BIO4HUMAN

D5.2

Hotspot analysis of the current and innovative solutions
-ANNEXES-

Responsible partner: WeLOOP

VIII. Annexes

A. EU projects review

As Bio4HUMAN (B4H) aims to identify biobased solutions to reduce solid waste generation in humanitarian contexts, specific indicators related to biobased products were required for the environmental analysis. Several other EU projects have also focused on biobased materials and have developed or identified relevant indicators and methodologies.

To identify and select a set of relevant indicators for the B4H project, and for the LCA of biobased materials in general, WeLOOP, ITENE, the University of Cantabria, and AIMPLAS reviewed four different EU projects and completed a template prepared by WeLOOP. The answers are presented below.

1. ALIGNED

a) Project Overview

- Name of the project: Aligning life cycle assessment methods and bio-based sectors for improved environmental performance

- Acronym: ALIGNED

- Programme (e.g., Horizon 2020, Horizon Europe, LIFE, etc.): Horizon Europe

- Duration and timeline: 36 months (start 01/10/2022-end 30/09/2025)

- Website (if available): https://alignedproject.eu/

- Short summary (objectives, scope, relevance to bio-based sector – max. 10 lines): The objective is to develop a harmonized methodological framework for improving the environmental and socio-economic performance of bio-based industrial processes by Life Cycle Assessment (LCA) methodology. The project is focused on five bio-based sectors: Construction, Woodworking, Textile, Pulp and Paper, and Bio-Chemicals, with iterative application in real industrial case studies.

The project also improves scientific methods related to LCA methodology, demonstrates their impact and empowers stakeholders for effective adoption.

b) Environmental Indicators Promoted in the Project

Indicator	Specific or non-specific to bio-based sector	Level of willingness (mandatory, recommended or experimental)	Implemented in SimaPro or not*	Relevance for Bio4HUMAN
Dynamic assessment of Climate change • GWP100(Levasseur and Ventura methods) • GWP500 • GTP50 • GTP100	Specific. Biogenic carbon flows always accounted (-1/+1 approach)	Experimental	No	Yes, for the biogenic. In addition, integrate time effects

Biodiversity impacts-Land Use and Land-Use Change (LULUC) impact assessment *“gPAF_2050_RCP26”, “gPAF_2100_RCP26”, “gPAF_2050_RCP45”, “gPAF_2100_RCP45”, “gPAF_2050_RCP85”, “gPAF_2100_RCP85”*	Yes, highly relevant for bio-based products due to their dependence on biomass and land resources.	Recommended as part of a tiered methodological framework. It was developed to improve biodiversity impact evaluation in future scenarios.	Yes , for tier 1, ALIGNED recommends current methods such as ReCiPe and IW+: ecosystem quality, already implemented in SimaPro.	Yes
Biomass availability	Yes, a method for modeling constraints to biomass availability under various circumstances.	-	No. There is a .csv file to market mix calculation analyses (FAOSTAT data)	Maybe, yes.

*** If not, are they described in a way that they could be modelled (data needs, formula, units)?** Yes, the methods are openly available in ZENODO (https://zenodo.org/records/10843259 and https://doi.org/10.5281/zenodo.11126481), with tools, tutorials, excel and guidelines.

- [D1.2] The output databases rely on the use of the LCA database ecoinvent and the software Premise (Open source tool in python), which will generate future databases compatible with both SimaPro and Brightway2 LCA software.

Also tools for interpreting uncertainty (tutorials and calculators in excel and python): ALIGNED D1.2 Description of scientific methods (Task 1.4 Framework for interpreting uncertainty). Uncertainty and sensitivity analysis should be included in all LCA studies, even if not at the highest level of complexity.

c) Methodology for Indicator Calculation

- How are the indicators calculated? - Is there a specific standard, guideline, or methodology used (e.g., ILCD, EN15804, PEF)?

- “Tiered approach”described in ALIGNED D1.2 Description of scientific methods (Task 1.4 Framework for interpreting uncertainty) and https://doi.org/10.5281/zenodo.10842720 .

Offers a **3-tier recommendation system** tailored to different levels of LCA expertise and data availability. This increases flexibility and usability depending on project needs and resource:

  - **Tier 1 is the recommendation for a basic use** of the methods that ensures the highest applicability, the lowest complexity, but also the lowest accuracy. The target audience is typically users with limited resources (time, knowledge, experience) for more advanced analysis. **With this Tier 1, only the GWP100 indicator can be interpreted.**

   - The highest tier (tier 3) is the recommendation for an advanced use of the methods, (highest accuracy but higher complexity.

- **Climate change: Carbon Flux model** (Excel tool. The model can replicate carbon stock results of empirical studies from productive forests with different thinning practices). The approach is -1/+1(-1 reflex sequestration of carbon and +1 an emission)

- Please describe the main data sources and assumptions (if available).

- **Climate change:** For dynamic carbon accounting: Carbon Flux model.

- **Biodiversity**: For Biomass availability: Forestry Production and Trade data from FAOSTAT.

- **Ecosystem quality**: Recipe End Point and IW+.

d) Relevance to Our Project

- Should we consider integrating these indicators into our project? Why or why not?

Yes. The same system boundaries are considered: cradle-to-grave. All biogenic and non-biogenic carbon flows are reported separately.

- What added value or limitations do they present for the evaluation of bio-based materials?

The LCA studies usually do not consider biodiversity indicators such as biomass availability and ecosystem quality. So, it is added value for BIO4HUMAN to include these indicators that are focused on bio-based products.

Indicators that are not already implemented in Simapro or that can´t be easily implemented can be a limitation.

- Any risks or challenges associated with their use?

The main risks include lack of expertise and knowledge, incompatibility with existing standards, and lack of reliable data.

2. BioRADAR

a) Project Overview

- **Name of the project**: Monitoring system of the environmental and social sustainability and circularity of industrial bio-based systems.

- **Acronym**: BIORADAR

- **Programme (e.g., Horizon 2020, Horizon Europe, LIFE, etc.)**: HORIZON-JU-CBE-2022

- **Duration and timeline**: 1 July 2023 – 30 June 2026. The project duration is 36 months

- **Website (if available)**: https://www.cbe.europa.eu/projects/bioradar https://www.bioradar.org/

- **Short summary (objectives, scope, relevance to bio-based sector – max. 10 lines):**

The objective of BIORADAR is to help organizations, policymakers and investors have the necessary information to step into a more sustainable, bio-based economic model. Thanks to new indicators and digital monitoring tools that will provide benchmarks and a self-assessment platform, they would be able to gauge the environmental and social impacts of industrial bio-based systems.

The project will consider:

- improving metrics and frameworks of bio-based systems,
- defining circularity indicators,
- evaluating the economic impact of bio-based systems,
- addressing social implications,
- identifying patterns, best practices and up-scaling opportunities,
- and developing digital tools.

b) Environmental Indicators Promoted in the Project

Indicator	**Specific or non-specific to bio-based sector**	**Level of willingness (mandatory, recommended or experimental)**	**Implemented in SimaPro or not***	**Relevance for Bio4HUMAN**
Material Reutilization Score (MRS)	General	Recommended	Not implemented. Could be modelled with data	No
Material Circularity Indicator	General	Recommended	Not implemented directly, but it can be modelled. It is very common, so it must have been part of a LCA inventory before	Yes
Cost-weighted-average MCI	General	Recommended	Can't be modelled as it is an economic indicator	Yes
MCI based on economic and residual value	General	Recommended	Can't be modelled as it is an economic indicator	No

Nutrient Removal Efficiency Indicator (NERI)	Fertiliser	Recommended	Implemented in SimaPro, no .csv available	No
Nitrogen Recycling Index (NRI)	Fertiliser	Recommended	Implemented in SimaPro, no .csv available	No
Circular Material Use Rate (CMU)	General	Recommended	Not implemented. It can be modelled easily	No
Circularity Indicator of Nutrient (CIN)	Fertiliser	Mandatory	Not implemented. No information abou data collection	No
Resource Pressure	Textile	Mandatory	Not implemented. It could be modelled	No
Material Durability Indicator (MDI)	Packaging	Recommended	It can't be modelled as it refers to durability	Yes
In-use occupation of materials	General	Recommended	It can't be modelled as it refers to the occupation of materials	No
Circular Index-CirculAbility model	General	Mandatory	Not implemented. It could be modelled	No
Indicators of circular economy for biofertilizer	Fertiliser	Recommended	Implemented in SimaPro, no .csv available	No
Green Protein Food Index (GFPI)	Fertiliser	Recommended	Not implemented, high difficulty for modellation	No
Recycling Effectiveness (RE)	Packaging	Mandatory	Not implemented. Easiy to model with data	No
Quality Model for Recycled Plastics (QMRP)	Packaging	Recommended	It can't be modelled as it refers to a quality property from plastics	No
Quality of Recycling Framework (QRF)	General	Recommended	It can't be modelled as it refers to a quality property from plastics	No
Emergy (Em)	General	Recommended	It can't be modelled as it is not meant for LCA purposes	Yes

Nitrogen Use Efficiency (NUE)	Fertiliser	Recommended	Implemented in SimaPro, no .csv available	No
Circularity Index (CI) for textiles	Textile	Recommended	Implemented in SimaPro, no .csv available	No
Circular Economy Index (CEI)	General	Recommended	Can't be fully modelled as it refers to different categories	No
Circular Economy Performance Indicator (CEPI)	General	Recommended	Can't be fully modelled as it refers to different categories	Yes
Circularity Index (CI)	General	Recommended	Not implemented. It could be modelled	No
Product-level circularity metric	General	Recommended	Not implemented. It could be modeled easily with data	No
Process yield / Net recovery	Packaging	Recommended	Not implemented. It could be modeled	No
Quality indicator (G)	Packaging	Recommended	Very general, other indicators are more specific, can't be modeled	No
Cyclical Use Rate Indicator	General	Recommended	Not implemented. It could be modeled	No
Longevity Factor	General	Recommended	Longevity factor can't be modeled with SimaPro	No

*** If not, are they described in a way that they could be modelled (data needs, formula, units)?**

Completed with the information from the deliverable 2.1 "Report on identification of circularity indicators methodologies for industrial biobased systems" from the BioRADAR Project. (https://www.bioradar.org/deliverables)

Indicators primarily based on mass flows (recycled, reused, virgin, waste), process efficiency, and specific nutrient flows generally lend themselves well to direct modeling in SimaPro.

Indicators that combine material flows with economic aspects, material quality, or those that are composite indices needing complex aggregation often require SimaPro to provide the raw LCI data, with the final calculation or weighting performed outside the software.

Indicators that measure physical/chemical properties, macroeconomic concepts, or those based on environmental assessment methodologies different from LCA (like Emergy) are typically not directly calculated within SimaPro's standard modules.

c) Methodology for Indicator Calculation

- How are the indicators calculated?

For this project, a total of 29 were identified. Each circularity indicator has its own formula. More information on the deliverable 2.1 "Report on identification of circularity indicators methodologies for industrial biobased systems" (https://www.bioradar.org/deliverables).

- Is there a specific standard, guideline, or methodology used (e.g., ILCD, EN15804, PEF)?

No specific method, guideline or methodology is mentioned.

- Please describe the main data sources and assumptions (if available).

Data sources for each of the 29 indicators can be found on the deliverable 2.1.

d) Relevance to Our Project

- Should we consider integrating these indicators into our project? Why or why not?

- Material Circularity Indicator (MCI): the degree to which the flow of materials has been minimized and the restorative flow has been maximized for its component materials, as well as how long and intensively it is used compared to a similar product in the industry average → for some products could be interesting to quantify this indicator, it gives relevant information.

- Cost-weighted-average MCI: modification to MCI to consider an economic aspect: the cost of recycling the materials → could be interesting if we want to include the economic part.

- Materia Durability Indicator (MDI): that tries to convey the durability aspect of the materials, involving its mechanical and chemical durability, as well as its environmental impact → in the deliverable it is used for packaging products, it is interesting because it can be potentially applicable to any material.

- Emergy (Em): the total amount of available energy needed directly and indirectly to make one product or service → one of the most interesting for the project. In the LCA point of view, it could give relevant information of the difference between bio-based and conventional products.
- Circular Economy Performance Indicator (CEPI): the ratio of the actual obtained environmental benefit in relation to the ideal environmental benefit according to quality → good indicator for comparisons of different products and scenarios.

- What added value or limitations do they present for the evaluation of bio-based materials?

They can be useful to give additional information about the environmental and economic impacts. Some of them can be used for comparisons too, which is interesting to see the advantages or disadvantages of different scenarios.

Most of the indicators that were not selected as important for the project are related with recycling products or processes, which is not the concept of bio-based products.

- Any risks or challenges associated with their use?

Risks: out of the scope of the project because they are not mainly focused on bio-based products.

Challenges: adaptation of new indicators to bio-based sector.

3. CALIMERO

a) Project Overview

- **Name of the project**: Industry Case Studies AnaLysis to Improve Environmental Performance and Sustainability of Bio-based Industrial Processes

- **Acronym**: CALIMERO

- **Programme (e.g., Horizon 2020, Horizon Europe, LIFE, etc.)**: Horizon Europe

- **Duration and timeline**: 3 years (2022-2025)

- **Website (if available)**: https://calimeroproject.eu/

- **Short summary (objectives, scope, relevance to bio-based sector – max. 10 lines):**

CALIMERO aims to create a common framework for all bio-based industries to evolve in terms of sustainability working with PEF indicators as well as with those proposed by CALIMERO. They mainly covert five sectors –

construction, woodworking, textile, pulp & paper and biochemicals. The general objectives are as below

- To identify main barriers and incentives to apply life cycle thinking sustainability approaches and source of impacts in the target bio-based sectors.
- To define reference case studies and identify levers to improve life cycle sustainability assessment methodologies and sustainability performances.
- To improve existing sustainability assessment methodologies and their implementation for the 5 bio-sectors within the scope:
- To develop a MOO framework of industrial processes that integrates the improved LCSA methodologies based on PEF, for optimization of bio-based industrial processes with sustainability indicators.
- To provide feasible solutions with better sustainability performance than the current situation for the five studied bio-based industry sectors and the procedures to monitor their sustainability performance

b) Environmental Indicators Promoted in the Project

From all indicators of Calimero D3.3, we selected the ones fostering raw materials replacement, avoiding high energy demanding valorisation processes

THEME	Indicator	Specific or non-specific to bio-based sector	Level of willingness (mandatory, recommended or experimental)	Implemented in SimaPro or not*	Relevance for Bio4HUMAN
	Job Creation Potential (JCP)	NO	experimental	No	Maybe, concerns WP6
	Plastics physical effect on biota (an impact category from IMPACT WORLD + V2.1 LCIA method)	NO	recommended	Can be implemented easily by importing the impact assessment method	YES
	Life Cycle Costing Indicators (LCCI)	NO	experimental	No	Maybe, concerns WP6
	DyPLCA	NO	Recommended	No, Brightway compatible Section 4 of Calimero D3.4 develops how it can be ran. Tool: dyplca.list.lu	YES
	LILaC(Land use Impact on Landscape Connectivity)	NO	experimental	NO A practical execution guide with step-by-step instructions will be delivered in report of WP5.	Maybe

				Full technical documentation of the code will be released at the same time.	
	Land use Impact on Particulate matter Removal	NO	experimental	NO Currently under development	Maybe
Circularity	Material Circularity Indicator MCI	NO	Recommended	NO web tool Material Circularity Indicator | Ellen MacArthur Foundation	Maybe
	Longevity	NO	experimental	NO, available formula	Maybe
	Cascade factor	YES	experimental	NO, available formula	YES
	Feedstock intensity	NO	experimental	NO, available formula	Maybe
	Product renewability	NO	experimental	NO, available formula	YES
	Energy intensity	NO	experimental	NO, available formula	YES
	%material circularity	NO	experimental	CTI module Close the loop indicators	YES
	%water circularity	NO	experimental	CTI module Close the loop indicators	YES
	Onsite water circulation (reuse & recycle)	NO	experimental	CTI module Close the loop indicators	MAYBE
	%critical material	NO	experimental	CTI module - Optimize de loop indicators	NO (could underline problems of reference but electronics are not replaced and no other critical materials are used)
	circular material productivity	NO	experimental	CTI module - Optimize de loop indicators	For WP6 (LCC)
	Nature impact	NO	experimental	CTI module - Impact of the loop indicators	YES
CRITICALITY	Amount of land used (h/year) in a product system	NO	experimental	Unknown	YES (indicator for global criticality tool)
	Water Depletion Index (WDI)	NO	experimental	Unknown	Maybe (indicator for global criticality tool)
	Production/consumption increase/decrease over the last five years	NO	experimental	Not applicable	Maybe (indicator for global criticality tool)
	Criticality	NO	experimental	Excel tool D3.3	Maybe (also considers not primary issues for B4H)

*** If not, are they described in a way that they could be modelled (data needs, formula, units)?**

c) Methodology for Indicator Calculation

- How are the indicators calculated?

Here are short descriptions but more info can be found in deliverable 3.3 of Calimero project.

- DyPLCA (Dynamic Process-based Life Cycle Assessment): a tool exists to get GHG emissions over time: dyplca.list.lu
- LILAC Land use Impact on Landscape Connectivity: focuses on the spatial arrangement of the landscape; and how well that configuration supports ecological flows such as dispersal and gene flow. The resulting structural connectivity metric will provide regional CFs that can complement existing local and global biodiversity layers in BioMAPS once the development is complete.

A practical execution guide, complete with step-by-step instructions and links to the script repository, will be delivered in one public report of WP5. Full technical documentation of the code will be released at the same time.

Circularity indicator:

- MCI : Measures the extent to which a product linear flow has been minimized and restorative flow maximized for its components materials, and how long and intensively it is used compared to a similar industry-average product

=1- LFI · F(X) with F(X) = Utility factor and $LFI = \frac{V + W_0 + \frac{W_F}{2} + \frac{W_C}{2}}{2M + \frac{W_F}{2} - \frac{W_C}{2}}$

- Longevity = A + B +C with A= initial lifetime, B= earned refurbished lifetime, C= earned recycled lifetime

The longevity indicator measures the contribution to material retention based on the amount of time a resource is kept in use in a product system. Is calculated by the sum of three different variables: the initial lifetime, earned refurbished lifetime and earned recycling lifetime

- Cascade factor: Assesses the utilization of biomass in multiple sectors and for multiple sectors/products (input perspective). It is a relevant indicator to understand the use of non-virgin material in a sector.

$$\text{Cascade in wood residues}: \left(B^i + \boldsymbol{R}^i_{(p.p.m)}\right) / \mathrm{B}^i$$

$$\text{Cascade in recycled products}: \left(B^i + \boldsymbol{R}^i_{(f.p.m)}\right) / \mathrm{B}^i$$

$$\text{Cascade in products}: \left(B^i + \boldsymbol{R}^i_{(p.p.m)} + \boldsymbol{R}^i_{(f.p.m)}\right) / \mathrm{B}^i$$

$$\text{Total CF}: \left(B^i + \boldsymbol{R}^i_{(p.p.m)} + \boldsymbol{R}^i_{(f.p.m)} + \boldsymbol{R}^i_{(f.v.e)} + \boldsymbol{R}^i_{(p.p.e)}\right) / \mathrm{B}^i$$

- Feedstock intensity:

Quantifies raw material consumption and is the ratio of the total amount of the main raw materials used to the total amount of useful outputs (end-products and co-products). Measured as a kg of feedstock. Formula is applied for a linear processes

$$\mathrm{FI} = \frac{M_{\text{raw mat}}}{M_{\text{main prod}} + M_{\text{co prod}}}$$

- Product renewability: Represents renewable nature of the materials used in a product. PR "0" representing non-renewability and "100" representing the ideal scenario of 100% renewability.

$$\mathrm{PR} = \left[\frac{M_{\text{Bio\_feed}} + M_{\text{Bio\_Comp\_inp}}}{M_{\text{net\_feed}} + M_{\text{net\_Comp\_inp}}} \times 100\right]$$

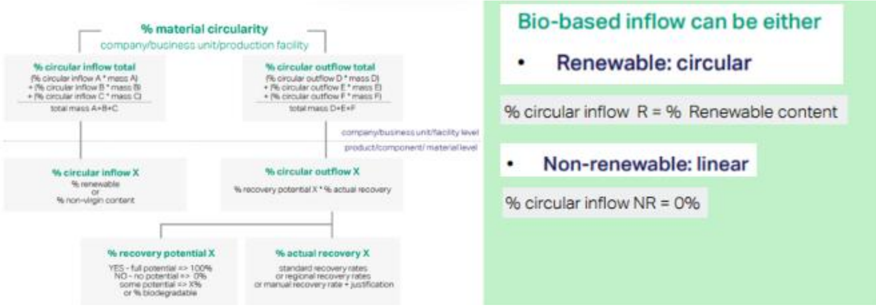
- Energy intensity: Defined as the ratio of the total amount of energy (fossil-derived, renewable energy, deducting any internally derived energy) to the total amount of products and co-products generated within the process.

  The expression represents linear processes $\mathrm{EI} = \frac{E_{\text{FosD}} + E_{\text{RenD}} - E_{\text{IntD}}}{M_{\text{Prod}} + M_{\text{Co.prod}}}$ (kWh/kg)

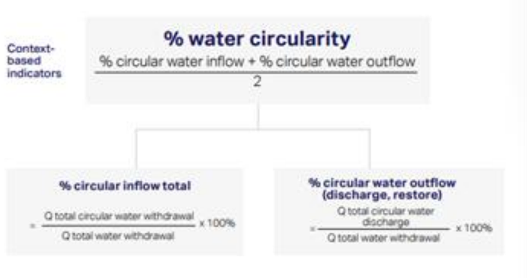
- Circular-process energy intensity: Represents EI for a circular process demonstrating waste valorisation and material circularisation strategies

$$\mathrm{CPEI} = \frac{E_{\text{FosD}} + E_{\text{RenD}} - E_{\text{IntD}}}{M_{\text{Prod}} + M_{\text{Co.prod}} + M_{\text{re.prod}}}$$

- %material circularity: Weighted average between % circular inflow and % circular outflow. The % circular inflow is determined by the % non-virgin content and % renewable content (sustainably grown bio-based sources). The % circular outflow is determined by the % recovery potential (which is focused on design) and the actual recovery.



- %water circularity: The purpose of water circularity is to lower freshwater demand and ensure water resource availability for all users and the environment. Circularity of water is therefore determined through the % circular water inflow and % circular water outflow, which in turn depend on local water conditions.



- Onsite water circulation (reuse & recycle)

Onsite water circulation (reuse & recycle)

$$= \frac{Q\ \text{water use} - Q\ \text{total water withdrawal}}{Q\ \text{total water withdrawal}} + 1$$

% critical inflow

$$\frac{\text{mass of inflow defined as critical}}{\text{total mass of linear inflow}} \times 100\%$$

- %critical material
- circular material productivity (more relevant for the LCC dimension)
- Nature impact focuses specifically on impact from land-use change.

"threat-weighted quality square kilometers" E*C*S = 100*0.5*4

$$(M_{xr}\ \text{X}\ \textit{Extent})\ \text{X}\ (M_{xrp}\ \text{X}\ \textit{Condition Change})\ \text{X}\ (M_{xri}\ \text{X}\ \textit{Significance})$$

- Water Depletion Index (WDI): valuates the risk of freshwater depletion by considering not just the water consumption but also how water is replenished through processes like atmospheric evaporation and precipitation, while capturing the vulnerability of regions to water shortages, taking into account both the local water availability and the overall water cycle dynamics (e.g., water recycling through evaporation). A higher WDI indicates a greater depletion risk.

WSi =Σ(gpsi _ WDIx), Where: gps: global production share, WDI: natural depletion index, i= analysed product/material, x=production country

- Production/consumption increase/decrease over the last five years: Average of yearly changes (%) in production (or consumption) taken for 5 years. Concerns World agriculture production (USDA, 2024 report)

- Biotic Resource Availability Indicator (BRAI): measures the availability of biotic resources, which decreases when the extraction of resources surpasses the replenishment rate, leading to resource depletion. This results in a reduction of the overall biotic resource stock. . A high BRAI refers to high possible restrictions.

= subtracting the replenishment rate from the extraction rate, multiplying it by the Thratened Species Index (TSI) and dividing it by the squared resource stock.

- Extraction rate: proportion of a particular bio-based material being harvested, sourced, or extracted relative to the available renewable resource or the overall supply of that material. Can be interesting for geographical availability

- Resource stocks: current volume or mass of a biotic resource that can be accessed, harvested, or utilized, based on its renewable capacity. This indicator provides a snapshot of the resource's available supply before extraction, reflecting its abundance or scarcity in the ecosystem. Can be interesting for geographical availability

- Replenishment rate (biotic resources): speed at which a bio-based resource, such as a plant, tree, or agricultural crop, can regenerate, grow, or reproduce to replace the portion of the resource that has been harvested or extracted. Can be interesting for geographical availability

- Food Security Index (FSI): A food crisis may be initiated due to the use of biotic materials in industrial sectors. The “Food first” principle has to be considered when assessing availability of biotic materials. This index determine the availability, accessibility, and affordability of food within a given region or country. Can be interesting for geographical availability

- Land-use regulation: is the product susceptible to exploit natural reserves, protected habitat for flaura and fauna ? Can be interesting for geographical availability

- Criticality: excel tool of D3.3 based on criticality indicators that concern minerals and metals or biotic materials. Depending on raw materials and region of production, criticality indexes show the risks.

- The plastics physical effect on biota is calculated according to IMPACT WORLD + V2.1 impact assessment method. More information can be found in their website: https://www.impactworldplus.org/

- Is there a specific standard, guideline, or methodology used (e.g., ILCD, EN15804, PEF)?

The circularity and criticality indicators will be used with excel tools. There are not related to LCA standards.

As mentioned, the JCP and LCC indicators have available excel tool. And plastics physical effect on biota is calculated according to IMPACT WORLD + V2.1 impact assessment method.

- Please describe the main data sources and assumptions (if available).

d) Relevance to Our Project

- Should we consider integrating these indicators into our project? Why or why not?

Considering the high ratio of plastic waste in the countries of DRC and South Sudan, and also, the focus of the project on reducing and replacing non-degradable plastics, studying of the Plastic debris effect on biota could be interesting.

The other parameters are selected because they can underline advantages or risks related to the use of bio-based materials which come from theoretically renewable resources.

For the JCP and LCC indicators, they are relevant for the technological based solutions which need to be employed in the target countries as they reflect economical and partially social aspects of the technologies.

- What added value or limitations do they present for the evaluation of bio-based materials?

The limitations could be the current development of the indicators and the availability of tools. Indicators that are not sufficiently developed are not going to be useful for B4H.

- Any risks or challenges associated with their use?

For JCP and LCC some of the required data may not be available therefore estimates should be used. The Plastic debris effect on biota is also a recently implemented method so its result should be carefully analysed since they might not be accurate.

4. LCA4Bio

a) Project Overview

- **Name of the project**: Harmonized Life Cycle Assessment methods for sustainable and circular BIO-based systems

- **Acronym**: LCA4BIO

- **Programme (e.g., Horizon 2020, Horizon Europe, LIFE, etc.):** HORIZON-CL6-2023-ZEROPOLLUTION-01-4

- **Duration and timeline**: 01/01/2024 – 31/12/2026, so the project duration is 36 months

- **Website (if available):** https://lca4bioproject.eu/

- **Short summary (objectives, scope, relevance to bio-based sector – max. 10 lines):**

The main objective of the project is to develop and validate a new set of improved, harmonized, precise, reliable, and applicable assessment methodologies for evaluating environmental impacts and circularity in biobased systems. These methodologies are to be designed for integration into certification schemes, thereby facilitating the international trade of biobased products and supporting the development of next-generation life cycle assessment (LCA) approaches.

To achieve this objective, the first step is to define a harmonized and improved methodology for assessing life cycle environmental sustainability and circularity in both high- and low-TRL (Technology Readiness Level) biobased systems. This will be followed by the development of practical tools to ensure the methodologies applicability. Finally, the methodology will be integrated into the PEFC (Programme for the Endorsement of Forest Certification) certification scheme to enable product certification and support international market access.

b) Environmental Indicators Promoted in the Project

Indicator	**Specific or non-specific to bio-based sector**	**Level of willingness (mandatory, recommended or experimental)**	**Implemented in SimaPro or not***	**Relevance for Bio4HUMAN**
Dynamic GHG emissions	Construction, woodworking, textile, pulp & paper; biochemicals		Under development	Maybe

*** If not, are they described in a way that they could be modelled (data needs, formula, units)?**

Same indicators than Calimero and currently under selection so a list of indicators is not available yet.

c) *Methodology for Indicator Calculation*

- **How are the indicators calculated?**

Using the improved European Product Environmental Footprint method (PEF) developed by CALIMERO.

- **Is there a specific standard, guideline, or methodology used (e.g., ILCD, EN15804, PEF)?**

/

- **Please describe the main data sources and assumptions (if available).**

/

d) *Relevance to Our Project*

- **Should we consider integrating these indicators into our project? Why or why not?**

Dynamic indicators are not really necessary for the B4H project activities because of the high TRL of the solutions screened, and their short life time. It could be interesting for building insulation materials.

- **What added value or limitations do they present for the evaluation of bio-based materials?**

- **Any risks or challenges associated with their use?**

Going out of the scope of our project.

B. Inventories updates

This annex presents the inventories that have been completed and/or updated from D5.1.

1. PLA inventories

For literature references, please refer to Table 20 of D5.2: *PLA production: literature for different production processes*.

- From maize:

Polylactic acid, granulate {GLO}| market for polylactic acid, granulate | Cut-off, U ecoinvent dataset (cannot be displayed)

- From sugarcane:

PLA, from primary crops: B4H Polylactic acid, granulate from sugarcane{BR}| B4H polylactic acid production, granulate | Cut-off, U				
Material	**Weight**	**Unit**	**Data set**	**Price**
Inputs				
sugarcane	1	ton	B4H Sugarcane {BR-SP}, closed loop | sugarcane production | Cut-off, U	**Around 1.20€/kg**
straw	45,85	kg	B4H Straw production {RoW}| straw | Cut-off, U	
tap water	1500	kg	Tap water {BR}| market for tap water | Cut-off, U	
quicklime	0,81	kg	Quicklime, milled, packed {RoW}| market for quicklime, milled, packed | Cut-off, U	
sulfric acid	15,5	kg	Sulfuric acid {RoW}| market for sulfuric acid | Cut-off, U	
ammonia	0	g	Ammonia, anhydrous, liquid {RoW}| market for ammonia, anhydrous, liquid | Cut-off, U	
phosphoric acid	0	g	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	
flocculant polymer	6,8	g	Chemical, inorganic {GLO}| market for chemical, inorganic | Cut-off, U	
antibiotics	0,9	g	Chemical, inorganic {GLO}| market for chemical, inorganic | Cut-off, U	
catalyst zeolite	21,4	g	Zeolite, powder {GLO}| market for zeolite, powder | Cut-off, U	
catalyst	13,9	g	Chemical, inorganic {GLO}| market for chemical, inorganic | Cut-off, U	
limestone	15,5	kg	Limestone, crushed, washed {RoW}| market for limestone, crushed, washed | Cut-off, U	
lubricating oil	13	g	Lubricating oil {RoW}| market for lubricating oil | Cut-off, U	
steel manufacturing	648,9	g	Metal working, average for steel product manufacturing {GLO}| market for metal working, average for steel product manufacturing | Cut-off, U	
Cr steel manufacturing	38,4	g	Metal working, average for chromium steel product manufacturing {GLO}| market for metal working, average for chromium steel product manufacturing | Cut-off, U	
Concrete	8,80E-04	m3	Concrete, normal strength {BR}| market for concrete, normal strength | Cut-off, U	
Bâtiment	1,80E-04	m2	Building, hall, steel construction {GLO}| market for building, hall, steel construction | Cut-off, U	
Outputs				
PLA	22	kg	**57.6%** economic alloctaion	
Ethanol	52,6	kg	**34.9%** economic alloctaion	
Gypsum	18,4	kg	**0.6%** economic alloctaion	
Electricity	118,1	kWh	**6.9%** economic alloctaion	
CO2,b	374,5	kg	Carbon dioxide, biogenic	
CO2,F	6,6	kg	Carbon dioxide, fossil	
CO,b	213,3	g	Carbon monoxide, biogenic	
N oxides	212,1	g	Nitrogen oxides, BR	
N2O	11,7	g	Dinitrogen monoxide	
S oxides	11,4	g	Sulfur oxides, BR	
CH4,b	87,9	g	Methane, biogenic	
VOC	14,8	g	VOC, volatile organic compounds, unspecified origin	
Particulates, >2,5µm, <10µm	240,4	g	Particulates, > 2.5 um, and < 10um	
Particulates, <2,5µm	120,3	g	Particulates, < 2.5 um	
Ethanol	106,1	g	Ethanol	

- From biowaste:

Adapted from *Polylactic acid, granulate {GLO}| market for polylactic acid, granulate | Cut-off, U* ecoinvent dataset (cannot be displayed).

The maize crop was erased of the inventory data. (dry mass)/(PLA output) yield was adapted, and a dry mass of BW was set to 58% as suggested in the literature. A scaling factor of (maize initial wet mass)/(BW initial wet mass) was applied to each input and output, except for water and wastewater, in the ecoinvent inventory.

- From fruit biowaste:

Adapted from sugarcane inventory with the assumptions that (i) the yield is similar, (ii) process wastes are industrially composted (not put back into the field with a closed loop), (iii) no electricity co-production, and (iv) energy requirements are similar to those of PLA from the maize process.

PLA, from primary crops: B4H Polylactic acid, granulate from fruit biowaste (based sugarcane process){BR}| B4H polylactic acid production, granulate | Cut-off, U			
Material	**Weight**	**Unit**	**Data set**
Inputs			
Biowaste (fruit)	1	ton	Biowaste entering the system
tap water	1500	kg	Tap water {BR}| market for tap water | Cut-off, U
quicklime	0,81	kg	Quicklime, milled, packed {RoW}| market for quicklime, milled, packed | Cut-off, U
sulfric acid	15,5	kg	Sulfuric acid {RoW}| market for sulfuric acid | Cut-off, U
flocculant polymer	6,8	g	Chemical, inorganic {GLO}| market for chemical, inorganic | Cut-off, U
antibiotics	0,9	g	Chemical, inorganic {GLO}| market for chemical, inorganic | Cut-off, U
catalyst zeolite	21,4	g	Zeolite, powder {GLO}| market for zeolite, powder | Cut-off, U
catalyst	13,9	g	Chemical, inorganic {GLO}| market for chemical, inorganic | Cut-off, U
limestone	15,5	kg	Limestone, crushed, washed {RoW}| market for limestone, crushed, washed | Cut-off, U
lubricating oil	13	g	Lubricating oil {RoW}| market for lubricating oil | Cut-off, U
steel manufacturing	648,9	g	Metal working, average for steel product manufacturing {GLO}| market for metal working, average for steel product manufacturing | Cut-off, U
Cr steel manufacturing	38,4	g	Metal working, average for chromium steel product manufacturing {GLO}| market for metal working, average for chromium steel product manufacturing | Cut-off, U
Concrete	8,80E-04	m3	Concrete, normal strength {BR}| market for concrete, normal strength | Cut-off, U
Building	1,80E-04	m2	Building, hall, steel construction {GLO}| market for building, hall, steel construction | Cut-off, U
electricity	1,828*22	kWh	Electricity, low voltage {GLO}| market group for electricity, low voltage | Cut-off, U
heat NG	17,537*22	MJ	Heat, district or industrial, natural gas {GLO}| market group for heat, district or industrial, natural gas | Cut-off, U
heat	0,15105*22	MJ	Heat, district or industrial, other than natural gas {GLO}| market group for heat, district or industrial, other than natural gas | Cut-off, U
Outputs			
PLA	22	kg	**57,6/(100-6,9)*100=61.9%** economic alloctaion
Ethanol	52,6	kg	**34,9/(100-6,9)*100=37.5%** economic alloctaion
Gypsum	18,4	kg	**0,6/(100-6,9)*100=0.644%** economic alloctaion
Electricity	0	kWh	**0%** economic alloctaion
CO2,F	6,6	kg	Carbon dioxide, fossil
N oxides	212,1	g	Nitrogen oxides, BR
N2O	0	g	Dinitrogen monoxide
S oxides	11,4	g	Sulfur oxides, BR
Ethanol	106,1	g	Ethanol
Wastes (Vinasse, filter cake mud, gypsum not put back into field)	679,1	kg	Biowaste {RoW}| treatment of biowaste, industrial composting | Cut-off, U

For mechanically recycled PLA, a wastewater output was added and process waste are considered industrially composted.

TABLE 27 D5.1			
Mechanically recycled PLA			
Material	**Quantity**	**unit**	**Dataset**
Input			
PLA sorted	1	Ton	**PLA, sorted waste {RER}**
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	%	Biowaste {RoW}| treatment of biowaste, industrial composting | Cutoff, U
Waste water	0,01	m3	Wastewater, average {RoW}| market for wastewater, average | Cut-off, U

2. Packaging and items solutions

In general, for each inventory modelled in D5.1, every **energy input** was considered at global (GLO) geography, or local geography (in the DRC and SS). DRC and SS energy mixes are in section IV.C. of D5.2.

In D5.1, several models refer to the following electricity dataset: Electricity, medium voltage {RoW}| market for electricity, medium voltage | Cut-off, U. This data is obsolete, and geography considered is global GLO for the work conducted in D5.2: **Electricity, medium voltage {GLO}**| market group for electricity, medium voltage | Cut-off, U.

Same observation was made "Natural gas, high pressure {RoW}| natural gas production | Cut-off, U" for dataset. As it is obsolete, it was replaced with "**Natural gas, high pressure {GLO}|** market group for natural gas, high pressure | Cut-off, U"

a) Food kit

- For **compostable pouch for RUTF**: end-of-life is home compost and production waste are not closed loop because it is a multimaterial compound, so it is difficult to recycle.

TABLE 13 D5.1

Bio-based sachets for RTUF				
Material	**Quantity**	**Unit**	**Dataset**	**Price**
Inputs				
PLA	1,19	g	Polylactic acid, granulate {GLO}| market for polylactic acid, granulate | Cut-off, U	0.047 €/ud
PBAT	1,19	g	1,4-butanediol {GLO}| market for 1,4-butanediol | Cut-off, U	
Cellophane	1,039	g	Cellophane production	
Metallized cellulose	1,039	g	Metallized cellulose	
Extrusion/coextrusion PLA+PBAT	Extrusion, co-extrusion {RoW}| extrusion, co-extrusion of plastic sheets | Cut-off, U Yield: 96.9%			

TABLE 13 D5.1			
Bio-based sachets for RTUF			
Adhesive lamination of the components of the bio-based pouch	Adhesive lamination Yield: 96.5%		
Shaping-Electricity[1]	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	Home compostable solutions, garden waste {RoW}| treatment of garden biowaste, home composting in heaps | Cut-off, U: See
Home compostable	0,23806526	g	Biowaste, garden waste {RoW}| treatment of garden biowaste, home composting in heaps | Cut-off, U

b) *Agricultural kit*

No specific modifications.

c) *WASH kit*

- In D5.1, **Organic sanitary pads** distribution was modelled but it is not adapted to our study where distribution is already included in "market for" datasets. Transportation inputs were deleted.

The end-of-life scenario mentioned in D5.1 is not adapted to our study. The hygienic pads are home compostable and modelled as such.

Also, only Indian product composition (D5.1, Table 23) was considered as it was the most impactful inventory (compared to US and France products). Energy inputs were considered with at global geography and not Indian.

Finally, the packaging part of the hygienic pads were deleted to ensure comparability in system boundaries across the deliverable.

TABLE 23 D5.1			
Sanitary Pads – IN Product			
Material/ Process	**Quantity**	**Unit**	**Dataset**
Inputs			

TABLE 23 D5.1			
Sanitary Pads – IN Product			
Paper	0	kg	Kraft paper {RoW}|market for kraft paper | Cut-off, U
Box	0	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 {GLO}| market group for electricity, medium voltage | Cut-off, U
Transport			
Truck	0	tkm	/
Boat	0	tkm	/
End-of-life			
Home compostable	0,0094	kg	Home compostable solutions, garden waste {RoW}| treatment of garden biowaste, home composting in heaps | Cut-off, U

d) Non-Food Items (NFI) kit

- **Biodegradable mosquito net** inventory was adapted by adding weaving loss (EI3.10 indicated ratio) compost. Also, contrary to what is modelled in D5.1, mosquito nets are not home compostable, it could only be industrially composted as it is made of PLA only.

TABLE 17 D5.1				
Mosquito nets (protection of 1person/year)				
Material	**Weight**	**Unit**	**Data set**	**Price**
Inputs				
>90% PLA	244,412	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**			
Home compostable	240,8	g	Industrially compostable solutions {RoW}| treatment of biowaste, industrial composting | Cut-off, U	
Home compostable	3,612	g	Biowaste {RoW}| treatment of biowaste, industrial composting | Cut-off, U	

e) Building insulation

- **Foams for insulation** inventory in D5.1 suggests a recycling at end-of-life, but PUR foam is thermoset and not easily recycled. It is not biodegradable, so end-of-life is open burning. To ensure system boundaries comparability within the hotspots analysis transport at EoL was deleted.

TABLE 18 D5.1			
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	0,00106	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	-1,44	kg	Carbon dioxide, biogenic
Wastewater	0,122	kg	Wastewater, average {RoW}| treatment of wastewater, average, wastewater treatment | Cut-off, U
End of Life			
PUR credits for recycling	0	kg	/
Incineration	1	kg	Waste bio-based polyurethane {GLO}| treatment of waste polyurethane, open burning | Cut-off, U (biogenic carbon emissions adapted to the product
Transport	0	km	Transport, freight, lorry >32 metric ton, EURO6 {RoW}| market for transport, freight, lorry >32 metric ton, EURO6 | Cut-off, U
Biogenic carbon	1,44	kg	Carbon dioxide, biogenic

- **Sheep wool insulation** emissions to water were detailed to overcome impact on water overevaluation of the sheep wool production. Also, the units for shed and activity were not accurate, and the fertilizing credits associated to N emissions to soil at EoL were deleted because wool degradability is particularly slow (as explained in IV.A. of D5.2.). Here is the corrected inventory.

TABLE 20 D5.1			
Wool insulation material			
Material	**Quantity**	**Unit**	**Dataset**
Inputs			
NH4NO3	0,0623	kg	Ammonium nitrate {RER}| market for ammonium nitrate | Cut-off, U
Fertilizer	0,00103	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	m2	Shed {CH}| construction | Cut-off, U
Soda	0,0157	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	ha	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 (=1,1kg)
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)	5,50E-01	kg	Ammonia
N2O (emissions to air)	4,10E-03	kg	Dinitrogen monoxide
CH4 biogenic (emissions to air)	1,40E-01	kg	Methane, biogenic
NO (emissions to air)	8,60E-04	kg	Nitrogen oxides
H2O (emissions to air)	3,20E-02	m3	Water/m3
Cd (emissions to GROUNDWATER)	2,30E-11	kg	Cadmium
Cd (emissions to river)	5,35E-10	kg	Cadmium
Cr (emissions to groundwater)	1,25E-06	kg	Chromium
Cr (emissions to river)	2,28E-07	kg	Chromium
Cu (emissions to river)	1,20E-06	kg	Copper

TABLE 20 D5.1			
Wool insulation material			
Pb (emissions to river)	3,60E-09	kg	Lead
Ni (emissions to river)	2,50E-07	kg	Nickel
NO_3 (emissions to groundwater)	7,90E-02	kg	Nitrate
PO_4 (emissions to river)	2,00E-03	kg	Phosphate
P (emissions to river)	7,60E-04	kg	Phosphorus
H_2O (emissions to groundwater)	1,80E-02	m3	Water, RoW
H_2O (emissions to river)	4,50E-03	m3	Water, RoW
Zn (emissions to river)	4,00E-06	kg	Zinc
Cd (emissions to soil)	-2,50E-10	kg	Cadmium
Cr (emissions to soil)	-1,40E-06	kg	Chromium
Cu (emissions to soil)	-1,20E-06	kg	Copper
Pb (emissions to soil)	-2,90E-09	kg	Lead
Ni (emissions to soil)	-2,10E-07	kg	Nickel
Zn (emissions to soil)	-2,60E-06	kg	Zinc
End-of-Life			
Compost	1,1	kg	Home compostable solutions, garden waste {RoW}| treatment of garden biowaste, home composting in heaps | Cut-off, U
N fertiliser credits	0	kg	Inorganic nitrogen fertiliser, as N {RoW}| market for inorganic nitrogen fertiliser, as N | Cut-off, U

- **Cellulose-based insulation** was added as a possible building insulation material as it was identified as an interesting bio-based material in Calimero EU project. The inventory is the following:

NOT IN D5.1			
Cellulose-based insulation			
Material	**Quantity**	**Unit**	**Dataset**
Inputs			
Paper	0,92	kg	Waste newspaper {GLO}| waste newspaper, Recycled Content cut-off | Cut-off, U
Boric acid	0,04	kg	Boric acid, anhydrous, powder {RoW}| boric acid production, anhydrous, powder | Cut-off, U
Aluminum hydroxide	0,02	kg	Aluminium hydroxide {GLO}| market for aluminium hydroxide | Cut-off, U
Magnesium sulfate	0,03	kg	Magnesium sulfate {GLO}| market for magnesium sulfate | Cut-off, U
Tap water	0,002	kg	Tap water {GLO}| market group for tap water | Cut-off, U
Electricity	0.15	kWh	Electricity, medium voltage {GLO}| market group for electricity, medium voltage | Cut-off, U
Outputs			

NOT IN D5.1			
Cellulose-based insulation			
Cellulose-based insulation	1	kg	/
Biogenic carbon	=0,444*44/12 = -1,63	kg	Carbon dioxide, biogenic
End of Life			
Open burning	1	kg	Waste paperboard {GLO}| treatment of waste paperboard, open burning | Cut-off, U: Hg amount and emissions corrected (0,3mg/kg of waste)

f) End-of-life by compost

Various end-of-life process in D5.1 suggested ecoinvent 3.10 generic data as waste treatment. However, these data did not cover C emissions properly, so the processes were modified by deleting biogenic CO_2 and CH_4 emissions. Then, **emissions were adapted to each composted material,** at their end-of-life by compost.

To replace Biowaste {RoW}| treatment of biowaste, industrial composting | Cutoff, U **in D5.1**			
Industrial composting of biowaste and biodegradable materials			
Material	**Weight**	**Unit**	**Data set**
Inputs			
Outputs			
Biowaste, industrial compost	1	kg	-
Carbon dioxide, biogenic	=carbon content*emissions (FCBA scenario)*M(CO2)/M(C)= C,b*0,05*44/12	kg	Carbon dioxide, biogenic
Methane, biogenic	=carbon content*emissions (FCBA scenario)*M(CH_4)/M(C)= C,b*0,05*16/12	kg	Methane, biogenic
Industrial compost without biogenic C emissions	1	kg	Industrially compostable solutions {RoW}| treatment of biowaste, industrial composting | Cut-off, U adpated copy of Biowaste {RoW}| treatment of biowaste, industrial composting | Cutoff, U

To replace Biowaste, garden waste {RoW}| treatment of garden biowaste, home composting in heaps | Cut-off, U **in D5.1**			
Home composting of biowaste and biodegradable materials			
Material	**Weight**	**Unit**	**Data set**
Inputs			
Outputs			
Biowaste, industrial compost	1	kg	-
Carbon dioxide, biogenic	=carbon content*emissions (FCBA scenario)*M(CO_2)/M(C)= C,b*0,05*44/12	kg	Carbon dioxide, biogenic

Methane, biogenic	=carbon content*emissions (FCBA scenario)*M(CH_4)/M(C)= C,b*0,05*16/12	kg	Methane, biogenic
Home compost without biogenic C emissions	1	kg	Home compostable solutions, garden waste {RoW}| treatment of garden biowaste, home composting in heaps | Cut-off, U adpated copy of Biowaste, garden waste {RoW}| treatment of garden biowaste, home composting in heaps | Cut-off, U

The carbon emissions are calculated material per material. See values in deliverable D5.2 section IV.B.2. and V.B.3.j)(2).

For simplification, **process scraps** waste treatment were modelled with unmodified end-of-life data (*Biowaste {RoW}| treatment of biowaste, industrial composting | Cutoff, U* and *Biowaste, garden waste {RoW}| treatment of garden biowaste, home composting in heaps | Cut-off, U*).

The **credits associated with composting** of the solutions are determined based on the composition in N, P or K of the products. Default values are retrieved from D5.1 Annex 1, Table 14 nutrient proportion after 6 months.

Fertilizing element	wt% of total solids of compost	Value for 1kg of biowaste treated: 0,651 kg of compost	Negative input process
N	x (default value:0,73)	-x*1 kg	Inorganic nitrogen fertiliser, as N {RoW}| market for inorganic nitrogen fertiliser, as N | Cut-off, U
P2O5	y (default value:0,19)	-y*1 kg	Inorganic phosphorus fertiliser, as P2O5 {RoW}| market for inorganic phosphorus fertiliser, as P2O5 | Cut-off, U
K2O	z (default value:0,28)	-z*1 kg	Inorganic potassium fertiliser, as K2O {RoW}| market for inorganic potassium fertiliser, as K2O | Cut-off, U

3. End-of-life solutions

- **Black Soldier Fly bioconversion** was revised and C emissions of 99.95kg were allocated to CO_2 emissions (99.95*44/12 kg of CO_2 output to air).

Table 28 D5.1			
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)	366,48	Kg/t organic waste	Carbon dioxide, biogenic
N (Emission to air)	6,45	Kg/t organic waste	Nitrogen
CH4 (Emission to air)	0,35	Kg/t organic waste	Methane, biogenic
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

- **Anaerobic digestion** inventory of D5.1 Table 28 was representing an average digester. To be more precise, the four digesters detailed in D5.1 Table 7 were modelled separately as follows.

1. Modular renewable biodigester	Amount	Unit	Description/Reference	Datasets
			Input	
High lignocellulose agricultural crops (straw bagasse, wheat & rape)	1000	kg	Vogeli et al. (2014) Table 3	biowaste entering the system, no impacts
Cow dung (inoculum)	100	kg		Manure, liquid, cattle {GLO}| market for
Energy consumption (No need of extra heat for the process, estimated Tº=25 ºC)	0	kWh		Electricity, medium voltage {GLO}| market group for
			Output	
Biogas	158,3	m3	Vogeli et al. (2014) Table 4, biogas composition 65% CH4 and 35%CO2	
Digestate	870,36	kg	All the parts of the organic waste that were not converted to biogas. Waste treatment : Biowaste, garden waste {RoW}| treatment of garden biowaste, home composting in heaps | Cut-off, U (modified, with no emission of biogenic C02 or CH4)	
	7	(g/kg)	Digestate liquid and solid data from EI 3.10 "Biowaste {RoW}| treatment of biowaste by anaerobic digestion | Cut-off, U" https://ecoquery.ecoinvent.org/3.10/cutoff/dataset/15839/documentation, g/kg of FM (fresh mass= liquid+solid digestate)	Inorganic nitrogen fertiliser, as N {RoW}| market for inorganic nitrogen fertiliser, as N | Cut-off, U
	15	(g/kg)		Inorganic phosphorus fertiliser, as P2O5 {RoW}| market for inorganic phosphorus fertiliser, as P2O5 | Cut-off, U
	25	(g/kg)		Inorganic potassium fertiliser, as K2O {RoW}| market for inorganic potassium fertiliser, as K2O | Cut-off, U
CO_2	74220,92	g /t waste	Carbon dioxide, biogenic	
CH_4	4,33	g /t waste	Methane, biogenic	
N_2O	0,09	g/t waste	Dinitogen monoxide	

2. Single gas digester	Amount	Unit	Description/Reference	Datasets
			Input	
All kinds of organic waste	1000	kg	Vogeli et al. (2014) Table 3	biowaste entering the system, no impacts
Cow dung (inoculum)	100	kg		Manure, liquid, cattle {GLO}| market for
Energy consumption (Thermophilic, Tº =55ºC)	76,76	kWh		Electricity, medium voltage {GLO}| market group for
			Output	
Biogas	159,5	m3	Vogeli et al. (2014) Table 4, biogas composition 65% CH4 and 35%CO2	
Digestate	891,4	kg	All the parts of the organic waste that were not converted to biogas. Waste treatment : Biowaste, garden waste {RoW}| treatment of garden biowaste, home composting in heaps | Cut-off, U (modified, with no emission of biogenic C02 or CH4)	
	7	(g/kg)	Digestate liquid and solid data from EI 3.10 "Biowaste {RoW}| treatment of biowaste by anaerobic digestion | Cut-off, U" https://ecoquery.ecoinvent.org/3.10/cutoff/dataset/15839/documentation, g/kg of FM (fresh mass= liquid+solid digestate)	Inorganic nitrogen fertiliser, as N {RoW}| market for inorganic nitrogen fertiliser, as N | Cut-off, U
	15	(g/kg)		Inorganic phosphorus fertiliser, as P2O5 {RoW}| market for inorganic phosphorus fertiliser, as P2O5 | Cut-off, U
	25	(g/kg)		Inorganic potassium fertiliser, as K2O {RoW}| market for inorganic potassium fertiliser, as K2O | Cut-off, U
CO_2	75568,36	g /t waste	Carbon dioxide, biogenic	
CH_4	6,92	g /t waste	Methane, biogenic	
N_2O	0,14	g/t waste	Dinitogen monoxide	

3. Micro biogas digester	Amount	Unit	Description/Reference	Datasets
			Input	
All kinds of organic waste	1000	kg	Vogeli et al. (2014) Table 3	biowaste entering the system, no impacts
Cow dung (inoculum)	100	kg		Manure, liquid, cattle {GLO}| market for
Energy consumption (Mesophilic, estimated Tº= 35ºC)	42,08	kWh		Electricity, medium voltage {GLO}| market group for
			Output	
Biogas	121,48	m3	Vogeli et al. (2014) Table 4, biogas composition 65% CH4 and 35%CO2	
Digestate	941,13	kg	All the parts of the organic waste that were not converted to biogas. Waste treatment : Biowaste, garden waste {RoW}| treatment of garden biowaste, home composting in heaps | Cut-off, U (modified, with no emission of biogenic C02 or CH4)	
	7	(g/kg)	Digestate liquid and solid data from EI 3.10 "Biowaste {RoW}| treatment of biowaste by anaerobic digestion | Cut-off, U" https://ecoquery.ecoinvent.org/3.10/cutoff/dataset/15839/documentation, g/kg of FM (fresh mass= liquid+solid digestate)	Inorganic nitrogen fertiliser, as N {RoW}| market for inorganic nitrogen fertiliser, as N | Cut-off, U
	15	(g/kg)		Inorganic phosphorus fertiliser, as P2O5 {RoW}| market for inorganic phosphorus fertiliser, as P2O5 | Cut-off, U
	25	(g/kg)		Inorganic potassium fertiliser, as K2O {RoW}| market for inorganic potassium fertiliser, as K2O | Cut-off, U
CO_2	90439,57	g /t waste	Carbon dioxide, biogenic	
CH_4	8,28	g /t waste	Methane, biogenic	
N_2O	0,17	g/t waste	Dinitogen monoxide	

4. Domestic biogas digester	Amount	Unit	Description/Reference	Datasets
Input				
Fibrous and non fibrous organic (e.g., animal manure, overstored food)	1000	kg	Vogeli et al. (2014) Table 3	biowaste entering the system, no impacts
Cow dung (inoculum)	100	kg		Manure, liquid, cattle {GLO}| market for
Energy consumption (average mesophilic-thermophilic, estimated T°= 45°C)	61,88	kWh		Electricity, medium voltage {GLO}| market group for
Output				
Biogas	111,3	m3	Vogeli et al. (2014) Table 4, biogas composition 65% CH4 and 35%CO2	
Digestate	954,5	kg	All the parts of the organic waste that were not converted to biogas. Waste treatment : Biowaste, garden waste {RoW}| treatment of garden biowaste, home composting in heaps | Cut-off, U (modified, with no emission of biogenic C02 or CH4)	
	7	(g/kg)	Digestate liquid and solid data from EI 3.10 "Biowaste {RoW}| treatment of biowaste by anaerobic digestion | Cut-off, U" https://ecoquery.ecoinvent.org/3.10/cutoff/dataset/15839/documentation, g/kg of FM (fresh mass= liquid+solid digestate)	Inorganic nitrogen fertiliser, as N {RoW}| market for inorganic nitrogen fertiliser, as N | Cut-off, U
	15	(g/kg)		Inorganic phosphorus fertiliser, as P2O5 {RoW}| market for inorganic phosphorus fertiliser, as P2O5 | Cut-off, U
	25	(g/kg)		Inorganic potassium fertiliser, as K2O {RoW}| market for inorganic potassium fertiliser, as K2O | Cut-off, U
CO_2	67762,99	g /t waste	Carbon dioxide, biogenic	
CH_4	5,91	g /t waste	Methane, biogenic	
N_2O	0,12	g/t waste	Dinitogen monoxide	

For **end-of-life biogas credits**, biogas is associated to a lower heating value of 22.73 MJ/Nm3 (at 273K and P_{atm}=1013.25 mbar, data from “*Biogas {RoW}| treatment of biowaste by anaerobic digestion | Cut-off, U*”) and not 21,6MJ as mentioned in D5.1. The thermal efficiency is set to 0.53, as documented in ecoinvent 3.10 “*Heat, central or small-scale, other than natural gas {RoW}| heat and power co-generation, biogas, gas engine | Cut-off, U*”.

As for composting, digestate is also associated with fertilising credits but with digestate fertilising elements content, retrieved from ecoinvent EI3.10 "*Biowaste {RoW}| treatment of biowaste by anaerobic digestion | Cut-off, U*" dataset documentation.

Here is the table of the anaerobic digestion credits:

	Credits	Amount /tonne of biowaste	Unit	Dataset (negative input)
Biogas production	Heat	=-x*22.73*0.53 x, biogas production in m3 of inventories above	MJ	Heat, central or small-scale, other than natural gas {RoW}| heat and power co-generation, biogas, gas engine | Cut-off, U Region is adapted to DRC or SS in sensitivity analysis.
Emission to SOIL	**Credits**	**Amount /tonne of biowaste**	**Unit**	**Dataset (negative input)**
	N fertiliser	-7,18	kg/ tonne of digestate	Inorganic nitrogen fertiliser, as N {RoW}| market for inorganic nitrogen fertiliser, as N | Cut-off, U
	P fertiliser	-3.33/M(P)*M(P205) =-14.4	kg/ tonne of digestate	Inorganic phosphorus fertiliser, as P2O5 {RoW}| market for inorganic phosphorus fertiliser, as P2O5 | Cut-off, U
	K fertiliser	-6.32/M(P)*M(P205) =-24.1	kg/ tonne of digestate	Inorganic potassium fertiliser, as K2O {RoW}| market for inorganic potassium fertiliser, as K2O | Cut-off, U

M(...), being the molar mass of the molecules/element in g/mol

C. LCIA Methodologies

This annex give more details on the Life cycle impact assessment methodologies used for the hotspots identification and analysis.

1. Environmental Footprint 3.1 (EF3.1) methodology (European Commission)

The EF3.1 impact categories provide a comprehensive framework to assess the potential environmental consequences associated with products, services, or systems throughout their life cycle. The 16 impacts categories cover a wide range of issues, including climate change, resource use, emissions to air, water, and soil, as well as impacts on ecosystems and human health. By structuring the assessment into distinct categories, EF3.1 ensures consistency, comparability, and transparency in environmental evaluations across different sectors and applications.

Indicators identified as relevant for the project are described in D5.2. section III.A. Here is a short presentation of the others impact categories not relevant for B4H:

- Acidification
  - *Unit:* mol H^+ eq
  - *Short description:* Emissions leading to acid rain, damaging soils, forests, freshwater, and infrastructure.
- Particulate Matter
  - *Unit:* disease incidence (impact on human health)
  - *Short description:* Mortality and morbidity caused by fine particulate matter emissions.
- Eutrophication, Marine
  - *Unit:* kg N eq
  - *Short description:* Excess nitrogen emissions to coastal waters leading to algal blooms and dead zones.
- Eutrophication, Terrestrial
  - *Unit:* mol N eq
  - *Short description:* excess nitrogen deposition on soils altering species composition and ecosystem health.
- Human Toxicity, Cancer
  - *Unit:* CTUh (comparative toxic unit for humans)
  - *Short description:* Potential harm to humans from long-term carcinogenic chemical exposure.
- Human Toxicity, non-Cancer
  - *Unit:* CTUh (comparative toxic unit for humans)
  - *Short description:* Human health impacts of long-term exposure to toxic chemicals not linked to cancer.
- Ionising radiation, human health
  - *Unit:* kBq U-235 eq
  - *Short description:* Human health impact from exposure to ionising radiation generated by energy production and materials
- Ozone depletion
  - *Unit:* kg CFC-11 eq
  - *Short description:* Loss of stratospheric ozone caused by halogenated substances, increasing UV-B radiation.

- Photochemical Ozone Formation
    - *Unit:* kg NMVOC eq
    - *Short description:* Ground-level ozone creation from volatile organic compounds and NOx under sunlight.
- Resource Use, Minerals and Metals
    - *Unit:* kg Sb eq
    - *Short description:* Depletion of mineral and metal resources used for technologies and infrastructure.

2. ReCiPe 2016 Endpoint methodology

ReCiPe 2016 Endpoint (H) methodology provides LCIA results in endpoint for 3 areas of protection: Human health (in DALY), Ecosystems (species.yr), and Resource (USD2013).

In this report, ecosystem endpoint damage category was used to demonstrate that the impacts of open-burning and open dumping were similar. So, Table 1 presents the impact categories contributing to Ecosystem damage results. The hierarchist methodology (H) represents a reasonable vision between an optimistic scenario (I) and a pessimistic scenario (E). See details in Table 2.

Table 1 ReCiPe 2016 Endpoint Methodology: Ecosystem damage category factors.

Damage category	Impact category	Factor	Unit
Ecosystems, species.yr	Global warming, Terrestrial ecosystems	1	species.yr / species.yr
	Global warming, Freshwater ecosystems	1	species.yr / species.yr
	Ozone formation, Terrestrial ecosystems	1	species.yr / species.yr
	Terrestrial acidification	1	species.yr / species.yr
	Freshwater eutrophication	1	species.yr / species.yr
	Marine eutrophication	1	species.yr / species.yr
	Terrestrial ecotoxicity	1	species.yr / species.yr
	Freshwater ecotoxicity	1	species.yr / species.yr
	Marine ecotoxicity	1	species.yr / species.yr
	Land use	1	species.yr / species.yr
	Water consumption, Terrestrial ecosystem	1	species.yr / species.yr
	Water consumption, Aquatic ecosystems	1	species.yr / species.yr

Table 2 ReCiPe 2016 Endpoint (H) Methodology: hierarchist perspective[1]

	Time perspective	Manageability	Required level of evidence
Individualist (I)	Short time	Technology can avoid many problems	Only proven effects
Hierarchist (H)	Balance between short and long term	Proper policy can avoid many problems	Inclusion based on consensus
Egalitarian (E)	Very long term	Problems can lead to catastrophe	All possible effects

[1] ReCiPe - PRé Sustainability

3. Impact World+ methodology

Impact World+ is an LCIA methodology developed by the International Life Cycle Collaboration (ILCC). It is globally regionalized and combines midpoint categories (impacts, as in EF3.1) and endpoint categories (damages, as in ReCiPe 216).

On top of the impacts categories already assessed by EF3.1 (IW+ does not have the same characterisation factors and calculation methods), LCIA results are also provided regarding the following impact categories (non-exhaustive list):

- Fisheries impacts
- Pastics effect on biota
- Land occupation and transformation

In this deliverable, this methodology is particularly interesting to evaluate the plastics effect on biota (in potentially disappeared fraction of species, PDF.m2.yr)