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Programmed biodegradation capability of bio-based materials and products, validated in specific environments

MAGICBIOMAT

Manufacturing Guiding Tool for Circular and Programmed Biodegradable Materials Under Open Environment Conditions

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Acronyms

BB	Biobased
BDM	Biodegradable Mulch
CAPEX	Capital Expenditure
CS1	Case Study 1
CS2	Case Study 2
CSR	Corporate Social Responsibility
CT-IPC	Centre Technique Industriel de la Plasturgie et des Composites
DIGI	Digiotouch
EoL	End of Life
EU	European Union
FU	Functional Unit
GA	Grant Agreement
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCSA	Life Cycle Sustainability Assessment
OK	Organik Kimya
OPEX	Operational Expenditure
PBAT	Polybutylene Adipate Terephthalate
PBS	Polybutylene Succinate
PCL	Polycaprolactone
PLA	Polylactic Acid
SB	System boundary
SETAC	Society of Environmental Toxicology and Chemistry
SHDB	Social Hotspots DataBase
S-LCA	Social-Life Cycle Assessment
TPS	Thermoplastic Starch
TUS	Technological University of the Shannon: Midlands Midwest
UNEP	UN Environment Programme
UNIPD	University of Padova (IT)

WBCSD	World Business Council for Sustainable Development
WP	Work Package

Executive Summary

Deliverable D7.2 documents the results of Task 7.2, marking the transition from the theoretical framework established in D7.1 “Life Cycle Sustainability Assessment (LCSA) methodology” to the operational data collection phase of the MAGICBIOMAT project. The primary objective of this task was to define the specific goal and scope for the project’s sustainability assessments and to begin the baseline data collection required for environmental, economic, and social analysis. A core output of this reporting period was the development of a dedicated Life Cycle Inventory (LCI) template by DIGI and IPC. This template was designed to capture not only the physical unit processes and mass balances but also the costs and value-chain sectors involved. Following the methodology defined in T7.1, this task involved:

- Goal and Scope Definition: Establishing the system boundaries for LCA, life cycle costing (LCC), and social-life cycle assessment (S-LCA) for both Paper-based Packaging (CS1) and Mulch Films (CS2) in compliance with ISO 14040/44 [1], [2] and UNEP guidelines [3].
- Baseline Data Collection: Gathering primary data from technical work packages (WPs) completed in Month (M)18 (WP1) and for those upcoming, via the personalized life cycle inventory (LCI) template and generic social survey questionnaires.

The scope presented in D7.2 provides the baseline necessary for the upcoming sustainability impact assessments, ensuring that the bio-based materials developed in MAGICBIOMAT are evaluated using high-quality, project-specific data.

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1. Introduction

The MAGICBIOMAT project employs a comprehensive sustainability validation process for its bio-based (BB) innovations, integrating environmental Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA).While the overarching assessment methodology was defined in Deliverable D7.1, the current deliverable (D7.2), details the practical implementation of that framework through Task 7.2 (M9–M18).

1.1. Objectives of Task 7.2

Task 7.2 focuses on the transition from methodology to data. The primary objectives addressed in this report include:

- **Application of Standards:** Defining the goal and scope for Environmental Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA) to ensure full compliance with ISO 14040/14044 and UNEP standards.
- **Template Development:** The creation of a specialized Life Cycle Inventory (LCI**)** template used to harmonize data collection across different partners and case studies.
- **Data Integration:** The initiation of baseline data collection regarding unit processes, costs, and social indicators from the project's technical work packages.

The scope definitions and data collection are applied to two case studies:

1. **Case Study 1 (CS1):** BB coating for Paper-based Packaging (Focus of IPC).
2. **Case Study 2 (CS2):** BB polymers for Mulching Films (Focus of DIGI).

By finalizing the scoping and initiating the inventory in this deliverable – scoping that is already substantially defined yet may continue to evolve as the project progresses (currently M18 of 48) - the project establishes a robust data foundation, which will continue to be strengthened for the subsequent sustainability modeling and impact interpretation.

1.2. Life Cycle Inventory (LCI) and Data Collection

In this phase, DIGI and IPC develop a specified LCI section. This inventory goes beyond traditional environmental flows to include direct/indirect costs. In addition, data collection was a collaborative effort involving TUS, UNIPD and OK, who provided technical baseline data from WP1, WP2, WP5, and WP6. Currently, the WPs work follows the schedule in Table 1.

Table 1: WPs duration and status compared to WP7 deliverables deadline.

WP	Status	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M 12	M13	M14	M15	M16	M17	M18
WP1	94%																		
WP2	0%																		
WP5	5%																		
WP6	0%																		
WP7	94%																		
Deliverables													D7.1						D7.2

Due to the reporting window (M16–17), data collection for WP2, WP5, and WP6 will not commence until M18. However, preliminary data for WP1 (which concludes in M18) is available and presented in the following sections. For the social dimension (S-LCA), data will be gathered through targeted survey questionnaires.

2. Life Cycle Assessment (LCA) Goal and Scope Definition

This section establishes the goal and the scope for the LCA of both case studies. The definition follows the ISO 14044 standard and the LCSA methodology established in D 7.1. While the two case studies target different industrial applications, they share a unified methodological approach regarding data quality, allocation, and general assumptions. This section first identifies the specific goals for each study and subsequently details the unique technical parameters defined within the scope (Functional Unit and System Boundaries) before concluding with the common methodological settings.

2.1. LCA: Goal Definition

In accordance with ISO 14040 and 14044 standards, the goal of this study is to evaluate the environmental and sustainability performance of two innovative BB applications developed within the MAGICBIOMAT project. While biodegradable alternatives offer a promising solution to plastic pollution and littering, many existing plastics fail to fully degrade in natural environments. This study specifically examines a portfolio of

materials with programmed biodegradability to ensure they break down effectively under diverse EU climates and open-environment conditions (soil, fresh water, and marine).

A) **Case Study 1 (CS1)** focuses on BB and biodegradable acrylic coating for paper-based tray packaging, engineered with controlled degradation to meet short-term requirements and mitigate littering in the packaging sector. The goal is to provide a scientific basis for quantifying how this coating reduces impacts on soil, water, air, and climate compared to a conventional, non-biodegradable petroleum-based coating for paper trays.

B) **Case Study 2 (CS2)** targets the production value chain of BB mulch films, which address the high rates of littering in agricultural settings by utilizing polymer transformation processes that prioritize end-of-life success in the field.

The intended application for both studies is to support the industrial development of circular material designs by identifying environmental "hotspots" during the current research and development stage. The intended audience includes the project consortium, industrial partners in the European bioeconomy, and EU regulatory bodies. As these results are intended for internal project optimization and technical development, no comparative assertions intended to be disclosed to the public are being made, and therefore no external critical review is required.

2.2. LCA: Scope

The scope of this LCA is defined to provide a transparent technical framework consistent with the MAGICBIOMAT Grant Agreement (GA) and ISO 14044 standards. The analysis follows an iterative framework, allowing the goal and scope, including functional units (FU) and system boundaries (SB), defined specifically for each case study in sections 2.2.1 and 2.2.2, to be refined as primary data and chemical formulations are validated by project partners.

- **Allocation Procedures:** In accordance with ISO 14044, allocation is avoided as no by-products are currently expected from the synthesis or extrusion processes. Should multi-output processes be identified during data collection, the allocation or system expansion approach will be redefined accordingly.
- **Impact Categories & Methodology:** The assessment focuses on categories critical to BB materials, specifically Climate Change, Water Consumption, Land Use and Eutrophication. The Life Cycle Impact Assessment (LCIA) methodology is selected on D7.1 based on literature review.
- **Data Requirements & Quality:**
    - **Primary Data:** Collected directly from partners (e.g., OK, TUS, UNIPD) for all "Core Processes" such as emulsion polymerization, drying, and molding.

- **Secondary Data:** Sourced from established databases like Ecoinvent for "Upstream" background processes.
- **Quality Standards:** Data must represent the European context and the project's horizon.

- **Assumptions & Limitations:** Initial assessments assume a linear flow from production to biodegradation. Potential reuse or recycling will be treated as alternative scenarios if data permits. Where specific data for innovative bio additives is unavailable, appropriate proxy data will be utilized.

The specific FU and SB tailored to each application are detailed in the following sections for CS1 and CS2.

2.2.1. Case Study 1 (CS1)

This study focuses on the production and end-of-life (EoL) of BB and biodegradable acrylic coating for paper tray for food packaging. The primary function is to provide a protective barrier to the food and the underlying paper tray, preventing direct contact, and moisture penetration while maintaining the integrity and environmental sustainability of the packaging material.

2.2.1.1. Functional Unit

Within the project framework, OK is responsible for the development of the coating. The paper tray will be purchased from an external supplier and used as a substrate for the coating application, resulting in a final product that meets the project objectives. At this stage, no information is available regarding the characteristics of the selected paper tray (dimensions, weight, etc.). The core of the project is the development of the coating by OK, as the paper tray already exists on the market.

Furthermore, in the comparison between a paper tray coated with a BB and biodegradable acrylic coating and a paper tray coated with a petro-based polyethylene (PE) coating, it is assumed that the paper substrate will be the same for both products. In this context, it seems appropriate, at this stage of the project, to define a declared unit rather than a functional unit: "1 kg of coating for paper tray intended for food use."

Once the project progresses and additional information on the paper tray becomes available, this declared unit can be refined into a more representative FU. In particular, the concept of protected surface area (in cm^2) and the coating thickness required to achieve equivalent performance must be integrated to ensure an iso-functional comparison between the two products. The biodegradation tests specified in Tasks 1.5 and 5.2 are conducted only on the coating. The results of the biodegradation tests on the finished product (paper tray with a bio-based and biodegradable coating), specified in Task 5.3, will help decide whether to include the paper tray in the comparative study, particularly if it affects the end-of-life results.

2.2.1.2. System Boundaries

The study employs a Cradle-to-Grave boundary without distribution and use stages, shown in

Figure 1, segmented into:

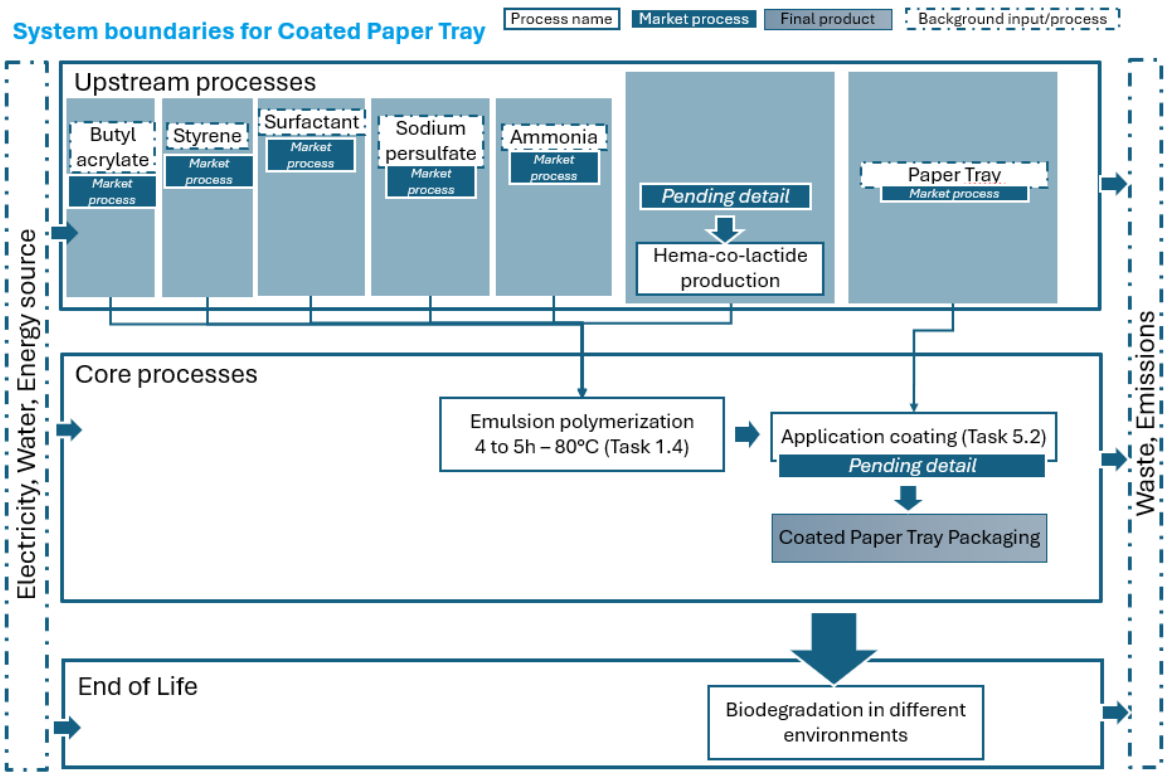


Figure 1 : CS 1 (paper tray) system boundaries.

- **Upstream:** Acquisition of raw materials (butyl acrylate, styrene, surfactants) and production of hema-co-lactide.
- **Core:** Emulsion polymerization and application of the coating onto the paper tray.
- **End-of-Life:** A 6-month biodegradation phase in various environments (home and industrial compost, or soil with a longer timeline).
- **Cross-cutting Flows:** All stages account for the consumption of electricity, water, and energy sources, alongside the resulting waste, wastewater, and emissions.
- **Distribution and Use:** with a comparative objective these stages will be the same for BB innovation and petro-sourced products. No partners are involved in these stages of the product life cycle.

2.2.2. Case Study (CS) 2

This second CS addresses the life cycle of innovative bio-based (BB) polymers intended for agricultural ground cover.

2.2.2.1. Functional Unit

The current reference flow is established as 1 kg of BB polymer produced. As the project progresses and material performance is validated by partners (TUS, UNIPD, IPC), this could transition to a more representative FU, such as area of soil covered, to better reflect the agricultural service provided.

2.2.2.2. System Boundaries

The assessment follows a Cradle-to-Grave boundary without distribution and use stages, as illustrated in

and Figure 3.

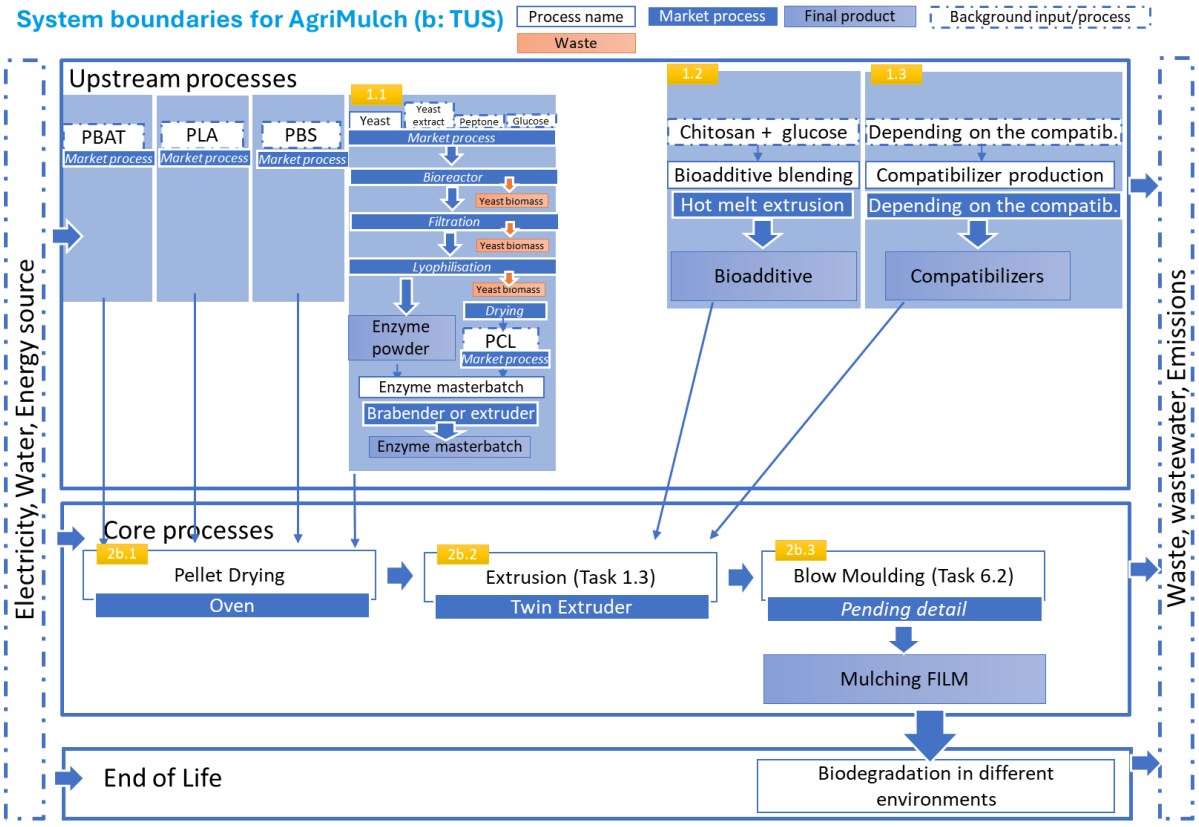


Figure 2: CS 2 (agri mulch) TUS system boundaries.

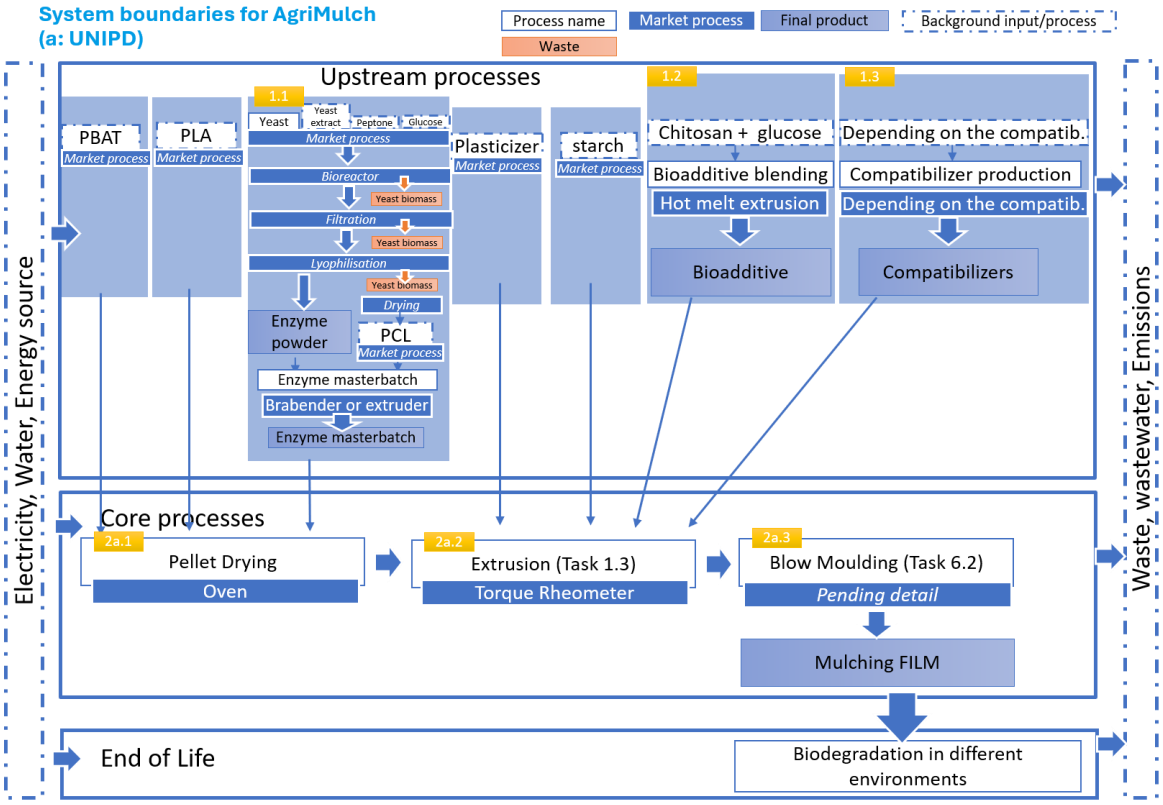


Figure 3: CS 2 (agri-mulch) UNIPD system boundaries.

Based on the outcomes achieved within WP1, the selection of the polymer system from among those developed by UNIPD and TUS has not yet been definitively established. Consequently, both systems are considered in the present assessment, while the final selection will be determined at a later stage, in line with the technical developments and validation activities planned under WP2 and WP6.

Although both system boundaries encompass the complete life cycle—from raw material acquisition through to end-of-life biodegradation—there are notable technical differences in their current configurations:

- **Upstream Processes:** Both systems include the sourcing of the primary polymers, namely Polybutylene Adipate Terephthalate (PBAT), Polybutylene Succinate (PBS), and Polylactic Acid (PLA), as well as the production of bioadditives and enzymes through bioreactor cultivation processes, which involve the use of Polycaprolactone (PCL). The main distinction lies in the composition of the polymer matrix:
    - **TUS (Figure 2):** Incorporates PBS as a key matrix component.
    - **UNIPD (Figure 3):** Includes a plasticizer and starch in the form of Thermoplastic Starch (TPS).
- **Core Processes:** This stage comprises the industrial conversion of raw materials into the final biodegradable mulching film. The primary difference between the two systems concerns the extrusion technology employed:

- **TUS (Figure 2):** Utilizes twin-screw extrusion technology.
- **UNIPD (Figure 3):** Employs a torque rheometer, indicating potential differences in processing scale and operational conditions. Both pathways include pellet drying and conclude with film production through blow moulding.

- **End-of-Life (EoL):** The end-of-life stage is identical for both systems and includes the biodegradation of the mulching films after use across relevant environmental compartments.
- **Cross-Cutting Flows:** All life-cycle stages account for the consumption of electricity, water, and other energy inputs, as well as the generation of waste, wastewater, and atmospheric emissions.
- **Distribution and Use Phase:** For comparative purposes, the distribution and use phases are assumed to be equivalent for both the bio-based innovation and the conventional petrochemical-based reference products. No project partners are directly involved in these stages of the product life cycle.

3. Life Cycle Costing (LCC) Goal and Scope Definition

The definition of Goal and Scope is the foundational step in applying the LCC methodology established in D 7.1. The purpose of this phase is to establish the "economic boundaries" and the functional basis for the assessment, ensuring that the financial data remains consistent with the environmental life cycle inventory. Rather than assuming specific outcomes, this section outlines the parameters required to objectively map the costs associated with the MAGICBIOMAT innovations.

3.1. LCC: Goal Definition

The goal of this LCC is to evaluate the economic performance of the innovative BB and biodegradable polymers developed within the project. The intended application is to identify the financial profile of these materials, specifically the BB acrylic coatings (CS1) and mulch films (CS2), by pinpointing cost drivers during the current research and development stage. This analysis is carried out to provide an internal scientific basis for comparing the total cost of ownership of these programmed biodegradable systems against available, conventional fossil-based alternatives. This comparison seeks to determine how the "circular by design" features and biodegradation impact the overall life cycle cost, whether through increased production expenses or potential savings at the end-of-life stage. The intended audience includes the MAGICBIOMAT project consortium and industrial partners. In accordance with the project's iterative nature, the results are intended for internal use to support design-stage decision-making and are not currently intended for public comparative assertions.

3.2. LCC: Scope and Boundaries

To maintain consistency with the LCA, the scope of the LCC follows the same FU and SB defined for environmental assessment.

- **System Boundaries:** The analysis covers the life cycle from "Cradle-to-Grave", encompassing raw material acquisition (BB monomers), the transformation and processes, then the EoL (biodegradation in open environments), excluding distribution and use.
- **Cost Categories:** The assessment tracks internal costs including capital expenditure (CAPEX), operational expenses (OPEX), and EoL management costs.
- **Functional Unit:** As explained in the LCA section, the FU will evolve over the project to integrate a function aspect (e.g., 1 square meter of coated paper or 1 hectare of mulched soil). Ensuring that the comparison between MAGICBIOMAT materials and conventional solutions is based on equivalent technical performance, the final FU will be used for LCC.

4. Social Life Cycle Assessment (S-LCA) Goal and Scope Definition

4.1. S-LCA: Goal Definition

In accordance with the ISO 14075 standard, the goal of this Social Life Cycle Assessment (S-LCA) is to evaluate the social impacts of the innovative bio-based and biodegradable polymers developed within the MAGICBIOMAT project. The study aims to identify social 'hotspots', highlighting both strengths and weaknesses, across the entire value chain, from raw material production to end-of-life management. Rather than performing a comparative assertion, this assessment focuses on providing a transparent sustainability profile of the industrialization process. The results are intended to support the transition to bio-based materials by offering a clear justification of their social performance to the public and stakeholders. The intended audience includes the MAGICBIOMAT consortium, industrial partners in the European bioeconomy, and EU regulatory and funding bodies. Finally, as this study is not intended for comparative claims, no formal critical review is required.

4.2. S-LCA: Scope

The scope of this S-LCA defines the technical framework and boundaries to ensure the analysis is transparent and consistent with the LCSA. The products studied remain the same: BB and biodegradable coated paper tray (CS1) and agricultural mulch film (CS2). The current declared/functional unit established for the LCA and LCC is also employed. They are completed for the S-LCA with a geographical area. For MAGICBIOMAT project, this area is Europe. If necessary, it would be fine-tuned later to one or more

countries. In addition, the SB are defined separately for each CS, while general framework applied is presented in this section.

- **Cut-off rules**

For LCA, cut-off rules are generally based on mass criteria, and sometimes on economic criteria, but they must always ensure that excluded elements have a negligible environmental impact. For S-LCA, cut-off rules rely on demonstrating a negligible social impact. Exclusions may therefore be justified, for example, by a very low amount of working time or a low added value. Furthermore, priority is given to foreground data provided by the organizations directly involved in the project, rather than to background data, which are often difficult to access and may have limited accuracy.

- **Data quality**

In S-LCA, several types of data are used:

  - **Primary data**: collected directly from project partners through questionnaires, particularly for major processes. Their reliability depends on the transparency and trust of the partners, and providing justification helps strengthen the robustness of the study.
  - **Secondary data**: sourced from databases such as the social hotspots database (SHDB). They will be used to identify the impact categories relevant to MAGICBIOMAT project and for upstream processes not managed by the partners.

Data quality must ensure sufficient representativeness of the project context, particularly regarding the objective of future industrialization scale in European area.

- **Assumptions and limitations**

Assumptions and limitations will be specified progressively as data are collected, depending on their availability. It is already established, however, that one or several European countries in which the product would be used will need to be selected, in order to ensure adequate representativeness for the end-of-life stage. Several countries could therefore be considered. Potential limitations of the study may also arise from limited information, particularly concerning components purchased on the market for which no producer partner has been identified.

- **Impact Categories**

Initially, according to the methodology used to carry out a S-LCA, it is essential to select the social issues relevant for this study. According to the World Business Council for Sustainable Development (WBCSD) [4], these are the following social topics, with the 11 mandatories for the chemical products:

  - Fair wages
  - Freedom of association, collective bargaining and labour relations

- No child labour
- No forced labour, human trafficking and slavery
- Workers occupational health risks
- Skills, knowledge and employability
- Safety management system for workers
- Access to basic needs for human rights and dignity
- Job creation
- Health and safety of local community's living conditions
- Impact on consumer health and safety.

It should be mentioned that the WBCSD guidelines follow those of UNEP/SETAC [3].

For each of the social topics, Annex 4 of WBCSD [4] sets out a definition, an indicator for assessing it, and one or more advanced indicators. Based on this guideline, an initial questionnaire was drafted. In addition, in order to have a complete overview of social impact for MAGICBIOMAT project, it is important not to miss out on an additional social topic, which can be relevant. The aim is to identify if there are other social impact categories to consider beyond the 11 mandatory. In the next phase of the project, a workshop will be organized with all the consortium partners to identify these topics together. A further study based on the SHDB database may also be carried out to confirm it. During this next stage, the questionnaire may be adapted to best suit the project; the 11 mandatory indicators can therefore be customized. And indicators will also need to be defined for additional topics (Figure 4).

OVERARCHING SOCIAL TOPICS		STAKEHOLDERS		
		Workers	Local communities	Consumers
SOCIAL AREAS		Social Topics		
	Bacis rights & needs	• Fair wages • Appropriate working hours • Freedom of association, collective bargaining and labor relations • No child labor • No forced labor, human trafficking and slavery • No discrimination • Social/employer security and benefits	• Access to basic needs for human rights and dignity (healthcare, clean water & sanitation, healthy food, shelter) • Respect for indigenous rights	• Direct impact on basic needs (healthcare, clean water, healthy food, shelter, education)
	Employment	• Management of reorganization	• Job creation	
	Health & Safety	• Workers' occupational health risks • Management of workers' individual health • Safety management system for workers	• Health and safety of local community's living conditions	• Impact on consumer health and safety
	Skills & Knowledge	• Skills, knowledge and employability	• Promotion of skills and knowledge	• Promotion of skills & knowledge
	Well-Being	• Job satisfaction	• Access to basic needs for sustainable development (infrastructure, ICT, modern energy) • Nuisance reduction • Developing relationship with local communities	• Consumer's product experience

Legend
Mandatory social topics
Additional social topics to be selected by a practitioner

Figure 4 : Social impact categories of WBCSD [4].

- **Limitations and assumptions**

The social assessment relies on partner questionnaires, which inherently introduces the risk of self-reporting bias. For instance, sensitive issues such as child labor are unlikely to be disclosed voluntarily due to their prohibited nature. To mitigate this, it is essential to collect supplementary evidence to verify and justify all responses. Furthermore, the MAGICBIOMAT project faces specific constraints: the limited number of industrial partners at certain life cycle stages and the low Technology Readiness Level (TRL) both impact the overall granularity and accuracy of the social assessment.

4.2.1. Case study (CS) 1: System Boundary

Focusing on the value chain of CS 1: Paper tray coating, stakeholders are assigned to the different life cycle stages in the Table 2. The system boundary is defined with included and excluded life cycle stages regarding social assessment.

Table 2 : S-LCA CS 1 System boundary, including identification of stakeholders.

Life cycle stages	Included	Excluded	Justification
R&D	-	R&D Team (MAGICBIOMAT project)	Social issues considered minor among R&D teams. Social issues identified through the CSR initiatives of the project organizations.
Raw material extraction	Biomass producer	Machine or consumables manufacturer	The manufacturing processes for machinery and consumables can have a significant social impact. However, we do not have any specific data (no partners) or general data.
Raw material production	OK, manufacturer of monomers or additives		
Manufacturing	OK, Manufacturer of coating and coated paper tray		
Distribution	-	Transport operators and	Transportation stages can have a significant social impact. However, this stage will remain the same for both

		vehicle manufacturers	systems. For the simplicity of the comparative study, this stage has been excluded.
Use	-	Consumers	There is no use difference between the innovative product and the reference. The difference in coating should not result any change in properties than the reference product.
End-of-Life	Operator collecting and sorting finished products Operator handling traditional end-of-life treatment (incineration, landfilling, recycling) Operator handling biodegradation		The impact of biodegradation on the MAGICBIOMAT innovation. No consortium partner handles this on behalf of a local authority.

To conclude, the three main life cycle stages of MAGICBIOMAT selected are:

- **Raw materials extraction and production:** for polymers or additives producers.
- **Manufacturing:** for product manufacturers.
- **End of Life:** for operators handling end-of-life and more specifically biodegradation.

4.2.2. Case Study (CS) 2: System Boundary

Focusing on the product developed within CS 2: Biodegradable mulch film, stakeholders are assigned to the different life cycle stages in the Table 3. The SB is defined with included and excluded life cycle stages regarding social assessment.

Table 3 : S-LCA Case Study 2 System boundary, including identification of stakeholders.

Life cycle stages	Included	Excluded	Justification
R&D		R&D Team (MAGICBIOMAT project)	Social issues considered minor among R&D teams. Social issues identified through the CSR initiatives of the project organizations.

Raw material extraction	Biomass producer	Machine or consumables manufacturer	The manufacturing processes for machinery and consumables can have a significant social impact. However, we do not have any specific data (no partners) or general data.
Raw material production	Manufacturer of monomers or additives		
Manufacturing	UNIPD/TUS (small scale) Manufacturer of Agri mulch		
Distribution		Transport operators and vehicle manufacturers	Transportation stages can have a significant social impact. However, this stage will remain the same for both systems. For the simplicity of the comparative study, this stage has been excluded.
Use	Consumers/End users	-	The product is meant to perform the same as already available solution, with the difference of being biodegradable. This can potentially have an impact on end users as they won't need to physically discard or remove or replace the film. No partner in the project is however directly involved in this phase.
End-of-Life	Operator collecting and sorting finished products Operator handling traditional end-of-life treatment (incineration, landfilling, recycling) Operator handling biodegradation	-	The impact of biodegradation on the MAGICBIOMAT innovation. No consortium partner handles this on behalf of a local authority.

To conclude, the three main life cycle stages of MAGICBIOMAT selected are:

- **Raw materials extraction and production:** for polymers or additives producers
- **Manufacturing:** for product manufacturer
- **Use:** for farmers

- **End of Life:** for operators handling end-of-life and more specially biodegradation.

5. Baseline Data Collection

Following the definition of the goal and scope, the next step is the Life Cycle Inventory (LCI). This is often the most extensive and challenging phase, particularly from an 'external' perspective where the analyst must rely on laboratory staff for primary data. Because the required data are not always readily available and templates can be difficult for practitioners to interpret, this phase requires frequent collaboration. Consequently, meetings were scheduled with partners to clarify data collection possibilities. Through these discussions, the SB and FU were defined and validated according to current production standards. Finally, Excel-based templates, one for each CS, were developed to facilitate data collection.

To facilitate this, a template was developed in Excel to collect both LCA and LCC data. The file is structured with individual spreadsheets, where each sheet represents a specific process line (the structure of which is visualized in Figure 5). While the template was sent to partners for completion and review, it is important to note that this phase remains ongoing. As partners are still optimizing material blends, the current data collection is partial and will be finalized as the production process matures. For this reason, this first iteration functions mostly to set the basis for the data collection that will be used later for the assessment.

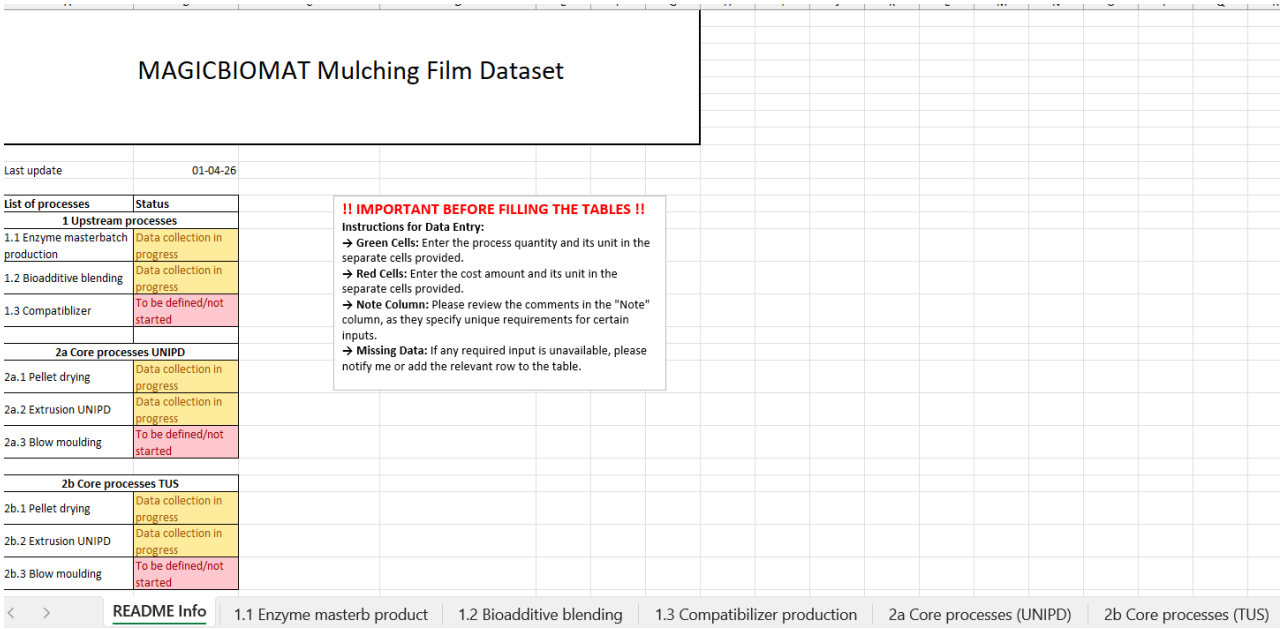


Figure 5: Data collection template main sheet for LCA and LCC data.

A single example sheet is shown as reference example in Table 4.

Table 4: Data collection template example.

	INPUT NAME	AMOUNT	UNIT	COST	UNIT	LOCATION	NOTES
	1.2.1 Bioadditive blending						
Input	Chitosan	124	g	49	€/kg	China, sea transportations 2 months, 15€/kg	Amount was provided in %wt
	Glucose	186	g	46.494	€/kg	Ireland, truck transport	Amount was provided in %wt; price is provided for 5kg as it is sold in that quantity, included shipping
Output	**Bioadditive**	300	g	TBC	TBC	TBC	Main product
	Waste	10	g	TBC	TBC	TBC	-
	Wastewater	TBC		TBC	TBC	TBC	-
	Emission	TBC	TBC	TBC	TBC	TBC	If measured
	By-product	TBC	TBC	TBC	TBC	TBC	It's a waste? Or by-product?
Energy	**Machine type, name**	PRISM twin-screw extruder		TBC	TBC	TBC	Hot melt extruder
	Electricity	0.302	kWh				-
	Diesel	TBC	TBC	TBC	TBC	TBC	-
	Gasoline	TBC	TBC	TBC	TBC	TBC	-
	Duration	90	min	TBC	TBC	TBC	How long is the process? (time)
	Max capacity	TBC	TBC	TBC	TBC	TBC	-

It should be noted that, the template is adapted to the SB according to the information provided.

5.1. Case Study (CS) 1

Regarding CS 1, the first data available to date is detailed in Annex Section 9.1.1. The current progress is summarized in Table 5. The primary objective of this initial collection phase was to validate the reporting template and ensure a streamlined assessment process moving forward. At this stage, the data should be considered provisional. Notably, while Task 1.4 is complete, data for the emulsion polymerization coating is currently not final. The list of ingredients should no longer change, but the quantities may still vary. Similarly, no economic data has been collected at this time, but the proposed template is designed to accommodate the information that our partners will be able to provide us with in the future. Furthermore, information regarding the paper tray and the coating application will only be available once WP 2 and 5 are well underway, likely after M18. This data will be collected as part of WP 8 and the initial assessment covered by D 8.1 and D 8.2.

Table 5 : CS 1 LCA / LCC data collection status.

List of processes	Status
1 Upstream processes	
1.1 Hema-co-lactide	Baseline completed
1.2 Paper Tray	To be defined/not started
2 Core processes	
2.1 Emulsion polymerization	Data collection in progress
2.2 Coating application	To be defined/not started

5.2. Case Study (CS) 2

The preliminary data for CS 2 is detailed in Annex section 9.1.2, with current progress summarized in **Error! Reference source not found.**. The primary objective of this initial collection phase was to validate the reporting template and ensure a streamlined assessment process moving forward. At this stage, the data should be considered provisional. Notably, while the associated task is complete, data for the compatibilizer production process is currently omitted. This is intentional, as OK is currently evaluating multiple polymer-blend configurations, and the selection of a compatibilizer, where applicable, has not yet been finalized for the target formulation. Data collection for this component will resume once the preliminary testing phase concludes, likely after M18. For all other processes already started, the data received is sufficient for this preliminary phase. However, as certain details regarding specific cost items and inputs are still outstanding, the datasets will be refined and updated once the formal modeling phase begins.

Table 6: CS 2 LCA / LCC data collection status.

List of processes	Status
1 Upstream process	
1.1 Enzyme masterbatch production	Baseline completed
1.2 Bioadditive blending	Baseline completed
1.3 Compatiblizer	To be defined/not started
2a Core processes-UNIPD	
2a.1 Pellet drying	Baseline completed

2a.2 Extrusion UNIPD	Baseline completed
2a.3 Blow moulding	To be defined/not started

2b Core processes-TUS	
2b.1 Pellet drying	Baseline completed
2b.2 Extrusion UNIPD	Baseline completed
2b.3 Blow moulding	To be defined/not started

6. Next steps

D7.2 concludes Task 7.2 and formally initiates Tasks 8.1 and 8.2, which will address the intermediate evaluation phases for both the LCA and the LCC. With the methodological framework now established and the preliminary scoping consolidated, the project is positioned to advance toward the analytical stages of sustainability assessment. The next steps of the project will therefore focus on several key activities:

1. The completion of primary data collection from all relevant project partners, ensuring that the datasets required for robust environmental and economic modelling are comprehensive and up to date.
2. The modelling of the two CS, integrating environmental and economic parameters to generate consistent and comparable assessment scenarios.
3. The interpretation of the results will function as a basis for the final sustainability evaluation to be conducted in WP9.

7. Conclusions

This deliverable establishes a comprehensive framework for the life cycle sustainability (LCS) evaluation by formalizing the initial goal and scope. Recognizing that sustainability assessments are inherently dynamic, this framework is designed to remain iterative, allowing for refinement as the methodology evolves and more granular data becomes available. With the SB and FU now clearly defined, the project has successfully transitioned into the second phase: the Life Cycle Inventory (LCI).

Although the LCI phase is currently in progress, its completion is aligned with the ongoing development of the two specific products under study. To ensure seamless integration between product development and sustainability reporting, a specialized data collection template has been developed and distributed to all

relevant partners. This proactive step not only facilitates the gathering of high-quality primary data but also ensures that the consortium is fully prepared for the subsequent data processing that will lead to the first definitive sustainability assessment.

8. References

[1] “ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework”.

[2] “ISO 14044: Environmental management — Life cycle assessment — Requirements and guidelines”.

[3] U. L. C. Initiative., “Global guidance principles for life cycle assessment databases.,” 2011.

[4] A. Brown, “Social Life Cycle Metrics for Chemical Products.,” 2016.

9. Annex

9.1. LCA/LCC data collection

9.1.1. Case Study (CS) 1

The data collection is accessible at the link below, only to the internal partners of the project due to confidentiality.

MAGICBIOMAT_PaperTray_datacollection.xlsx

9.1.2. Case Study (CS) 2

The data collection is accessible at the link below, only to the internal partners of the project due to confidentiality.

MAGICBIOMAT_Mulch Film_datacollection.xlsx

9.2. S-LCA

The mandatory social topics can be visualized from page 64 to page 83 of the “Social Life Cycle Metrics for Chemical Products - A guideline by the chemical sector to assess and report on the social impact of chemical products, based on a life cycle approach” [4]