to ITENE experts on this process, the yields at laboratory scale that have been obtained are between 38%-45% (with commercial Lactic acid, the yields are between 62-68%).

Therefore, for modelling this PLA obtained from organic waste the following modifications were included to the PLA Ecoinvent 3.11 Process : *Polylactic acid, granulate {GLO}| polylactic acid production, granulate | Cut-off, U"*

- The maize crop was erased of the inventory data
- Fermentation yield for obtaining Lactic acid of 70%

[79] Reprocessing and Recycling of Poly(Lactic Acid): A Review

- Polymerization yield for obtaining PLA of 41.5%

PHB production

Polyhydroxybutyrate (PHB) is a bioplastic that is also used in packaging in different sectors. The origin of this kind of bioplastic is in bacteria which needs a source rich in sugars for growing and accumulate PHB. Table 29 includes the inventory data of the PHB.

Table 29. Inventory data of PHB production

PHB production			
Material	**Quantity**	**unit**	**Dataset**
Input			
Water	78.3	Kg	Tap water {Europe without Switzerland}| tap water production, conventional treatment | Cut-off, U
H2O2	52.9	kg	Hydrogen peroxide, without water, in 50% solution state {RER}| market for hydrogen peroxide, without water, in 50% solution state | Cut-off, U
Sulfuric acid	3	Kg	Sulfuric acid {RER}| market for sulfuric acid | Cut-off, U
Phosphoric acid	8.1	Kg	Phosphoric acid, industrial grade, without water, in 85% solution state {GLO}| market for phosphoric acid, industrial grade, without water, in 85% solution state | Cut-off, U
Sugar	1010	Kg	Sugar, from sugarcane {GLO}| market for sugar, from sugarcane | Cut-off, U
Heat	2123	Kg	Heat, district or industrial, natural gas {RER}| market group for heat, district or industrial, natural gas | Cut-off, U
Electricity	(1360+18.1+18.1 +1770+263.5+5 12)*0.2	kw h	Electricity, medium voltage {RER}| market group for electricity, medium voltage | Cut-off, U
Steam	1065+9.6+3819 +489E3	MJ	Steam, in chemical industry {RER}| market for steam, in chemical industry | Cut-off, U
Output			
PHB	1	Ton	-
Wastewater treatment	65.2	M3	wastewater, unpolluted {RoW} market for wastewater, unpolluted | Cut-off, U

4. Conclusions

This Deliverable on Data collection from the innovative bio-based solutions and reference scenario is the baseline for the future work on *T5.2 Hotspots analysis of the current and innovative solutions*. The solutions included in this deliverable will be modelled and analysed to determine the hotspots of the current and innovative bio-based waste management solutions.

This document fulfils the objectives that were set on Bio4HUMAN Grant Agreement for this T5.1:

- The goal and scope of the system was set to be "Cradle to Grave" to analyse the whole Life Cycle of the bio-based solutions including the end of life.

- The functional unit was established for each of the innovative bio-based solutions depending on its function.

- The template for data collection of products and technologies/processes was elaborated by WeLOOP. This template can be used for gathering data in other projects, making it replicable.

- The data of the reference scenarios, current practices, and logistics was collected by WeLOOP with the help of PIN/PAH. The reference scenarios were defined as four different kits: non-food, WASH, food basket and construction. In each of the kits, different items with its current package are included.

- The data of the bio-based solutions were collected by the LCA partners that collaborated in this task based on its expertise as stated along the report. This data was collected from consultations with the providers of the solutions, review of data base and the existent bibliography.

The data collection stage (LCI) is the most time-consuming stage of the Life Cycle Analysis. Data is often unavailable or classified as confidential by companies, thus it becomes necessary to search known databases, articles, sector-specific documents, or even consult experts on the subject. For the data inventory, data on bio-based solutions has been collected as global and European market averages, as no country-specific data has been provided.

Finally, it is worth mentioning that the results that will be obtained with the modelling of these inventories are estimated with a mathematical model that predicts their potential environmental impact. Therefore, the results of *T5.2 Hotspot analysis of the current and innovative solutions*, will provide a guide to the possible environmental performance of the bio-based solutions.