D5.3. Methodology for the Social-Life Cycle Assessment

7-KVC

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List of Acronyms

A2C	TERRITORIAL CIRCULAR SYSTEMIC SOLUTION FOR THE UPCYCLING OF RESIDUES FROM THE AGRIFOOD SECTOR
ARCHA	ARCHA SRL
AVASA	AGRUPACION DE VIVERISTAS DE AGRIOS SA
CETEC	ASOCIACION EMPRESARIAL DE INVESTIGACION CENTRO TECNOLOGICO DEL CALZADOY DEL PLASTICO DE LA REGION DE MURCIA
DoA	Description of Action
GHG	Greenhouse Gas
IDEA	IDEACONSULT LIMITED LIABILITY COMPANY
ILO	International Labour Organisation
JRC	Joint Research Center
KVC	KNOWLEDGE VALUE CONSULTING
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
NEP	New Ecological Paradigm
PHBV	Poly(3-hydroxybutyrate-co-3-hydroxyvalerate)
PU	Public
PXP	ASOCIACION DE ORGANIZACIONES DE PRODUCTORES DE FRUTAS Y HORTALIZAS DE LA REGION DE MURCIA
RVL	REVOLVE PLANET
SGRB	STICHTING GREENPORT REGIO BOSKOOP
S-LCA	Social Life Cycle Assessment
SO-LCA	Social Organisational Life Cycle Assessment
SSbD	Safe and Sustainable by Design
SSH	Social Sciences and Humanities

TRL	Technology Readiness Level
UNEP	United Nations Environmental Programme
VFY	STICHTING VERTIFY
ViSS	Viable, safe and sustainable PHBV value chain for food packaging applications
WP	Work Package

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Keywords

- Safe and sustainable by design
- Social sustainability
- Social acceptance
- Delivery systems
- Evaluation framework

Glossary

Safe and Sustainable by Design (SSbD) Framework: The SSbD framework is a holistic approach initiated by the European Union to ensure that new chemicals and materials are inherently safe for people and the environment and sustainable throughout their life cycle. Rather than evaluating safety or sustainability only at end-of-pipe, SSbD embeds these criteria from the very start of innovation. In practice, this means integrating safety (toxicological, ecological) and sustainability (environmental, social, economic) considerations into the design, production, use, and end-of-life of materials. The European Commission's Chemicals Strategy for Sustainability explicitly calls for developing SSbD criteria to shift industry towards chemicals and materials that cause minimal harm across their lifecycle. Under SSbD, materials should deliver their intended function while minimising health and environmental risks, lowering pollution, and supporting circularity.

SSbD product: Shall mean any product – including in the context of providing a service (considering the full life cycle) – which is intended for consumers or likely, under reasonably foreseeable conditions, to be used by consumers and whether new, used or reconditioned. When referring to Safe and Sustainable-by-Design products, this definition covers only the products that can also be identified as chemicals or materials (as defined above). Thus, the term 'product' in the Sustainable-by-Design context is used as part of the term "chemical product" or "material product", meaning chemicals and materials that are intended for consumers, or likely to be used by consumers. An example of a 'chemical product' is paint, and an example of a material product is "impregnated wood"[1].

Biodegradable Materials in SSbD: Within biodegradable materials, SSbD emphasises designing products that degrade safely and do not accumulate or leave persistent pollutants. For example, the framework encourages polymers whose degradation products are non-toxic and fully assimilated by natural processes. In agriculture, this is crucial since materials like mulch films or foams often remain in soils. A safe-by-design biodegradable polymer should break down into benign substances (e.g. biomass, CO_2, water) without harming soil biota or water quality. A sustainable-by-design material would also have a low ecological footprint in production, use, and disposal, supporting climate goals and resource efficiency. Thus, SSbD provides a structured lens to examine biodegradable PHA (polyhydroxyalkanoates), ensuring they meet safety standards and sustainability benchmarks concurrently.

PHAntastic Mulch Films and Growth Foams: **PHAntastic** is a Horizon Europe project focusing on PHA-based (Polyhydroxyalkanoates[2]) innovative agricultural solutions. Specifically, PHAntastic develops two families of delivery systems for agro-inputs: (1) mulch films and (2) growth foams, both made from PHA polymers. These materials act as carriers of active bioproducts (e.g. amino acids, hydrolysed proteins, micronutrients, elicitors, beneficial microbes) to crops, aiming to replace conventional plastics and agrochemicals. The mulch films are designed to cover soil (preventing weeds, reducing evaporation, regulating temperature) while slowly releasing nutrients or biopesticides at the soil-plant interface. The growth foams serve as substrates or root zone conditioners that deliver bioproducts to seedlings or young plants. By using PHA (a bio-based, compostable polymer derived from microbial fermentation), these systems are intended to biodegrade in soil, avoiding persistent plastic waste. Importantly, PHAntastic explicitly seeks compliance with SSbD by involving experts to guide design choices. This means the mulch films and foams are being formulated and assessed against SSbD criteria (safety, sustainability, circularity) from the outset, rather than retrofitting sustainability after development. For instance, the project aims to achieve at least 25% reduction in fertiliser use and 50% reduction in pesticides by 2050 through controlled release features, while also cutting plastic pollution (targeting 680 tonnes less microplastic in soil by 2050).

Social Life Cycle for PHAntastic: Social LCA examines impacts on stakeholders (farmers, workers, consumers, local communities) across the value chain – for instance, job creation in rural biomass supply, or labour conditions in biopolymer factories. High-profile reviews (e.g. Spierling et al. [2]) highlight that bio-based plastics can reduce certain environmental impacts (especially climate change potential) but may shift burdens (e.g. agricultural land/water use, eutrophication from feedstock farming). Socially, they note concerns like competition with food crops and working conditions in feedstock harvesting.

Disclaimer

[2] Polyhydroxyalkanoates (PHAs) are a family of bio-based polymers produced by microorganisms.

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1. Executive summary

This document details the Social Life Cycle Assessment (S-LCA) methodology within the PHAntastic project, emphasizing the social sustainability of PHA-based agricultural solutions within the Safe and Sustainable by Design (SSbD) framework. The methodology is structured in two phases: the (re)design phase, which proposes design guiding principles, and the assessment phase, which evaluates social aspects using Social Organisational Life-Cycle Assessment (SO-LCA) and other social metrics. The assessment framework considers core dimensions like sustainability and circularity, acceptability, and environmental awareness, incorporating inputs from end-users and an expert group. This approach aims to provide a comprehensive evaluation of the social impacts of PHAntastic's mulch films and growth foams, supporting the project's goal to demonstrate increased social benefits in line with the Safe and Sustainable by Design (SSbD) framework.

This comprehensive framework draws upon interdisciplinary expertise and methodologies adapted from previous European projects (ViSS and A2C), addressing current limitations in social sustainability assessment. It features a stakeholder-inclusive approach targeting end-users, organisations, workers, and expert consultations to ensure that PHAntastic delivery systems not only meet technical requirements but also achieve meaningful social acceptance, delivering positive impacts throughout their lifecycle.

2. Introduction

The Safe and Sustainable by Design (SSbD) Assessment Framework developed for the PHAntastic project represents a methodologically rigorous approach to evaluating agricultural biotechnology innovations through an integrated sustainability lens. The framework operationalises sustainability assessment by systematically deconstructing the social domain into quantifiable metrics while preserving their interconnected nature, as given by the concept itself.

At its epistemological core, the assessment framework transcends reductionist social evaluations by positioning PHAntastic's biodegradable mulch films and growth foams within a complex socio-technical system. This approach acknowledges the inherent limitations of conventional social analyses that fail to capture externalities, socio-organizational implications, and long-term systemic transitions in agricultural practices.

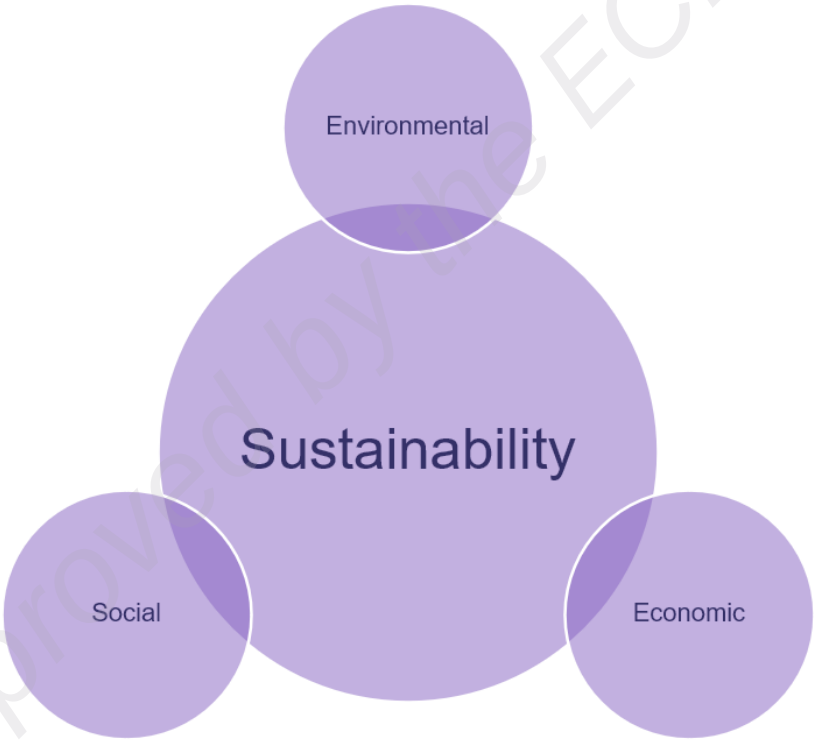

Figure 1 Sustainability aspects

The assessment of social aspects with a life cycle perspective (Social Life Cycle Assessment, S-LCA) is a rather young field of research compared to the assessment of ecological impacts of value chains via Life Cycle Assessment (LCA) and has been less in focus during the last decades of life cycle sustainability assessment [2]. This can be explained by the perception of ecological aspects to be more urgent on the one hand and by the complexity of social and economic issues and their interdependencies on the other.

This emphasis on environmental over social assessment is clearly demonstrated in the bioplastics industry, where ecological LCA has dominated sustainability discussions. The bioplastics industry (encompassing bio-based and biodegradable plastics) has seen a surge in sustainability assessments over the past decade. Researchers employ LCA to quantify environmental impacts (carbon footprint, energy, water, ecotoxicity, etc.) of bioplastics compared to conventional plastics [3], [4]. Many studies show that, while bioplastics can reduce fossil resource use and often carbon emissions, outcomes vary depending on feedstock cultivation (which can cause indirect land use change or require fertilisers) and end-of-life (some biodegradable plastics need industrial composting) [3].

In summary, state-of-the-art assessments show bioplastics' promise (reduced fossil dependency, new green jobs, potentially lower GHG emissions) alongside challenges (higher cost, need for improved end-of-life infrastructure, trade-offs in land use). This context sets the scene for evaluating PHAntastic's mulch films and foams under the SSbD lens, using cutting-edge LCA, LCC (Life-Cycle Costing), and S-LCA methodologies.

The application of these methodologies is operationalised in Work Package (WP) 5 "*SSbD Framework and regulatory compliance*". The four dimensions that will be considered in the project (risk&safety, environmental, social and economic), correspond to a specific task in the Work Package: the risk and safety dimension corresponds to task 5.1 "Risk and safety assessment and regulatory compliance"; the environmental dimension to task 5.2 "Environmental sustainability assessment"; the social dimension to task 5.3 "Social sustainability assessment" and finally the economic dimension will be dealt with task 5.4 "Economic sustainability assessment". Each dimension has appointed a partner responsible for leading the evaluation and producing the corresponding deliverables to ensure a complete approach to SSbD. IDEA and ARCHA PHAntastic partners are the safety and sustainability specialists in the SSbD, regulatory framework, data management and chemoinformatics, leading task 5.1, CETEC is the responsible partner of the environmental dimension (task 5.2) and KVC, as social sciences and humanities (SSH) expert, is the partner in charge of the social (task 5.3) and economic dimension (task 5.4).

The present framework corresponds to the first deliverable of a series of three documents (D5.3, D5.6 and D5.12) that are associated with task 5.3 and delivered as a guidance tool to implement the assessment in the subsequent two phases of evaluation (see Figure 3). In month 27, the assessment framework will be implemented, and a preliminary social assessment will be performed. This will serve to test the methodology and indicators defined to ensure that an accurate result is delivered in month 46 with deliverable *D.5.12 "Final Social-Life Cycle Assessment."*.

Complementing WP5 activities, *task 4.3."End-user evaluation"*, integrated in WP4 *Demonstration of PHAntastic delivery systems in collaboration with end-users*, brings to the assessment the integration of the end-users' views. In the present framework information on how this is going to be articulated is presented, but the results of the end-users' views will be presented on deliverable D.4.2 at the end of the project.

The aim of the evaluation is to prove that PHAntastic delivery systems will increase social acceptance based on S-LCA. To achieve these objectives, a combination of methods presented in this deliverable will be used under the umbrella of the SSbD framework. Following the introductory section, the SSbD approach and the other metrics to be used in the evaluation are outlined (Section 3 Methodology: SSbD framework and assessment design). In Section 4 Social sustainability by design (So-SbD) and SO-LCA, the social dimension of the SSbD approach is presented, including specific sections for the design principles (So-SbD | Design phase), and the methodology for the assessment phase (Assessment phase: methodology). Finally, the conclusions are presented in Section 5.

3. Methodology: SSbD framework and assessment design

Social Sciences and Humanities (SSH) disciplines are critical to understand conditioning factors of social acceptance, and to develop informed industry and policy recommendations. These disciplines are integrated into PHAntastic in order to define the roadmap to pinpoint end-users' needs and to assess the social sustainability of the mulch films and growth foams via advanced research, as well as qualitative and statistical analysis. Thus, besides developing these delivery systems for biopolymers, the project will tackle their risks, safety, sustainability, **social** and economic assessment throughout the whole product development process, in line with the SSbD framework and other social metrics. Indeed, the project´s Specific Objective SO5 is "*to demonstrate increased safety, environmental benefits and positive social and economic impacts, of PHAntastic delivery systems in line with the Safe and Sustainable by Design (SSbD) framework*".

To fulfil this objective, particularly regarding the social dimension, the assessment of the social sustainability of the expected delivery systems will primarily utilise the SSbD approach, with the Social Organisational Life-Cycle Assessment (SO-LCA) as the central methodology, complemented with other social metrics.

The following section explains our approach to evaluating social sustainability, showing how social factors fit into the larger Safe and Sustainable by Design (SSbD) framework, giving readers the necessary context. The practical challenges and limitations when assessing agricultural solutions made from PHBV materials are also presented.

As shown in Figure 2, the social sustainability assessment framework is structured around three core dimensions that provide a comprehensive evaluation approach: sustainability and circularity, acceptability and environmental awareness. "Sustainability and circularity" address how the delivery systems generate positive social change while adhering to Safe and Sustainable by Design (SSbD) principles, essential for creating long-term sustainable responsible solutions that minimise negative impacts throughout their lifecycle. "Acceptability" examines how stakeholders perceive and adopt the delivery systems, incorporating both usability considerations and end-user acceptance, which is crucial for ensuring market success and practical implementation. "Environmental awareness" measures both community and personal

Figure 2 Social sustainability assessment core dimensions

levels of consciousness regarding environmental issues, which is vital for fostering behavioural changes that support sustainable practices and create receptive conditions for bio-based innovations.

Capture social impact requires an imbricate set of metrics. Table 1 shows how the dimensions are envisaged to be assessed, defining the preliminary selected tools and methods, as well as those elements to be considered. Targets expected to be consulted are also included:

			Main targets			Expert group				
Dimension	**Tools & methods**	**Elements of the assessment per dimension**	PHAntastic End-users	PHAntastic Organisations	PHAntastic Workers	Industry	Consumers	Safety & risk analysis	Regulation	Circularity/ Environment
Sustainability and circularity	SSbD	Integration of SSbD principles in the design		X		X	X	X	X	X
	SO-LCA	Social changes generated	X	X	X					
Acceptability	Ad-hoc questionnaires	Acceptance of bio-based products	X			X	X			
	Ad-hoc questionnaires	Functionality/ usability of the delivery systems	X							
	Ad-hoc questionnaires	Buying tendencies of farmers: assess market fit	X							
	Ad-hoc questionnaires	CO-determining factors: how well delivery systems meet users' needs & areas for improvement	X			X	X	X	X	X
Awareness	NEP[3]	Environmental awareness	X		X					

Table 1 PHAntastic social evaluation matrix: dimensions, tools and targets; Source: elaborated by the authors

Research findings reveal that technology acceptance is a complex and multi-faceted phenomenon [5]. According to the literature, and in line with psychological definitions for individuals **acceptance** as an actors position, is the degree to which a phenomenon is taken up– liked/disliked, actively supported or resisted, or passively tolerated– by relevant social actors, i.e. the ones who make those choices [6]. In PHAntastic its analysis is taken as a dimension where diverse aspects will be studied, trying to align them with the Technology Acceptance Model [7], being probably one of the most widely cited model in the field of technology acceptance [8].

Our study investigates several key aspects that determine how different stakeholders receive and adopt PHBV-based delivery systems, examining four interconnected elements that influence the potential success of bio-based agricultural products in real-world contexts. Acceptance concept in sustainable projects is still broad and under agreement, the compilation of metrics that is going to be used in PHAntastic is a methodological proposal based previous experiences with research projects.

[3] NEP: New Ecological Paradigm scale

First, the general acceptance of bio-based products will be assessed through targeted questionnaires designed to gauge stakeholders' willingness to adopt these alternative solutions, exploring attitudes toward sustainability innovations and identifying potential barriers to acceptance. Second, the functionality and usability evaluation will examine how effectively the delivery systems perform their intended agricultural functions while providing a positive user experience.

The assessment of farmers' buying tendencies represents a crucial market-oriented component, investigating the economic and practical factors that influence purchasing decisions, including price sensitivity, perceived value, compatibility with existing farming practices, and anticipated benefits. Finally, the examination of co-determining factors provides deeper insights into how well delivery systems meet users' specific needs, identifying critical improvement areas by analysing contextual elements that might enhance or inhibit adoption.

By employing specialised ad-hoc questionnaires for each element, this multifaceted approach to acceptability provides a comprehensive understanding of the human and market factors that ultimately determine whether technically sound and environmentally responsible innovations will succeed in practical application.

End-users (PXP, AVASA, SGRB, VFY) will be involved through task 4.3. to gather feedback on their experience using PHAntastic delivery systems and their perceived strengths and areas for improvement. to evaluate market fit and social acceptance of the products. The report on their experience, including perceived strengths and areas for improvement will be delivered at the end of the project under WP4, as deliverable *D.4.2 "Evaluation of the PHAntastic delivery systems by end-users".*

In order to evaluate the **environmental concern** of end-users and other relevant stakeholders, the revised New Ecological Paradigm (NEP) scale will be used [9], [10]. The structure of the NEP consists of five conceptual interrelated facets underlying a general ecological worldview, expressed through fifteen statements or items. Items are designed to tap each of the five hypothesized facets of an ecological worldview: the reality of limits to growth (1, 6, 11), antianthropocentrism (2, 7, 12), the fragility of nature's balance (3, 8, 13), rejection of exemptionalism (4, 9, 14) and the possibility of an ecocrisis (5, 10, 15). Respondents are asked to indicate the strength of their agreement or disagreement with each statement, using a Likert scale ranging from 1 to 5. Responses to these fifteen statements are then used to evaluate the different dimensions proposed by the authors as part of the environmental awareness construct [11]. Although the dimensionality of the NEP has been questioned, we will use the scales proposed by the authors for descriptive purposes, in order to better explore the different nuances of the environmental awareness construct in our sample [9]. Respondents are asked to indicate the strength of their agreement or disagreement with each statement. Responses to these fifteen statements are then used to construct various statistical measures of environmental concerns. The eight odd-numbered items are worded so that agreement indicates a proecological view, and the seven even numbered ones so that disagreement indicates a proecological worldview. After correcting the directionality of the items, the geometric mean and standard deviation of the results obtained in the NEP for each dimension or scale were calculated.

This part of the assessment will include a literature review to track the evolution of industry awareness regarding bio-based alternatives to conventional plastics, examining changing attitudes, adoption patterns, and market drivers over time. Also, information will be gathered to understand how producers' awareness on the reduction of agrochemicals usage have been influenced. To validate and contextualise these findings, consultations will be made to the expert group when necessary.

The main targets of PHAntastic assessment are end-users, organisations and workers, being complemented by the insights of the expert group that will be build up after the framework submission. This expert group, composed of a diverse, multidisciplinary panel of specialists representing key stakeholder perspectives includes end-users (farmers), industry representatives, consumers, safety and risk analysts, regulatory specialists, and experts in circularity and environmental sustainability. The engagement of this actors will be achieved together with the collaboration of RVL as stakeholder engagement leaders.

In alignment with the objectives set out in the Dissemination and Communication Plan (D&C Plan), detailed in **D7.2**, the structured engagement of these stakeholders plays a crucial role in enhancing visibility, supporting project impact, and ensuring effective knowledge transfer across the agrifood ecosystem and beyond. The expert group's contributions, combined with strategic communication approaches and tailored messaging, will strengthen the dissemination of PHAntastic's innovations, fostering collaboration, policy uptake, and cross-sectoral awareness. These efforts directly support the project's overarching goals of reducing agrochemical and microplastic pollution while amplifying alignment with key EU strategies such as the Farm to Fork Strategy and the Zero Pollution Action Plan. Further information on stakeholder engagement mechanisms, key performance indicators, and communication strategies can be found in **D7.2 – Dissemination and Communication Plan**.

PHAntastic evaluation is framed in three key moments as represented in Figure 3: the evaluation methodology elaboration, a first preliminary assessment to analyse the usefulness and relevance of the tools (questionnaires, indicators…) proposed, and the final assessment of the PHAntastic delivery systems.

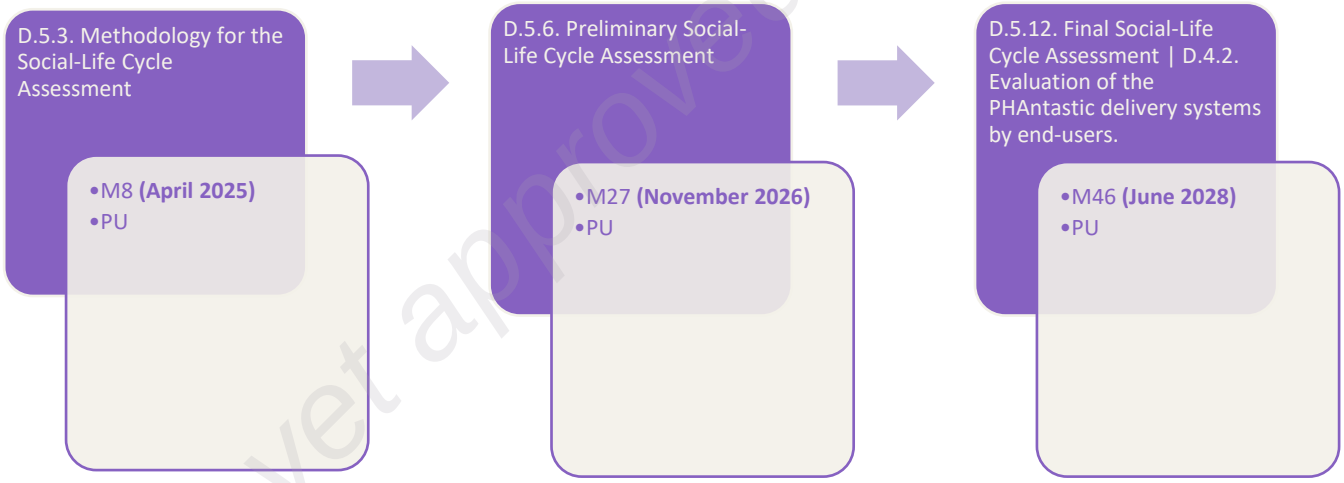

Figure 3 PHAntastic social evaluation timeline

The social evaluation framework for PHAntastic employs a multidimensional assessment approach designed to comprehensively capture how the developed delivery systems affect key stakeholders across various domains. At the core of this framework, SSbD methodology serves as the overarching guiding principle for the entire sustainability assessment. This hierarchical positioning is deliberate and essential: if delivery systems are not designed from the outset with proper integration of social values and sustainability principles, subsequent evaluations across other dimensions will inevitably fall short of acceptable performance targets.

By positioning SSbD as the foundational methodology, we ensure that social considerations are embedded at the design phase, creating a solid base upon which other assessment dimensions can build meaningful evaluations of stakeholder impacts.

To achieve this, different activities will be carried out (i.e. needs assessment, expert group definition, literature review, two workshops that will serve to showcase the evaluation results and to gather feedback on the relevance and adequacy of the delivery systems, consultations to technical partners and the expert group, data collection etc.). The recruitment process will be made together with RVL as stakeholder engagement leaders. It needs to be highlighted at this point, that due to the nature of the research projects and the necessity to tailor the activities to the needs (technical and managerial) of the project at each development stage, always under the agreements included in the DoA, the activities (timeline, descriptive nuances) might change.

To ensure cohesive integration across all dimensions of our social sustainability assessment, PHAntastic will employ a cross-dimensional analysis matrix that identifies correlations, contradictions and synergies between sustainability metrics. This will be done together with structured reflection workshops where technical partners and stakeholders collaboratively interpret integrated results to translate assessment findings into concrete design modifications will be organised as stated above.

3.1. Sustainability and circularity dimension

SSbD can be defined as a pre-market approach to chemicals and materials (**or products**) design that focuses on providing a function (or service), while avoiding volumes and chemical and material properties that may be harmful to human health or the environment, in particular groups of chemicals likely to be (eco) toxic, persistent, bio-accumulative or mobile [12]. In essence, this approach supports the design, development, production, and use of chemicals and materials that focus on providing a desirable function (or service) with the most cost-effective economic factors considering sustainability while avoiding or minimising negative impacts on human health, the environment and society [13]. Overall product sustainability should be ensured by minimizing the environmental footprint of chemicals in particular on climate change, resource use, ecosystems and biodiversity from a life cycle perspective [14].

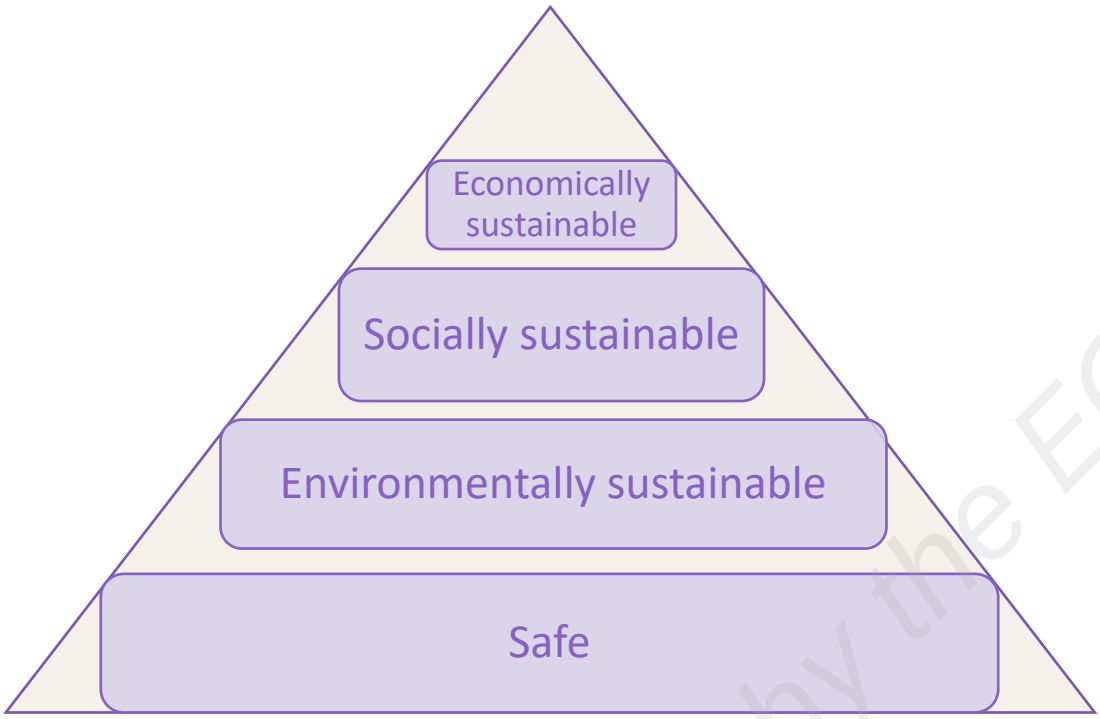

Figure 4 SSbD dimensions; Source: elaborated by the authors (adapted from [14])

Following the indications given by the Joint Research Centre (JRC), which is the leading institution in the development of the SSbD approach, PHAntastic SSbD approach is composed of two phases. The first phase is the (re)design phase, in which design guiding principles and categories are proposed to support the design of the novel products. In the second phase, the safety and sustainability assessment phase, the different components of safety, environment, social and economic aspects of the novel products are evaluated to ensure that the principles applied result in the best performance in terms of relevant indicators for the four mentioned dimensions (safety, environmental, social, and economic sustainability respectively).

Re-design phase.

The first component ((re)design phase) is framed by SSbD overarching principles that have been identified including: 1) Material efficiency, 2) Minimizing the use of hazardous chemicals/materials; 3) Designing for energy efficiency; 4) Using renewable sources; 5) Preventing and avoiding hazardous emissions; 6) Reducing exposure to hazardous substances; 7) Designing for end-of-life; and 8) Consideration of the whole life cycle (Table 2).

SSbD principles	Definition
SSbD 1 Material efficiency	Pursuing the incorporation of all the chemicals/materials used in a process into the final product or full recovery inside the process, thereby reducing the use of raw materials and the generation of waste.

SSbD principles	Definition
SSbD 2 Minimise the use of Hazardous chemicals/materials	Preserve functionality of products while reducing or completely avoiding using hazardous chemicals/materials where possible.
SSbD 3 Design for energy	Minimise the overall energy used to produce a chemical/material in the manufacturing process and/or along the supply chain.
SSbD 4 Use renewable sources	Target resource conservation, either via resource closed loops or using renewable material/ secondary material and energy sources.
SSbD 5 Prevent and avoid hazardous emissions	Apply technologies to minimise and/or to avoid hazardous emissions or pollutants in the environment.
SSbD 6 Reduce exposure to hazardous substances	Eliminate exposure to chemical hazards from processes as much as possible. Substances which require a high degree of risk management should not be used and the best technology should be used to avoid exposure along all the life cycle stages
SSbD 7 Design for end of-life	Design chemicals/materials in a way that, once they have fulfilled their function, they break down into products that do not pose any risk to the environment/humans. Design for preventing the hindrance of reuse, waste collection, sorting and recycling/upcycling.
SSbD 8 Consider the whole life cycle	Apply the other design principles thinking through the entire life cycle, from supply-chain of raw materials to the end-of-life in the final product.

Table 2 SSbD design principles; Source: Caldeira et al. (2022) adopted by the EC JRC, 2022 [13]

The principles abovementioned focus mainly on the technical requirements and/or approaches leading to safety and environmental goals. However, the scope of the PHAntastic project goes beyond these dimensions. In particular, the economic and social aspects of the sustainability concept are not addressed as such within the current widely used SSbD principles.

Regarding this concern, it is important to note that there is a current initiative working on standardising common principles and assessment methodologies for a European joint SSbD approach that encompasses the work published by the JRC used in this report. This initiative is under consultation and recognises the need to develop in the short-term specific design principles and assessment tools to enable the economic and social sustainability dimensions to be better incorporated into practice. More specifically, in PHAntastic, the objective is to advance the novel delivery systems from TRL 3-4 to TRL 6.

Assessment phase

The second component (assessment phase) helps to identify the performance of the chemical, material or component developed for each SSbD dimension (safety, environmental, social and economic) through different verification indicators. At the end of the evaluation, a composite indicator will be constructed following the European Commission recommendations proposed under the safe, sustainable, and circular perspectives from an early stage of development, that is processes at low-TRL [15]. In PHAntastic, the evaluation phase applies to either newly developed chemicals and/or materials or to existing chemicals and/or materials. The goal of the continuous assessment is to ensure that the new products improve their safety and sustainability performance during production, use and/or end-of-life, which to some extent is equivalent to carry out a LCA for the environmental dimension, a SO-LCA for the social one and a LCC for the economic one.

The assessment phase comprises six steps that can be carried out sequentially or in parallel and that correspond to different projects tasks:

1. *Hazard assessment of the chemical/ material/ components (task 5.1.1. led by IDEA): analysis of the properties of the chemical or material to understand their hazard potential.*
2. *Human health and safety aspects in the chemical/material/component production and processing phase (task 5.1.2. led by ARCHA): health and safety aspects related to the chemical/material production and processing (all the processes are covered) are assessed.*
3. *Human health and environmental aspects in the final application phase (task 5.1.3 & 5.1.4. led by ARCHA): application/use-specific exposure to the chemical/ material and the associated risk are assessed.*
4. *Environmental sustainability assessment (task 5.2. led by CETEC): to consider impacts along the entire chemical/ material life cycle using Life Cycle Assessment, assessing several environmental impact categories.*
5. *Social sustainability assessment (task 5.3. led by KVC): to provide information on the scientific basis and available approaches for the assessment of social impacts.*
6. *Economic sustainability assessment (task 5.4. led by KVC): to provide information on the scientific basis and available approaches for the assessment of economic impacts.*

The present framework (D.5.3) focuses on the social part of the assessment, which is centred on analysing the acceptability, its codetermining factors, and the social impact of PHAntastic delivery systems.

Concretely, the methodology used in the social dimension is based on the guidelines established by the JRC [16] for the SSbD design principles and assessment criteria and on the framework [17] developed in the European Funded project ViSS ("*Viable, safe and sustainable PHBV value chain for food packaging applications*"). In PHAntastic, we have tailored these frameworks to our specific context of PHA-based delivery systems for agricultural applications. While maintaining the core social sustainability aspects from the SSbD framework and established S-LCA guidelines, we've adapted our approach to prioritize indicators most relevant to agricultural delivery systems, modified social assessment boundaries to account for the pre-commercial TRL 6 stage, and focused specifically on the unique stakeholder dynamics within the agricultural value chain. These adaptations enable us to evaluate potential social acceptance and impacts while acknowledging data limitations at this development stage. Section

4 provides our comprehensive approach to social sustainability assessment within PHAntastic's specific context, focusing on the five principles of Health, Influence, Competence, Impartiality, and Meaning-making as they apply to biodegradable agricultural solutions.

Social aspects are included in the JRC framework as a dimension to be explored, since the methodologies to assess it are less mature than the environmental one. Some methodological challenges have not been solved yet, and their application in case studies is more heterogeneous compared to the environmental LCA [13]. For these reasons we will follow the framework developed in the ViSS project as a complementary approach[4].

Concretely, the design principles of the social dimension of the sustainability concept have not yet been agreed or defined within the existing guidelines. Also, the approach to include social sustainability assessment is not yet fully agreed upon, mainly based on some related LCA approaches, namely S-LCA or SO-LCA whose application is still in an exploratory status and/or differ on the methods used in the (few) cases where these relevant components of the sustainability dimension are addressed. **Given the limited existing guidance in these dimensions and the significant advancements made in the ViSS project, its methodological approach will be adapted and applied to the PHAntastic social assessment framework**.

In ViSS, several steps were taken in order to ensure methodological relevance and an accurate definition of social principles and assessment indicators[5]. Firstly, a harmonised terminology for the different elements of the SSbD framework was presented. This harmonisation enabled consistency of definitions, a common general understanding and the normalisation of terms:

> *All the SSbD dimensions include specific overarching Design Principles. The Categories (also called "classes" or "groups") refer to wider thematic ensembles key in the different four SSbD dimensions (safety, environmental, social, and economic sustainability respectively). The Categories aggregate a series of main "Aspects" (also referred to as "sub-categories" or "impact categories" in the literature). The Aspects correspond to the relevant characteristics of the Categories. To perform the qualitative and quantitative assessment at a more operational level, Indicators (or Criteria) are used. The Aspects can be composed of one or more Indicators.*

Principles > ***Categories*** *(class, group)* > ***Aspects*** *(sub-categories, impact categories)* > ***Indicators*** *(criteria)*

In PHAntastic, this harmonisation is also adopted for the social *(and economic)* dimension.

Moreover, in order to develop the guiding principles, a multi-step approach combining existing principles with new developments was implemented. Initially, the ViSS team validated the European Commission's JRC safety and environmental principles [13] while conducting a literature review to establish new social and economic sustainability dimensions. A workshop with internal experts facilitated this process and helped adapt the European Commission's three-part structure: 1) defining aspects and indicators, 2) establishing assessment criteria with thresholds, and 3) creating evaluation scoring systems. **The**

[4] For more information, please see D.6.3. SSbD and Social Readiness evaluation framework (SRL) [17]

[5] The framework is not confined to the social dimension; it also encompasses the other three dimensions (safety, environmental and economic). In the PHAntastic project, insights obtained for the economic dimension will also be used for the social one (see deliverable D.5.4.).

framework's co-design phase specifically incorporated economic and social sustainability elements through participatory methods which will be used in this framework and in the economic assessment one.

Thus, in this assessment specialised SSbD questionnaires designed to capture technical compliance with safety standards, regulatory requirements, circular economy principles, and environmental, economic and social impact considerations will be employed. These tools are administered to a diverse group of stakeholders with relevant expertise, including, end-users, PHAntastic organisations and organisations' workers. By targeting these specific groups, the evaluation captures multiple perspectives on how well the delivery systems adhere to SSbD principles. Section 4 of this deliverable dig deeper into the social principles and indicators that will be used in this dimension.

Limitations of the SSbD social analysis

As stated at the beginning of this section, the social part of the SSbD methodology is still under development and discussion. It is evident that this presents a range of new opportunities for exploration, along with a variety of constraints that must be given due consideration when implementing these methodologies.

A composite SSbD index will be constructed weighting heterogeneous indicators. The **choice of weights** can significantly influence outcomes and may be subjective. Also, further methodological refinements should better incorporate upstream and downstream value chain actors to enable a more holistic systemic assessment. **Defining correctly the value chain** is critical in order to adequately measure the impacts of the project

It is also important to consider that the use of LCC, S-LCA, and LCA to determine the **sustainability performance of technologies lack in their forward-looking approach**, hence, scaling effects when evaluating emerging technologies is needed. In particular, prospective Life Cycle Sustainability Assessment (LCSA) is a prerequisite for a comparative evaluation not only for emerging technologies but also for mature technologies [18].

Moreover, a barrier for implementing S-LCA in organisations involved in the circular economy is the lack of social performance comparable tools and indicators. Existing tools are limited in their effectiveness by the lack of quantitative data **linking social impacts to company operations**. The S-LCA methodology, introduced in 2009, remains a nascent approach with limited research application. The SO-LCA variant represents an even more recent development, having been included only in the 2020 edition of existing guidelines. Also, the methodology faces significant constraints that fundamentally limit its comprehensive evaluation potential. The **absence of generic databases and the complexity of social data collection** further complicate performance tracking and impact assessment. But one of the biggest critical methodological gaps lies in the inability to **establish direct cause-effect relationships between technological changes and the evaluated social impacts**. Unlike environmental life cycle assessments, the social assessment approach cannot definitively attribute specific social transformations to technological interventions.

Table 3 summarises the limitations outlined above and how they will be addressed in PHAntastic:

Limitations	***PHAntastic approach: how they will be addressed***
Subjective weighting of indicators	Transparent documentation of all weighting decisions with clear rationale; multi-stakeholder validation of weights through expert consultation workshops
Value chain definition complexity	Development of a structured value chain mapping; clear definition of system boundaries with special attention to upstream feedstock production and downstream soil impacts; regular review of value chain boundaries as the project progresses
Forward-looking approach limitations	Explicit consideration of temporal dimensions in impact assessment; complementary use of acceptance studies to project future social implications
Lack of social impact data linkage to operations	Mixed-methods approach combining quantitative metrics with qualitative assessments; development of project-specific indicators that connect operational aspects to social outcomes; collaboration with end-users to identify relevant operational-social linkages
Limited database availability	Prioritization of primary data collection for critical social aspects; structured approach to expert elicitation where data gaps exist; transparent documentation of data quality and uncertainty; leveraging knowledge from similar agricultural innovation studies
Weak cause-effect relationship establishment	Implementation of contribution analysis rather than attribution claims; use of theory of change approaches to establish plausible linkages

Table 3 Limitations and PHAntastic approach; Source: elaborated by the authors

By systematically addressing these methodological limitations through the strategies outlined above, PHAntastic's social assessment framework will provide a robust evaluation of the biodegradable delivery systems despite the inherent challenges of assessing pre-commercial technologies. This approach not only strengthens the validity of our findings but also contributes to advancing social sustainability assessment methodologies for agricultural innovations more broadly.

4. Social sustainability by design (So-SbD) and SO-LCA

The object of the present methodological proposal is to contribute to a more socially sustainable design of novel products and materials. So-SbD is key for industrial processes because the concerned value chains may affect a wide range of social factors: social justice, impact in ecosystems that can reduce the wellbeing of affected populations, welfare of workers, political corruption, the health of workers and communities, and fair treatment of workers among others. But, although important, the social dimension is in general less taken into consideration than the environmental dimension. Including social sustainability in the design aims to protect individuals and collectivists' rights while maximizing common welfare [19]. The objective of So-SbD is to inform decision-making to design a product that optimizes its positive social impact instead of creating social harm.

The process involves the definition of complex criteria that help foresee potential impacts in individuals or groups but there is not a full agreement among practitioners on the definition of social sustainability.

4.1. So-SbD | Design phase

The main objective of So-SbD is to consider, in all the steps of the lifetime of a product, the impact that it can have on society. From the perspective of So-SbD, products should be designed considering the objective of improving social well-being (or at least not deteriorating it). Social sustainability involves a wide range of aspects: from the workers that produce the good or service to the community that can benefit or be affected by the production and disposal of the product, considering the users and decision-makers. In that sense, So-SbD implies considering a wide range of points of view and their arbitration, and the definition of acceptability thresholds. Therefore, taking a holistic approach is key in carrying out So-SbD. As for other pillars of SSbD, the definition of principles that frame the process is key.

In the design of a new product, we propose to follow Missimer´s [20] five principles for social sustainability that should be taken into consideration to support sustainability from the social perspective (Table 4). Missimer's principles were chosen because the principles are associated with the five stakeholder categories identified by the UNEP: workers, value chain actors, society, local community and consumers [21] and because it links Social Sustainability principles with social aspects. The five principles that products should follow are:

SSbD principles (based on SOCIAL SUSTAINABILITY)	Definition and Examples of actions	Corresponding social aspect	Application in PHAntastic
HEALTH: Health and wellbeing	**Avoid physical, mental, and emotional injury and illness across the value chain.**	*Forced labour* *Working hours*	PHAntastic will develop delivery systems that reduce farmer exposure to conventional

	Action: Desing products that minimises (and ideally avoids) exposure to hazards and integrate wellbeing considerations for all stakeholders. The product should minimise potential harm for the user.	*Health and safety (workers, consumers)* *Safe and healthy living conditions* *Secure living conditions* *GHG footprint* *End-of-life responsibility* *Affordability*	agrochemicals and minimize occupational hazards through biodegradable formulations that eliminate the handling and disposal requirements of conventional plastics.
INFLUENCE: Stakeholder influence & participation	**Foster meaningful participation of affected stakeholders in decision-making processes throughout product development and implementation.** *Action: Implement inclusive design processes that integrate feedback from diverse stakeholders, particularly end-users.*	*Social benefits, legal issues…* *Wealth distribution* *Public commitment to sustainable issues* *Technology development* *Community engagement* *Local employment* *Feedback mechanisms*	PHAntastic will establish multi-stakeholder consultation workshops with farmers, agricultural workers, and local communities to incorporate their perspectives in the iterative design of delivery systems, creating agricultural solutions that address real-world needs and constraints.
COMPETENCE: Competence Development	**Contribute to skills enhancement and knowledge transfer across the value chain.** *Action: The production process should consider training of workers and provide competence development. Design products that create opportunities for learning and competence development for workers, users, and communities.*	*Equal opportunities/ No discrimination* *Workers' rights* *Fair competition* *Supplier relationship* *Respect intellectual property rights* *Contributions to economic development* *Technology development* *Access to material resources* *Access to immaterial resources* *Delocalization and migration* *Local employment* *Secure living conditions*	PHAntastic will focus on facilitating knowledge exchange of best practices for biodegradable agricultural solutions among end-users. The project will document practical experiences from field trials with farmers and create accessible resources to share lessons learned about optimal usage of the delivery systems, supporting practical skill development through straightforward knowledge transfer.
IMPARTIALITY: Equitable Value Distribution	**Ensure fair distribution of benefits and burdens across stakeholders and generations.** *Action: Design systems that distribute value equitably throughout the value chain, particularly to vulnerable stakeholders.*	*Fair salary* *Equal opportunities/ No discrimination* *Social benefits, legal issues, social security* *Workers' rights* *Sexual harassment prevention* *Suppliers' relationship* *Corruption prevention* *Poverty alleviation* *Transparency* *Affordability*	PHAntastic delivery systems will be developed with price points accessible to different scales of agricultural operations, while quantifying potential economic benefits for end-users.

MEANING-MAKING: Meaning-Making & Cultural Alignment	**Support the creation of individual meaning[6] and co-creation of common meaning, respecting diverse cultural contexts.** *Action: To respect employees' individual culture. Associate the organization to a purpose that is understood and followed by the workers & design products that align with cultural values and enhance the meaning of agricultural work.*	*Promoting social responsibility* *Public commitment to sustainable issues* *Access to immaterial resources* *Cultural heritage* *Community engagement* *Local employment* *Transparency*	PHAntastic will develop delivery systems that respect traditional agricultural knowledge while enhancing farmers' sense of environmental stewardship, documenting how biodegradable solutions align with cultural values around land stewardship and sustainable farming practices

Table 4 Social sustainability principles (based on Missimer, 2015 [20]) and PHAntastic approach

The previous table integrates Missimer's social sustainability principles with the practical aspects identified in the SO-LCA methodology, providing a structured approach to applying social sustainability principles within the specific context of PHAntastic's biodegradable agricultural solutions.

4.2. Assessment phase: methodology

Based on the SO-LCA methodology, and the learnings from two European research projects[7] [8], this section proposes a series of criteria to contribute to the social sustainability assessment in PHAntastic.

SO-LCA is a framework used to assess the social impact of the goods and services life cycles [21]. The sustainable design involves the entire value chain of the new product (from raw material producers to consumers and end-of-life) and the side effects of related activities throughout all life cycle stages. The framework for the assessment will be given by the social sustainability principles presented above.

The guidelines for SO-LCA of products [21] consider five categories of stakeholders: **workers**, **value chain actors**, **society**, **local community**, and **consumers**. This categorisation will be followed in the present assessment.

The stakeholder category **WORKERS** corresponds to eight aspects aimed to consider:

- *whether the organisation doesn't **use forced or compulsory labour**;*
- *whether practices concerning **wages are in compliance with established standards** and if the wage provided is meeting legal requirements;*

[6] How people make sense of life events, relationships and themselves [22].

[7] Agro2Circular (A2C) is a H2020 project implementing a SO-LCA in the Murcia Region for the development of bioplastics to substitute conventional packaging plastics and the upcycle of fruit and vegetable waste. The deliverables related to the social evaluation and that were used to develop PHAntastic framework were *D.7.8. Socioeconomic and sociocultural analysis report (Draft)* [23] and *D.7.9. Socioeconomic and sociocultural analysis report (Final)* [24].

[8] ViSS is a HORIZON EUROPE project which aims to produce and validate a bio-based plastic from the copolymer poly(3-hydroxybutyrate-co-3-hydroxyvalerate) commonly known as PHBV. ViSS will source PHBV from industrial organic residues and transform it into quality food packaging that is non-toxic, recyclable and biodegradable. The deliverable taking as reference in this case is *D6.3. SSbD and Social Readiness evaluation framework (SRL)* [25].

- *if the **number of hours effectively worked is in accordance with the International Labour Organization (ILO) standards** and when overtime occurs, compensation is planned and provided to the workers, in terms of money or free time;*
- *how **equal opportunity practices** are managed and the presence of discrimination in the opportunities offered to the workers;*
- *the **rate of incidents** and the status of prevention measures and management practices in the organisation;*
- *whether and to what extent an organisation provides **social benefits and social security** to workers;*
- *the compliance of the organisation **with freedom of association and collective bargaining standards**, and*
- *whether an organisation might create or tolerate working conditions in which **sexual harassment** occurs, and to what extent company actions are successful in preventing sexual harassment.*

The second stakeholder category is **VALUE CHAIN ACTORS**, to which five aspects correspond. These were aimed to:

- *assess if the organisation's **competitive activities are conducted in a fair way** and in compliance with legislations preventing anti-competitive behaviour, anti-trust, or monopoly practices;*
- *assess whether the enterprise promotes **social responsibility among its suppliers** and through its own actions;*
- *evaluate if the organisation considers the potential **impacts or unintended consequences of its procurement and purchasing decisions on other organisations**, and act with due diligence to avoid or minimize any negative impact (ISO 26000), and*
- *evaluate the extent to which the value created in the production process **is distributed in an equitable way to all the actors of the value chain**.*

SOCIETY has also been considered. Within this stakeholder category, five aspects for criteria were analysed, aiming to:

- *assess to what extent the selected organisations **are engaged in reducing its sustainability impacts**;*
- *assess to what extent the organisation, product or service contributes to the **economic development of the society**;*
- *assess whether the organisation participates in **joint research and development** for efficient and environmentally sound technologies;*
- *evaluate if an organisation has implemented appropriate measures to **prevent corruption** and if there is evidence that it has engaged or has been engaged in corruption and*
- *measure the presence or not of activities, such as strategies, action plans, and investment, aimed at **reducing the poverty** of society at different geographical levels (from local to international) and undertaken by the organisation itself or linked with the product life cycle (from production to recycling and/ or disposal).*

LOCAL COMMUNITY is also considered according to eight aspects. The aim of the selected aspects is to:

- *assess the extent to which organisations respect, work to protect, to provide or to improve community access to **local material resources, infrastructures & immaterial resources** (this includes the value chain adapted to favour the local economy);*
- *evaluate whether organisations contribute to **delocalization, migration**, or "involuntary resettlement" within communities and whether populations are treated adequately;*

- *check whether an organisation **respects local cultural heritage** and recognizes that all community members have a right to pursue their cultural development;*
- *assess how organisations impact **community safety and health**;*
- *appraise whether an **organisation includes community stakeholders** in relevant decision making processes. It also considers the extent to which the organisation engages with the community as a whole;*
- *assess the role of an organisation in directly or indirectly affecting **local employment**, and*
- *evaluate how organisations impact the **security of local communities** with respect to the conduct of any private security personnel and how the organisation interacts with state-led forces.*

The last stakeholder category considered is **CONSUMERS**. This category is built up by five aspects to assess how the organisations relate with their customers. Concretely it sought to:

- *identify the existence and scope of systematic efforts to address consumer **health and safety** across the organisations involved in the life cycle of a product and/ or service;*
- *assess the effectiveness of management measures to support **consumer feedback**. In addition, this aspect may assess other management practices related to customer feedback;*
- *assess if the organisation communicates on all issues regarding its product and **social responsibility in a transparent way** (including traceability);*
- *evaluate if there exist (if applicable) any management efforts to address the social impacts of **product or service end-of-life**, and*
- *assess if the proposed product is **affordable and has a competitive price** in line with the market (also considering the price compared to hazardous alternatives).*

In order to monitor that all the social sustainability principles are covered by the assessment (and therefore that the products comply with them), we linked all aspects of the different categories to the social sustainability principles outlined above (Table 5):

Stakeholder categories		Workers								Value Chain actors					Society					Local Community									Consumers				
Social sustainability aspects		Forced labour	Fair salary	Working hours	Equal opportunities/Discrimination	Health and Safety	Social benefits, legal issues, social security	Workers' rights...	Sexual harassment	Fair competition	Promoting social responsibility	Supplier relationships	Respect intellectual property rights	Wealth distribution	Public commitment to sustainability issues	Contributions to economic development	Technology development	Corruption	Poverty alleviation	Access to material resources	Access to immaterial resources	Delocalization and migration	Cultural heritage	Safe and healthy living conditions	Community engagement	Local employment	Secure living conditions	GHG Footprint	Health and Safety	Feedback mechanism	Transparency	End-of-life responsibility	Affordability
Social sustainability principles	**Health**	X		X		X																		X			X	X	X			X	X
	Influence						X							X	X		X								X	X				X			
	Competence				X			X		X		X	X			X	X			X	X	X				X	X						
	Impartiality		X		X		X	X	X			X						X	X												X		X
	Meaning-making										X				X						X		X		X	X					X			

Table 5 Link between followed social principles and aspects; Source: Adapted from: Missimer, 2015 [20]. NOTE: The crosses mean that an Aspect relates to a Principle. Some Aspects, such as supplier relationships, can be linked to more than one principle.

The Table 6 below summarises the key details proposed for the implementation of the SO-LCA assessment (retrieved from A2C [23] & ViSS [25] projects, JRC [26], PSILCA [27] and CEFIC [16]). To reinforce the relevance of SO-LCA, the correspondence between Aspects and the Sustainable Development Goals (SDG) concerned is also included. The selected indicators are based on a systematic integration of empirical findings from multiple European research projects (A2C, ViSS) and established methodological frameworks. The indicator set was further informed by peer-reviewed social sustainability assessment literature [19], [21], [28], [29], [30], from both agricultural and bioplastics sectors, ensuring comprehensive coverage of relevant social dimensions while maintaining practical applicability in the specific context of biodegradable agricultural delivery systems.

STAKEHOLDER CATEGORY	ASPECTS	INDICATORS	RELATED SDGs[9]
WORKERS	Forced labour [A2C, PSILCA, UNO, CEFIC; JRC]	- Employment terms - Forced Labour	3, 8, 10
	Fair salary [A2C, PSILCA, UNO, CEFIC, JRC]	- Living wage per month - Minimum wage, per month - Organisation average wage, per month	1, 2, 3, 4
	Working hours [A2C, PSILCA, UNO, CEFIC, JRC]	- Flexibility - Full-time staff	3, 8
	Equal opportunities/Discrimination [A2C, PSILCA, UNO, CEFIC, JRC]	- Gender equality - Equal opportunities policies	1, 4, 5, 8, 10
	Health and safety [A2C, PSILCA, UNO, CEFIC, JRC]	- Occupational safety measures - Lost time injury frequency rate	2, 3, 6, 8
	Social benefits, legal issues, social security [A2C, PSILCA, UNO, JRC]	- Evidence of violations of laws and employment regulations	3, 8, 9, 11
	Workers' rights / Freedom of association and collective bargaining [A2C, PSILCA, UNO, CEFIC, JRC]	- Trade unions density - Collective Bargaining Agreement	8, 10, 16
	Sexual harassment [A2C, UNO, JRC]	- Sexual harassment incidents reported	8
VALUE CHAIN ACTORS	Fair competition [A2C, PSILCA, UNO, CEFIC, JRC]	- Sanctions for anti-competitive behaviour	12
	Promoting social responsibility [A2C, PSILCA, UNO, CEFIC, JRC]	- Promotion of Corporate Social Responsibility - Suppliers audit	12
	Supplier relationships [A2C, UNO, CEFIC, JRC]	- Suppliers' communication relationship	12
	Wealth distribution [A2C, UNO, JRC]	- Fair price definition	1, 8, 10
	Respect intellectual property rights [CEFIC, JRC]	- Number of property rights infringements	9, 12, 16
SOCIETY	Public commitment to sustainability issues [A2C, UNO, JRC]	- Presence of publicly available documents as promises or agreements on sustainability issues	12, 17
	Contributions to economic development [A2C, PSILCA, UNO, JRC]	- Total taxation per capita	1, 2, 3, 4, 8, 9
	Technology development [A2C, UNO, JRC]	- Technology transfer - Investments in technology development/ transfer	4, 9, 17
	Corruption [A2C, UNO, PSILCA (value chain actors), JRC]	- Corruption	16
	Poverty alleviation [A2C, UNO, JRC]	- Poverty alleviation programme	1, 2
LOCAL COMMUNITY	Access to material resources [A2C, PSILCA, UNO, CEFIC, JRC]	- Environmental management system	9, 12
	Access to immaterial resources [A2C, UNO, CEFIC, JRC]	- Community education initiatives	4, 12
	Delocalization and migration [A2C, PSILCA, UNO, JRC]	- Immigrant workforce rate	9, 10, 11

[9] For more information on the SDG: THE 17 GOALS | Sustainable Development

		- Organisational procedures for integrating migrant workers into the community	
	Cultural heritage [A2C, UNO, JRC]	- Funding dedicated to support and promote cultural heritage	11
	Safe and healthy living conditions [A2C, PSILCA, UNO, CEFIC, JRC]	- Promotion of community health	3, 6
	Community engagement [A2C, UNO, CEFIC, JRC]	- Diversity of community stakeholder groups that engage with the organisation - Number of meetings with community stakeholders	11, 12
	Local employment [A2C, UNO, CEFIC, JRC]	- Workforce hired locally - Spending on locally based suppliers	8
	Secure living conditions [A2C, UNO, CEFIC, JRC]	- Security complaints by the community	3, 16
CONSUMERS	Health and safety [A2C, UNO, CEFIC, JRC]	- Labelling - Consumer complaints - Presence of a Quality and/or Product Safety Management System	2, 3, 12
	Feedback mechanism [A2C, UNO, JRC]	- Presence of consumers feedback mechanism	12
	Transparency [A2C, UNO, JRC]	- Organisation communication transparency	9, 12
	End-of-life responsibility [A2C, UNO, JRC]	- Internal management systems	12, 15
	Affordability [JRC, CEFIC, JRC]	- Potential price in comparison to market equivalent	10, 12

Table 6 Pre-selected aspects and indicators

The assessment of the selected social criteria will be done following an SSbD score (0 to 4) or SSbD level (fail or pass) when the scoring is not possible. The assessment of the indicators will be done with secondary data (conveniently referenced) when available or directly consulting experts when this data is not available.

5. Conclusions

PHAntastic will develop and evaluate two innovative delivery systems designed according to Safe and Sustainable by Design (SSbD) principles, comprising specialised biodegradable mulch film for horticulture and growth foam for nurseries. To ensure full adherence to SSbD methodology, establishing a robust assessment framework is imperative. Deliverable 5.3 represents the initial phase in validating compliance with the social dimension of the SSbD approach, complementing the environmental, economic and safety assessments to provide a holistic sustainability evaluation of these novel agricultural solutions. This framework also sets the stage to achieve Milestone 5 "*PHAntastic delivery systems pass the assessments on SSbD, biodegradability, regulatory, environmental, economic, and social acceptance*," which represents a critical validation point for the project's success.

The current status of design principles in the SSbD approach, which are fundamental to guarantee the “by design” intention, are still not proposed nor discussed for the social (or economic) dimension of sustainability. While theoretically and conceptually the tridimensionality nature of sustainability (environmental, economic and social) is well acknowledged, the actual and practical application remains mostly limited to environmental aspects. The need of social sustainability principles is a must for the comprehensive and logical evolution of the SSbD approach, and PHAntastic framework includes a proposal for them based on solid literature. PHAntastic will work on providing a set of principles for these dimensions to be applied in a research project (with TRL6 as maximum expected level achievement) thus, it represents a step forward in the field.

Regarding the assessment phase, as stated along the document, the methodologies to evaluate the social dimension of sustainability are still under discussion. Although the present framework proposes already a uniformed terminology, the limitations of the social approach do not help to improve decision-making. In future research, a comparison between methods (S-LCA vs SO-LCA) could provide to the community a valuable view on how to start working to agree on a conceptual framework for the social sustainability assessment of early-stage research projects. The expected PHAntastic SSbD social assessment outcomes aim to respond to current limitations therefore contribute to a more robust and, more evidenced-based indicators for the social dimension in order to support sound decision-making.

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