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PRIMED

D3.2. Specific Bio-based value chain map for each LLab

LUT University

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DISCLAMER

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1. Contents

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Acronym Glossary

CHP	*Combined Heat and Power*
CNG	*Compressed Natural Gas*
EFSA	*European Food Safety Authority*
EU	*European Union*
GO	*Guarantee of Origin*
LLab	*Living Lab*
LNG	*Liquefied Natural Gas*
R&D	*Research and Development*
SAT	*Agricultural Transformation Society*
SWOT	*Strengths, Weaknesses, Opportunities, Threats*
TRL	*Technological Readiness Level*
USA	*United States of America*

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2. Executive Summary

This deliverable consists of five key sections, bringing contributions across several partners engaged in Work Package 3 (WP3) of the EU Horizon PRIMED project. Attainment of varied WP3 objectives have been reported in this deliverable, including conducting techno-economic assessment and risk analysis of the Living Labs' processes as well as developing novel bioeconomy value chains by identifying new opportunities for scaling.

First, a preliminary techno-economic assessment of nine (9) value chains selected by the Living Labs has been performed, aiming to pre-screen the economics under relevant commercial scales. Each value chain has been described through a process block diagram, including the main processes steps to convert the raw materials to final products. The specific technologies associated to the main processes has been also identified and characterized through operational parameters, conversion yields and specific consumption of chemicals and utilities. Capital investments, operating costs and revenues for each value chain have been estimated within a realistic range of feedstock conversion capacity. Cost estimations have been used to assessment preliminarily the economic performance of the value chains by comparing achieved minimum selling priced of the main product and the expected market values.

Second, the techno-economic pre-assessment has been complemented by a risk analysis which focuses on feasibility, scalability and go-to-market risks associated with each LLab's processes. The analysis estimates specific market demand in the upcoming years and the investment required for the same, while bringing insights from local success stories operating similar value chains.

Third, a multi-stakeholder value chain mapping exercise and value chain synergies analysis has been done, wherein the perspective is broadened beyond the LLabs to explore how other local actors position the relevance of the LLabs with their ecosystems. It is evident that several emerging synergies have and are being established with other existing and upcoming value chains and partners. These synergistic relationships provided a more contextual landscape to undertake an ecosystemically grounded SWOT analysis. Community integration, local leadership and exemplarity are identified as cross-cutting strengths, and can be tapped into further to develop partnerships focused on commercialisation. Regulation and underdeveloped commercial strategies are identified as the strongest barriers across all LLabs.

Fourth, this is followed by a dedicated section on the policy and regulatory landscape, which identified three main types of barriers that are hindering or will block the establishment and development of the new value-chains: feedstock regulations, market access and competitiveness, and existing financial frameworks, by this order of priority.

Finally, the analysis of value chain governance explicates on processes preceding and shaping the initiation of governance, such as selection of new actors via considerations like ecosystemic embeddedness, process viability and commercialisation potential and pathways. The analysis also describes aspects around which the governance logics of these LLabs have come to be consolidated, including socio-ecological remediation, community belongingness, scientific advancement and long-term radical futuring. This is followed by multi-stakeholder mapping of present governance practices and structures in the ecosystems of the LLabs, and it is found that governance practices and informal structures are more common towards the earlier stages of value chain development as well as in ecosystems wherein the value chain emerged from within one entity (scientific entity) instead of the community. Governance structures are found to be better developed in LLabs that have stronger community rootedness.

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3. Introduction

This deliverable aims to further the work done under the scope of the PRIMED project by building on the knowledge from different work packages and creating a bridge between the state-of-the-art and the potential futures for each of the LLabs. We do this by focusing on furthering the detailing of previously presented LLab-specific value chain maps enhancing and reorienting them for evolving processes, priorities, partnerships and ecosystems that we witness within each LLab, as we shed light on LLabs' explorations of existing and potential synergies within and beyond their value chains.

The objectives of Work Package 3, that are pertinent to this deliverable, include:

- Selection of specific value chains for each LLab based on technological risk analysis
- Co-design and develop business models for LLabs that are balanced, sustainable, profitable, and aligned with bioeconomy.
- Create sustainable value chains that promote the revalorisation of resources and reduce bio-waste.
- Identify and assess new opportunities for scaling up in bioeconomy
- Leveraging emerging technologies.

-

Specifically for the bioeconomy context of the value chains in this project, we adopt Lokesh et al. (2018)'s definition of bio-based value chains as a set of circular and cascading, interconnected and dynamic activities that deliver products by adding value to bulk materials—such as organic feedstocks from primary and secondary industries—transforming them into high-value products through integrated biorefineries.

Bio-based value chains include a sequence of processes or steps (Lokesh et al., 2018):

1. **Feedstock recovery:** The first step involves the recovery of bulk materials or feedstocks. These are primarily composed of biomass from various sources and different suppliers:
    - Primary producers: farming, fisheries, and forestry
    - Novel organic materials: e.g., microalgae
    - Secondary sources: food, chemical, and hospitality industries (solid and sludge waste)
    - Industrial and municipal waste: sludge, industrial wastewater, and household organic waste
2. **Geographic regions and cascading use**: These feedstocks are typically found in specific geographic regions identified as areas with biomass potential (Lokesh et al., 2018). In these regions, it is essential to understand waste management systems, waste treatment processes, and the separation of bulk materials for cascading use. This step relies on thermochemical and biochemical processes and technologies.
3. **Pre-treatment and manufacturing:** Once collected, feedstocks must often undergo pre-treatment to prepare them for manufacturing. In some cases, they may enter the manufacturing process directly without pre-treatment. In this stage bio-based value chains involve technological providers and developers, chemical providers, service providers
4. **Distribution, product consumption and end use**: The final step involves packaging and distributing the processed materials either to end users or to other industries, where they serve as raw materials, and return to the circularity of the process. In this stage bio-based value chains involve end users, market partners, service and business partners.

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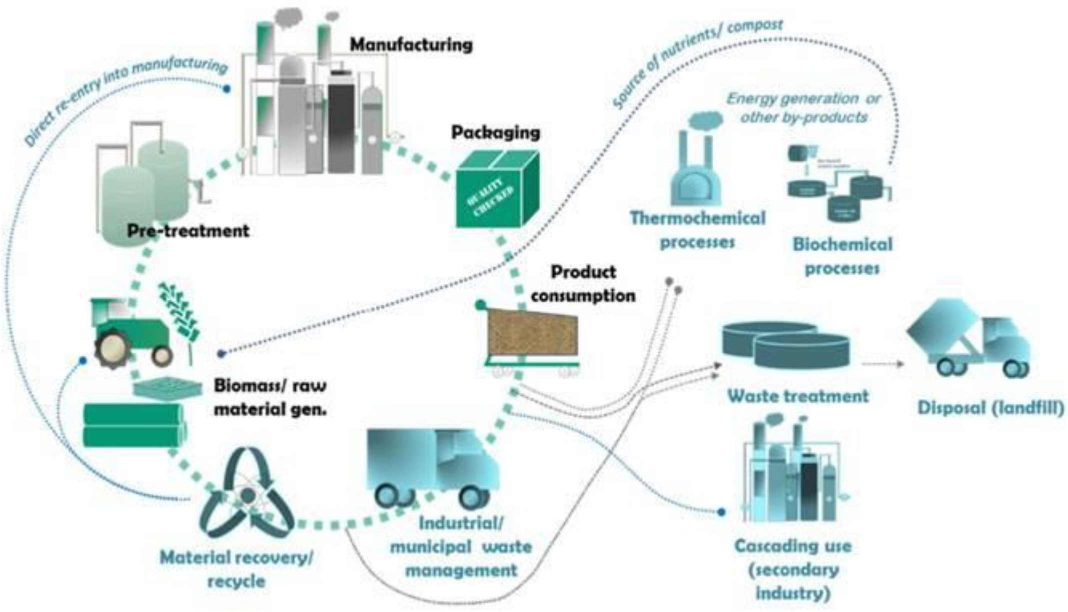

Figure 1. A generalised map of a bio-based value chain (Lokesh et al., 2018:4).

Aligning this preliminary understanding of bio-based value chains with the Work Package objectives, this deliverable is structured as described below.

Section 4 presents a pre-screening of value chains and technologies selected by each LLab, aiming to assess preliminarily the economic feasibility of each value chain within relevant conversion capacities. The main approach has been to estimate a realistic range of the expected levelized production cost - so called minimum selling price - for the main products compared to the current market prices.

Section 5 presents a techno-economic risk analysis of LLabs and their regional ecosystems. For each Living Lab, the annual feedstock availability and current processing capacities are quantified, and scalability risks and opportunities are explored. The outputs are segmented by local market categories. Each scenario is evaluated against technical, regulatory, financial, and social risk dimensions. Risks are mapped against potential impacts to visualize phased expansion pathways. Assumptions are grounded in regional policy frameworks, local project ecosystems (with a list of success cases included at the end), and potential strategic partnerships identified to de-risk each development phase.

Section 6 presents value chain analyses and co-design of value chain synergies for each LLab. It adopts a multi-stakeholder approach (using multi-stakeholder workshops as well as site visits and individual interviews) to analyse the key actors and thei activities, emerging value chain synergies, efforts towards ensuring feedstock availability, gaps in relevant sustainability schemes and finally, an overarching SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis.

Section 7 presents a policy and regulatory screening for each LLab, and aims to work as a regulatory check of the value-chains created to validate them and avoid barriers during the demonstration and implementation stages. This analysis relies on a bottom-up approach and therefore, inputs provided by the Living Labs and other relevant local stakeholders during the workshops.

Section 8 presents a value chain governance analysis for each LLab, adopting a multi-stakeholder approach (using multi-stakeholder workshops as well as site visits and individual interviews) to analyse processes involved in initiating new actors into the LLabs' ecosystems, emergent logics the LLabs co-develop to govern them and finally, evolving governance practices and structures.

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4. Pre- screening of technologies and value chains

4.1 Methodology

This section reports preliminary techno-economic assessment of selected value chains for each Living Lab, which includes the following mains aspects:

1. Main composition of the raw feedstock and cost associated with the collection and transport to the conversion plant.
2. Main operational parameters, conversion yields and specific consumption of chemicals and utilities for the main processes involved.
3. Estimation of capital investment, operating costs and revenues as a function of the overall conversion plant capacity.
4. Preliminary economic assessment of each value chain based on the achieved minimum selling priced (defined below) of the main product compared to expected market values.

The minimum selling price (MSP) of the product is defined as levelized cost of production calculated as the average unit price required so that the overall net present value (NPV) of the plant over its lifetime becomes zero given based on an expected rentability. It is calculated from

$$MSP = \sum_{i=1}^{N}\left[(1+r)^{-i}\left(C_{INV,i} + C_{OP,i}\right)\right] / \sum_{i=1}^{N}\left[(1+r)^{-i} t_{p,i} \dot{M}_{P.i}\right]. \quad (1)$$

In this equation, $C_{INV,i}$ and $C_{OP,i}$ are the total permanent investment and the annual operating cost, N is the lifetime of the conversion plant in years, r is the expected internal rate of return, $t_{p,i}$ is the annual operating time and $\dot{Q}_{P.i}$ is the annual quantity of main product. In this calculation, revenues from byproducts are considered as negative operating cost. The techno-economic results included in this report assumed an internal rate of return of 10% and an annual operating time of 8000 h.

4.2 Results

4.2.1 Living Lab 1: ALC Bio-Lab (Leader: Alcarras Bioproductors)

Value chains

VC1: Direct aerobic composting of pig slurry and cow manure using agricultural residues as substrate.

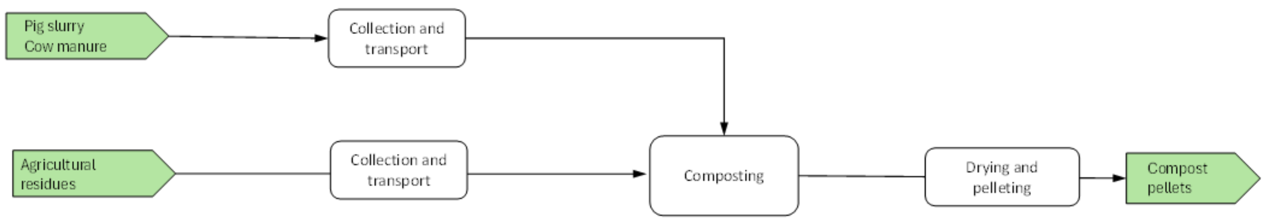

Figure 2. Process block diagram for the VC1 of ALC.

VC2: Anaerobic digestion of pig slurry and cow manure for production and heat and power, with end use of the digestate for production of compost. The main processes include collection and transport of the pig slurry and cow manure to the biogas production plant, followed by anaerobic digestion for production of biogas, direct combustion of biogas in a reciprocating engine for production and electricity with recovery of heat from the combustion flue gas. The digestate from anaerobic digestion is dewatered and use directly for production of compost using agricultural residues as substrate.

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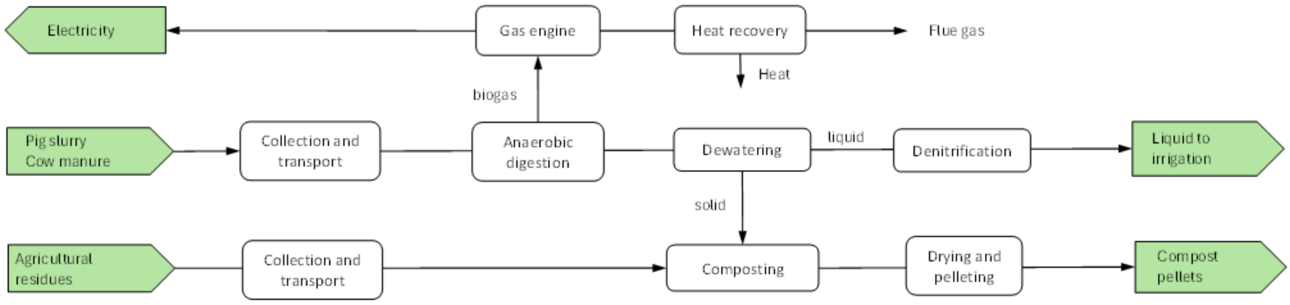

Figure 3. Process block diagram representing schematically the VC2 of ALC.

VC3: Production of compressed and liquified biomethane from pig slurry and cow manure, the main process including collection and transport of the pig slurry and cow manure followed by anaerobic digestion for production of biogas, treatment of the biogas for separation of acid gases (CO2/H2S) and compression/liquefaction of the biomethane. The digestate from anaerobic digestion is dewatered and use directly for production of compost using agricultural residues as substrate.

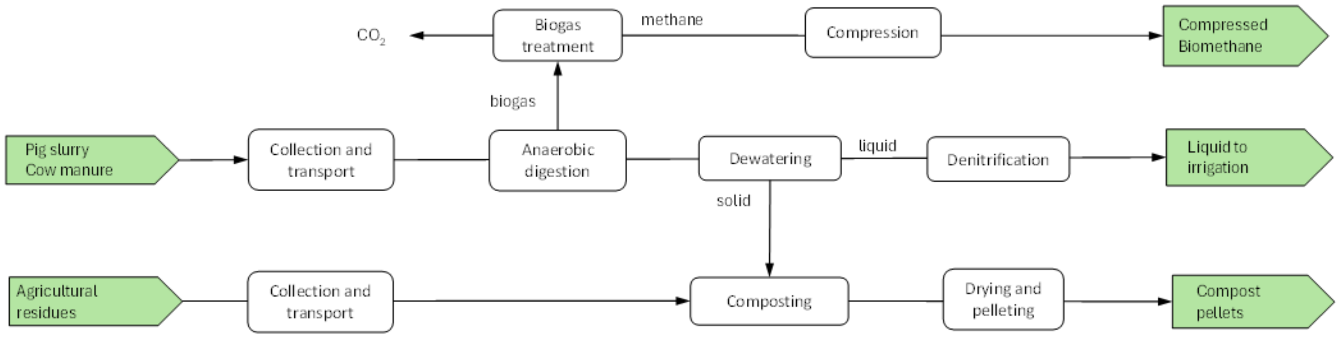

Figure 4. Process block diagram representing schematically the VC3 of ALC.

Technologies

The main process parameters of the technologies involved in VC1-VC3 of Alcarras are listed in Table 1. Composting is assumed to be aerobic with air dosing rate of 30Nm3/h/m3 and residence time of 60 days. The anaerobic digestion (AD) is assumed to be mesophilic with an operational temperature of 38 deg. C. The AD reactor is design as a continuous stirred tank with flexible membrane for collection of the biogas. The heating system of the AD process is assumed to be both by preheating of the feed and heating jacket using hot water as heating medium. The combined heat and power production is based on a reciprocating gas engine with heat recovery of the flue gas after combustion by heat exchanger to produce hot water. Dewatering of the digestate is based on screw press. Separation of ammonium from the liquid effluent after dewatering takes place in an air stripper operating at 90 deg. C and pH of 8, with use of lime for adjusting the pH. The air stream containing the ammonia from the stripper is taken to a scrubber for absorption of the ammonia in an aqueous solution of sulphuric acid with formation of ammonium sulphate. Upgrading of the biogas for production of biomethane takes place by membrane separation of the CO2 assuming a CH_4 purity of 97%.

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Table 1. Main process data for the anaerobic digestion and dewatering.

Parameter	Typical value (range)
Total solids content of pig slurry	3 %wt.
Total solid content cow manure	30 %wt.
Operating temperature in anaerobic digestion	38 deg. C
Total solids content in feed to Anaerobic digestion	6 %wt.
Hydraulic retention time in anaerobic digestion	25 days
Biogas production from anaerobic digestion	200–300 Nm3/ton solids
Biogas LHV	18.4 – 20 MJ/kg
Methane content in biogas	60 -65 % vol.
Total solids content after dewatering	30 %wt.
Polyelectrolyte consumption by dewatering	270 kg/ton
Power production efficiency, gas engine	38.2%
Heat recovery efficiency, gas engine	19.2%
CH4 purity from membrane separation	97%
Delivery pressure, biomethane	300 bar-g
Residence time, NH3 stripping	1 h
Air dosing, NH3 stripping	110 Nm3/m3 (stripper volume)
CaO consumption, NH3 stripping	6.6 kg/m3
Operating temperature, NH3 stripper	90 deg. C
pH, NH3 stripper	8.0
Acid consumption, NH3 absorber	8 – 13 kg/m3 (liquid feed)
Ammonium sulphate production, NH3 absorber	11.8 - 19.7 kg(dry)/m3(liquid feed)
Air dosing in composting	30 Nm3/h/m3
Max. operational temperature composting	40 deg. C
Residence time	60 days
Substrate consumption in composting	0.42 t/t (digestate)
Heat demands	
Anaerobic digestion	89.4 MJ/ton (feed)
NH3 stripping	62.8 MJ/m3 (liquid feed)
Electric power consumption	
Anaerobic digestion (including feeding)	12.0 kWh/ton (feed)
Dewatering	20 kWh/ton (dry solids, digestate)
CO2 membrane separation	0.20 kWh/Nm3 (CO2)
CH4 compression	0.23 kWh/Nm3 (CH4)
Denitrification (stripping + absorber)	7.7 kWh/m3 (liquid feed)
Compost	9 kWh/t (feed)

Economic assessment

The economic assessment considers the feedstock processing capacity varying in the range of 10 to 100 kt/year. Tables 2 and 3 shows the distribution of equipment cost and operating cost for each value chain as a function of the feedstock capacity.

VC1. The total specific equipment and operating costs are in the range 0.21-0.11 M€/t/h and 5.5-5.7 €/t. Assuming an internal rate of investment of 10%, the estimated minimum selling of compost, shown in Figure 4, varies within the range of 30 to 45 €/t. These values are lower than reported market price of non-certified bulk compost for agricultural use, varying in the range of 50 to 150 €/t, depending on the quality and market location.

VC2. The total specific equipment in the range 0.97-0.58 M€/t/h, with the anaerobic digestion and denitrification systems represent about 75% of the total equipment cost. The total operating costs are in the range 11-12.2 €/t., with the cost of feedstock supply representing the highest contribution. Depending on the market price, revenues from compost can cover between 30 and 50% of the total operating costs. Assuming an internal rate of investment

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of 10%, the estimated minimum selling price of electricity, shown in figure 5, varies within the range of 0.30 and 0.9 €/kWh for biogas yields ranging 200-300 Nm3/dry-t and compost selling price of 45 and 90 €/t. These values are significantly higher than current market electricity prices, which can be assumed to be about 0.1 €/kWh in average over time. The profitability of producing electricity depends to a large extend on additional revenues from both CO_2 credits, which can represent 0.08-0.2 €/kWh of electricity produced, and compost.

VC3. The total specific equipment in the range 0.93-0.59 M€/t/h and total operating costs are in the range 13.8-14.8 €/t. The equipment cost of upgrading the biogas to biomethane is similar to the cost of the CHP system. On the other hand, operating cost in VC3 are higher than for VC2 mainly due to increase in the net heat demand. The estimated minimum selling price of biomethane, shown in figure 5, varies within the range of 0.13 and 0.32 €/kWh for biogas yields ranging 200-300 Nm3/dry-t and compost selling price of 45 and 90 €/t. The MSP values of biomethane are significantly lower than the MSP of electricity in VC2. This is due to the low electric production efficiency that can be achieved by the CHP using biogas. Market prices for biomethane are around 0.15 – 0.18 €/kWh, and are expected to increase significantly in the coming future in Europe due to shortages in natural gas supply.

Direct production of compost using the solid fraction of pig slurry and cow manure is a mature technology which leads to economic viability with internal rate of investment above 10% for production capacities above 10 kt/year and compost market prices around 50 €/t. Improves quality and achieving certification can increase the selling price of compost above 150 €/t, leading to high profitability.

Considering the use of pig slurry and cow manure in anaerobic digestion, the production of biomethane has a better economic performance than the production of electricity and heat. Including revenues from CO2 credits and based on biogas yields of 200 Nm3/dry-t, the production of biomethane can achieve 10% internal rate of return with plant capacities above 50 kt/y. The profitability can be improved by increasing production capacity and increase further revenues from compost. Other strategies that can improve the overall economy of VC2 and VC3 are the co-digestion with other urban biowaste fractions where gate-fees can charged.

Table 2. Distribution of equipment costs (M€) distribution among main systems for the LLab1 (ALC) value chains based on feedstock processing capacities of 10 / 50 / 100 kt/y.

Plant capacity (kt/y)	VC1	VC2	VC3
Biogas production	-	0.60 / 2.1 / 3.7	0.60 / 2.1 / 3.7
CHP	-	0.17 / 0.64 / 1.13	-
Biogas upgrading	-	-	0.10 / 0.30 / 0.48
Methane compression	-	-	0.06 / 0.18 / 0.29
Dewatering	-	0.04 / 0.14 / 0.24	0.04 / 0.14 / 0.24
Denitrification	-	0.33 / 1.03 / 1.68	0.33 / 1.03 / 1.68
Composting	0.27 / 0.82 / 1.3	0.08 / 0.25 / 0.41	0.08 / 0.25 / 0.41

Table 3. Distribution of unit operating costs (€/t) distribution for the LLab1 (ALC) value chains based on feedstock processing capacities of 10 / 50 / 100 kt/y.

Plant capacity (kt/y)	VC1	VC2	VC3
Feedstock supply	4.0	4.0	4.0
Consumables	0.31	1.84	1.84
Electricity (consumption)	0.90	2.0	2.3
Heat (consumption)	-	1.53	4.25
Maintenance	0.53 / 0.33 / 0.27	2.8 / 1.9 / 1.6	2.4 / 1.8 / 1.5
By-products revenues	-	4.2	4.2

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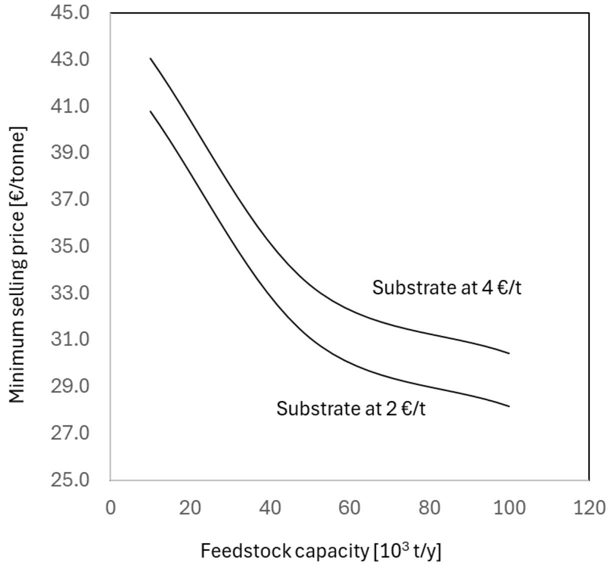

Figure 5. Calculated variation of the minimum selling price as a function of plant capacity for compost produced from pig slurry, cow manure and agricultural residues as substrate material, assuming a return of investment of 10%.

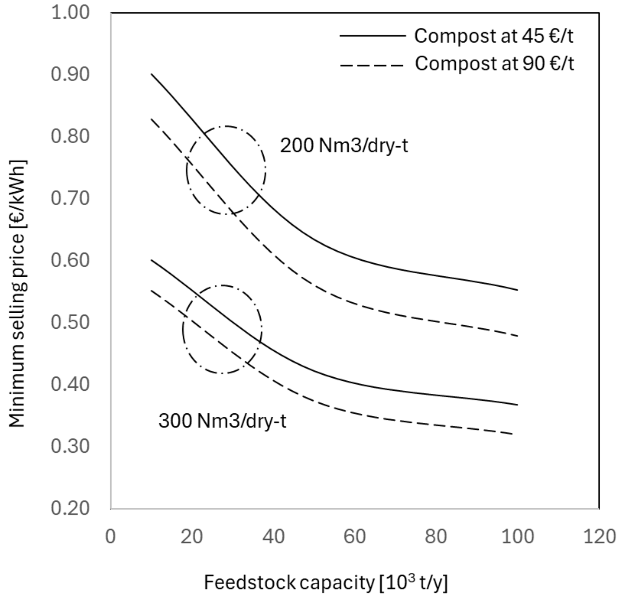

Figure 6. Calculated variation of the minimum selling price as a function of plant capacity for production of electricity and heat from biogas and use of digestate for production of compost (LLab1, VC2) based on biogas yields of 200 and 300 Nm3/dry t and compost.

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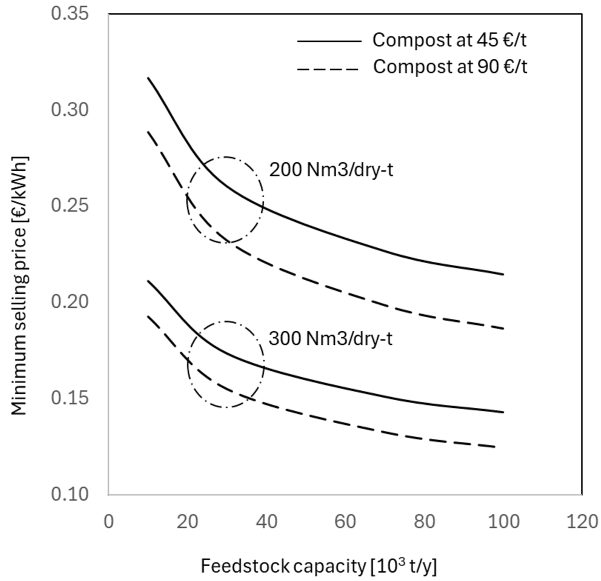

Figure 7. Calculated variation of the minimum selling price as a function of plant capacity for production of compressed biometahe from biogas and use of digestate for production of compost (Llab1, VC3) based on biogas yields of 200 and 300 Nm3/dry t and compost.

4.2.2 Living Lab 2: Bio-Silica Lab (Leader: CeNTI)

Value chains

VC1: Production of raw bio-silica from rice husk, the main processes including calcination of the rice husk, solubilization of the rice husk ash from calcination under alkaline conditions, precipitation by gelation of dissolved silica under acid conditions, and drying of the wet silica.

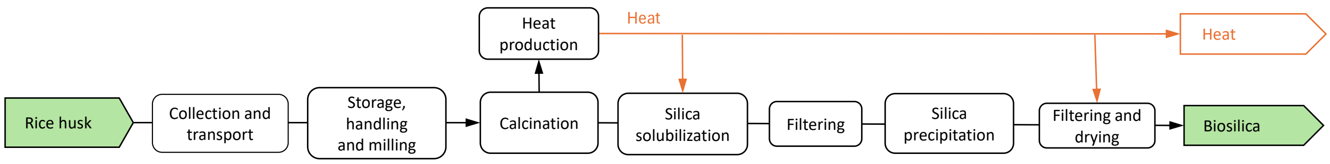

Figure 8. Process block diagram representing schematically the production of raw bio-silica from rice husk via calcination, alkaline solubilization and acid gelation (LLab2, VC1).

VC2: Production of raw bio-silica from ashes produced from biomass combustion plants. This value chain avoids the calcination process, and the ash is fed directly into the solubilization process. The heat demands by the solubilization and drying processes required an external energy source.

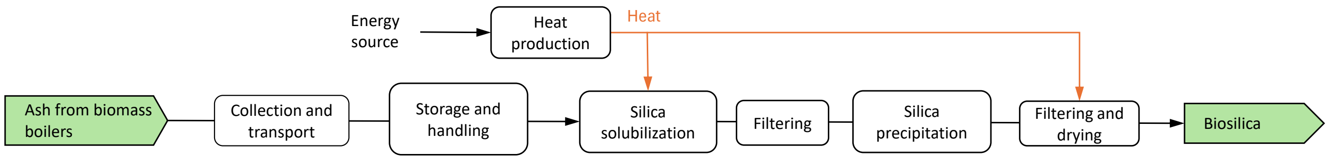

Figure 9. Process block diagram representing schematically the production of raw bio-silica from ash derived from rice husk combustion via alkaline solubilization and acid gelation (LLab2, VC2).

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Technologies

The main process parameters are shown in Table 4. Particle size reduction of the rice husk before calcination is assumed to be performed by hammermills followed by screening. The design of the calcination reactor is assumed to be fixed bed, using flue gas as a heating medium. The gases released from rice husk during calcination are combusted in a separated reactor with recovery of heat from the flue gas in water-tube boiler. Both the solubilization and precipitation of the silica takes place in a stirred reactor with continuous dosing of NaOH (solubilization) and nitric acid (for gelation) to regulate the pH. Preheating of the feed to the solubilization reactor is performed in a shell and tube heat exchanger using hot water as heating medium. Filtering of the aqueous solutions after solubilization and gelation is based on bag filters. Drying of wet silica is based on fluidized-bed dryer using flue gas a heating medium. For VC2, it is assumed that the heat production is based on natural gas boilers.

Table 4. Main process data for the production of raw silica from rice husk or silica-containing ash.

Parameter	Typical value (range)
Moisture content of rice husk	15 - 20% wt.
Rice husk dry composition	
Volatiles + fix carbon	89.6% wt. dry
Ash	10.4% wt. dry
Si	7% wt. dry
Other elements	3.3% wt. dry
Si content in biomass derived ash	7% wt. dry
Silica extraction yield	70 - 90% [a]
Operating temperature, calcination	700 °C
Residence time, calcination	6h (2.5 heating + 3.5 holding)
Base silica solubilization	NaOH
Acid, gelation	Nitric acid
Moisture content raw silica product	5% wt. [b]
Heat demands:	
Calcination	1.27 GJ/t (feed)
Solubilization	2.7 GJ/ t (dry ash)
Silica drying	303.4 MJ/t (wet silica)
Electric power consumption:	
Handling and milling	15.0 kWh/t (feed)
Calcination	25 kWh/t (feed)
Solubilization	10 kWh/t (feed)
Filtering	2.0 kWh / m3 (solubilization product)
Silica drying	25.0 KWh/ t (wet silica)

Notes: [a] Range assumed to be representative for upscaling the CENTI process, defined as the dry mass of SiO2 obtained after extraction divided by the dry mass of rice husk ash from calcination; [b] Assumed.

Economic assessment

The economic assessment considers the processing capacity varying in the range of 10-100 kt/year of rice husk (VC1) and 1-10 kt/year of ash (VC2). Tables 5 and 6 shows the distribution of equipment cost and operating cost for each value chain as a function of the feedstock capacity.

VC1. Within the capacity range of 10-100 kt/year of rice husk, the total specific equipment cost varies between 1.5 and 0.7 M€/t/h, with the calcination and the drying of wet silica accounting for above 90% of the total. Excluding the cost of feedstock supply, the operating cost per unit mass of rice husk is in the range of 181-187 €/t, the cost of chemicals representing above 95% of this value. The cost of supply of rice husk, which depends on the location of the silica production plant relative to the rice husk sources. It is assumed that rice husk is transported by heavy-duty trucks with average transport distances between 50 and 200 km.

This corresponds to transport cost in the range of 45-180 €/t. Revenues from exporting excess heat generated from calcination can reach about 250 € per kg rice husk, covering most of the operating cost and contributing significantly to improve the economic performance of this value chain. Figure 9 shows the estimations of the minimum selling price of raw silica produced from rice husk for plant capacities in the range of 10-100 kt/year of rice husk. Assuming an average cost of rice husk supply of 100 €/t, the estimated minimum selling of raw silica varies within the range of 0.4-0.6 and 0.5-0.75 €/kg for extraction yields of 70 and 90% respectively. The effect of the feedstock transport distance on the minimum selling price is shown in Figure 9 (right). For high extraction yields and assuming that the while excess heat can be sold, short distances between the silica production plant and the rice husk source can lead to MSP, implying that revenues from heat export cover all capital and operational expenditure. However, it is important to mention here that all investment associated to the export of the heat (as district heating or steam supply) are not included in this preliminary analysis and needs to be addressed further as part of the WP5 activities.

VC2. For this value chain, the quantities of silica-containing ash available are one order of magnitude lower than rice husk. Therefore, the plant capacity considered varies between 1 and 10 kt/year of ash. Within this range, the total specific equipment cost varies between 6.3 and 3.1 M€/t/h, with the cost of the heat production and drying of wet silica accounting for above 15 and 80% respectively. Excluding the cost of feedstock supply, the operating cost per unit mass of ash is in the range of 1094-1115 €/t, mainly due to chemicals consumption. For this value chain, the cost of natural gas for production of heat is about 27 €/t. Estimations of the minimum selling price of raw silica produced from ash is shown in Figure 10. For the plant capacity range considered and assuming an average cost of rice husk supply of 100 €/t, the estimated minimum selling of raw silica varies within the range of 1.6-1.7 and 2.2-2.3 €/kg for extraction yields of 70 and 90% respectively. Variation of the MSP for this value chain is less dependent on the plant capacity than VC1 since the impact of the operating costs on the MSP is significantly higher than the impact from capital investment. Figure 10 (right) shows the influence of the transport distance on the minimum selling price. Due to the higher cost of chemicals consumption per unit mass of ash, the effect of supply cost is less prominent for this value chain.

Market prices of raw biosilica depends on the quality, varying in the range of 0.3-1.0 €/kg for low quality bulk biosilica, and 1-5 €/kg for high quality. The use of rice husk for production of raw silica (VC1) has shown a good economic performance due to co-production of excess heat from the calcination process leading to minimum selling prices within the reference market values for low quality silica. The calcination process has been proven to play an important role in the morphology and quality of the silica product. Therefore, including this system as part of the production plant can represent an advantage to control the quality of the product and thus the selling price. Producing silica from ash exhibits minimum selling prices above current market prices for low quality bio-silica. Also, the chemical composition and physical properties of the silica contained in the ash can not be controlled, which represents a risk in ensuring sufficient quality in the silica product.

Table 5. Distribution of equipment costs (M€) distribution among main systems for the LLab2 (CENTI) value chains based on feedstock processing capacities of 10 / 50 / 100 kt/y for VC1 and 1 / 5 / 10 kt/y for VC2.

Equipment	VC1	VC2
Storage, preparation and handling	0.07 / 0.27 / 0.47	0.01 / 0.04 / 0.07
Calcination and heat recovery	0.94 / 2.64 / 4.50	-
Ash solubilization and filtering	0.01 / 0.03 / 0.05	0.01 / 0.03 / 0.05
Gelation and filtering	0.01 / 0.02 / 0.03	0.01 / 0.02 / 0.03
Drying	0.88 / 2.31 / 3.50	0.64 / 1.97 / 3.20

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Table 6. Distribution of unit operating costs (€/t) distribution for the LLab2 (CENTI) value chains based on feedstock processing capacities of 10 / 50 / 100 kt/y for VC1 and 1 / 5 / 10 kt/y for VC2.

	VC1	VC2
Feedstock supply	45 – 180	45 – 180
Consumables	175.4	1038
Electricity (consumption)	1.6	9.95
Heat (consumption)	-	27.0
Maintenance	3.8 / 2.1 / 1.7	18.2 / 9.6 / 7.3
Other fixed operating cost	5.7 / 3.2 / 2.6	27.3 / 14.4 / 10.9
Net heat export (revenue)	250	-

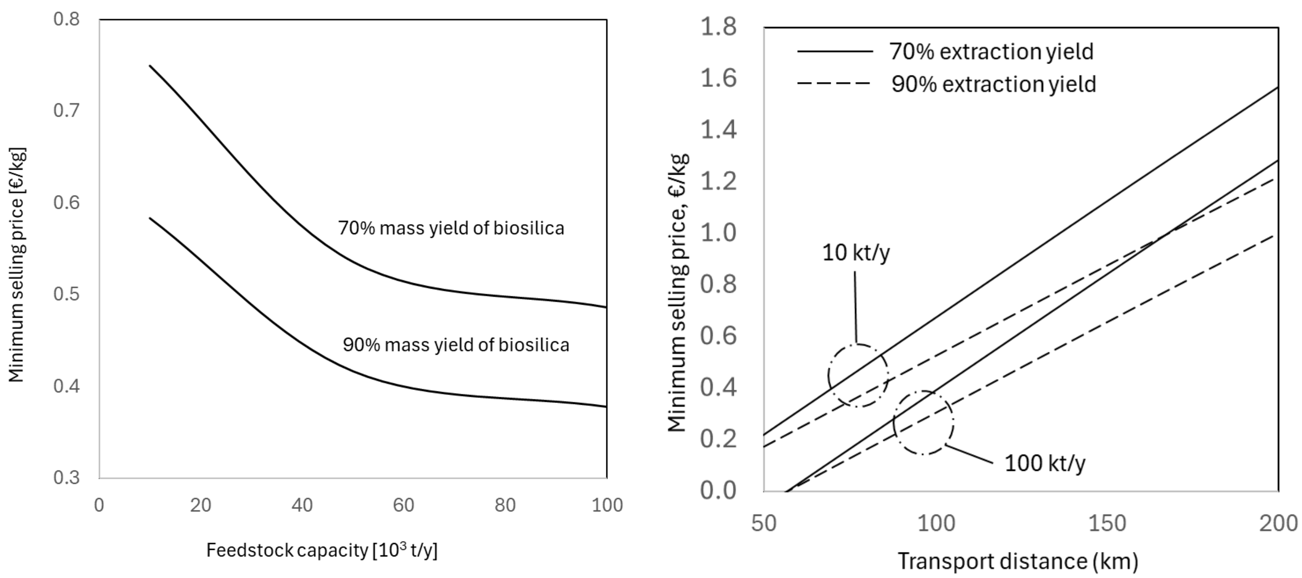

Figure 10. Calculated variation of the minimum selling price as a function of plant capacity for raw bio-silica produced from rice husk (left, VC1) and ash residues from rice husk combustion (right, VC2) with mass yields of 70 and 90%, assuming a return of invest.

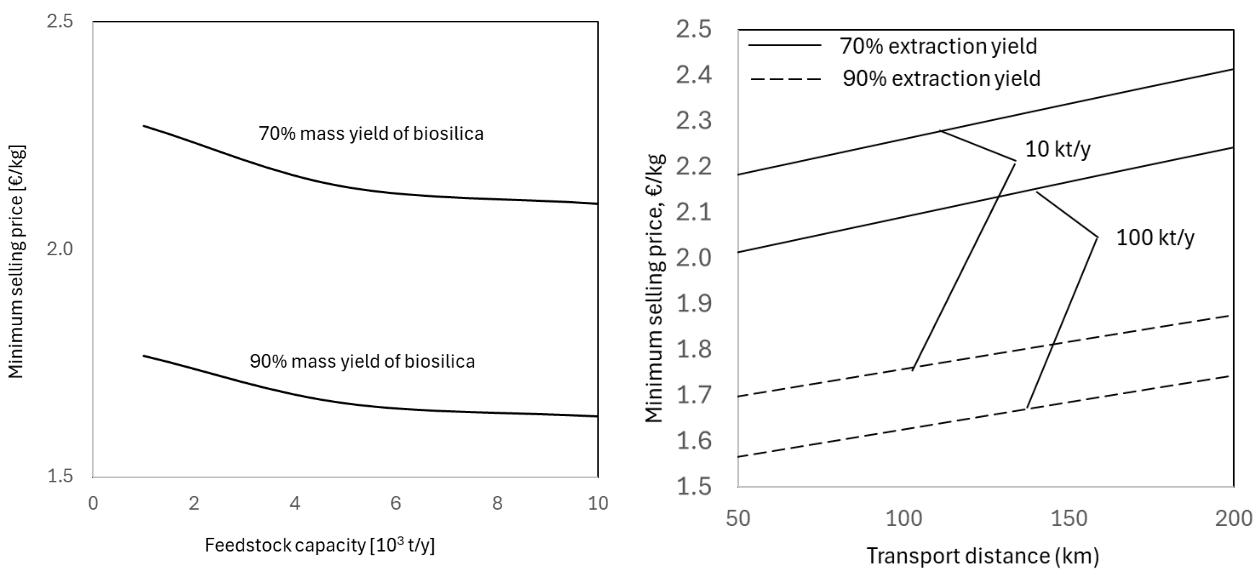

Figure 11. Calculated variation of the minimum selling price as a function of plant capacity for raw bio-silica produced from rice husk (left, VC1) and ash residues from rice husk combustion (right, VC2) with mass yields of 70 and 90%, assuming a return of invest.

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4.2.3 Living Lab 3: Liguria Bio-Lab (Leader: FILSE)

Value chains

VC1: Fermentation of fish waste for production of biofertilizer.

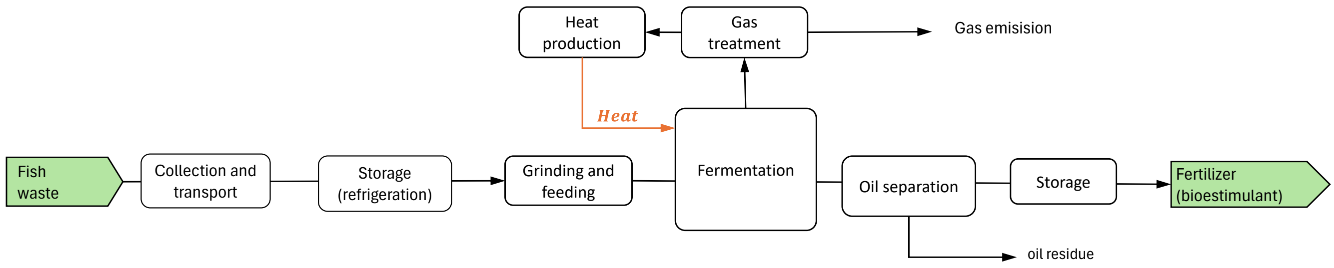

Figure 12. Figure 12. Process block diagram representing schematically the production of biofertilizer from fish waste via fermentation (LLab3, VC1).

Technologies

It is assumed that fish waste requires refrigeration at 4.0 deg. C during storage. Reduction of size particle before fermentation is based on twin-shaft grinder. Feeding of fish waste into the reactor is based on screw conveyor. Fermentation reactor is designed as a stirred reactor with heat jacket. Separation of the oil phase from the fermentation product is based on gravimetric separator with surface scrapping.

Table 7. Main process data for the fish waste fermentation

Parameter	Typical value (range)
Moisture content of fish waste	50 %wt.
Refrigeration temperature	4.0 deg. C
Storage time	1h
Operating temperature, fermentation	30 - 40 deg. C
Residence time, fermentation	21 days
Sugar dosing	kg/ kg (feed)
Gas production, fermentation	50-100 Nm3/dry ton (feed)
LHV gas from fermentation	5-10 MJ/kg
Heat demands	
Fermentation	80.0 MJ/ton (feed)
Electric power consumption	
Refrigeration	2500 kWh/m3 (feed)
Handling and milling	15.0 kWh/t (feed)
Fermentation	10 kWh/t (feed)

Economic assessment

The economic assessment considers the processing capacity varying in the range of 1-5 kt/year of fish waste. Tables 8 and 9 shows the distribution of equipment cost and operating cost for the value chain as a function of the feedstock capacity. Within the capacity range considered, the total specific equipment cost varies between 6.2 and 3.8 M€/t/h, with the digestor and heating accounting for above 85% of the total. Excluding the cost of collection and supply of the fish waste, the operating cost per unit feed mass is in the range of 35.4-15.8 €/t.

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Because of the low-capacity range for this value chain, fixed operating costs due to equipment maintenance and labour are dominant and can represent almost 80% of the total operating costs for the lowest plant capacities. These results indicate the importance of having a robust and automated design of the fermentation reactor to reduce the need for equipment maintenance and labour cost. Estimations of the minimum selling price are shown in figure 12. Considering mass yields of biofertilizer of 40 to 80%, minimum selling prices are in the range of 3.5-100 €/kg. The results shown in Figure 12 shows a rapid decrease of the MSP as the plant capacity increases due to the reduction of fixed operating costs per unit mass of feedstock. At present, market prices for liquid biofertilizers varies between 1 and 5 €/litre. Therefore, achieving economic viability of this value chain requires plant capacities above 3 kt/year. Still, there are several strategies for reducing production cost that should be addressed, such as the effect of adding a gate fee for processing the fish waste and the equipment design to ensure robustness and automation of the process to minimize maintenance and labour costs.

Table 8. Distribution of equipment costs (M€) distribution among main systems for the LLab3 (FILSE) value chains based on feedstock processing capacities of 1 / 2.5 / 5 kt/y.

Capacity (t/y)	1000	2500	5000
Storage and refrigeration	0.05	0.10	0.17
Milling	0.01	0.02	0.04
Digestor	0.64	1.22	1.97
Heat production	0.03	0.04	0.06
Separation and storage	0.04	0.08	0.14

Table 9. Distribution of unit operating costs (€/t) distribution for the LLab3 (FILSE) value chains based on feedstock processing capacities of 1 / 2.5 / 5 kt/y.

	VC1
Consumables	2
Heat	1.88
Electricity	2.66
Maintenance	7.7 / 5.9 / 4.8
Other fixed operating costs	1.1 /0.72 /0.53
Labour	20 / 8 / 4

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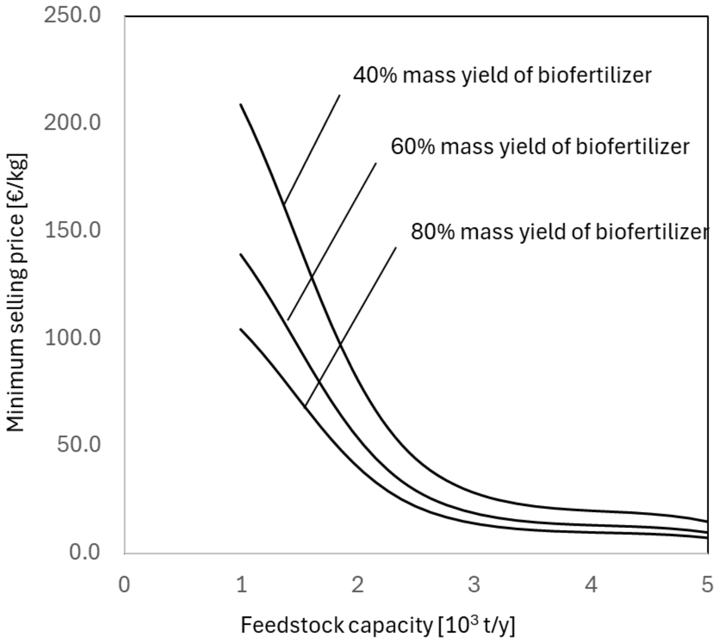

Figure 13. Calculated variation of the minimum selling price as a function of plant capacity for production of biofertilizer from fish waste for mass yields of 20 and 40%, assuming a return of investment of 10%.

4.2.4 Living Lab 4: BioEire Lab (Leader: IBF)

Value chains

VC1: Production of biochar from forest residues via pyrolysis. The main process steps include collection and transport of the forest residue, chipping and drying of the feedstock for reducing particle size and moisture content, pyrolysis with production of biochar and a combustible product gas, and combustion of the product gas with steam production. The biochar product is used for soil amendment. The produced heat is partially used to cover the demand by the drying and pyrolysis processes, and the remaining is exported.

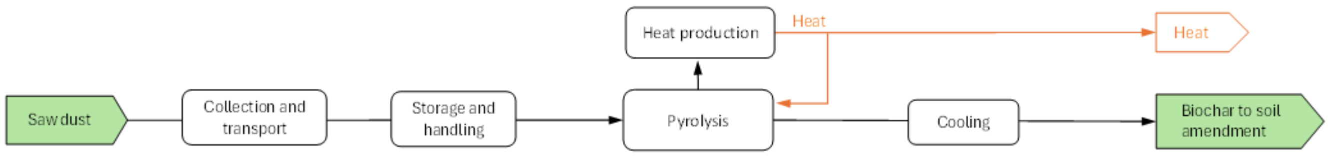

Figure 14. Process block diagram representing schematically the production of biochar from forest residues via pyrolysis (LLab4, VC1).

VC2: Production of biochar from saw dust residues via pyrolysis. It is assumed that the particle size and moisture content of the saw dust meets the required conditions by the pyrolysis process, therefore chipping and drying are not included. The produced heat is partially used to cover the demand of pyrolysis process, and the remaining is exported.

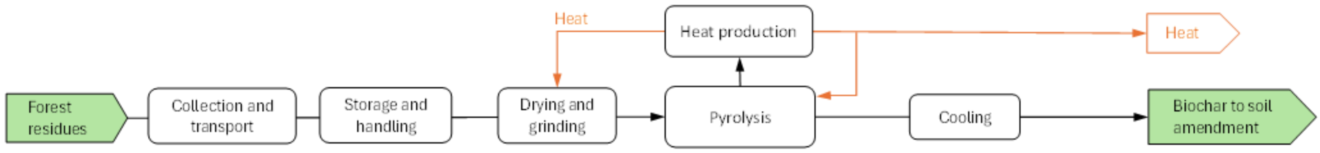

Figure 15. Process block diagram representing schematically the production of biochar from forest residues via pyrolysis (LLab4, VC2).

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Technologies

The main process parameters are shown in Table 10. Forest residues are assumed to have a moisture content of 50% and requires reduction of particle size and drying before the pyrolysis process. It is assumed that saw dust does not required particle size reduction nor drying. The particle size reduction of the forest residues is assumed to be performed by hammermills and screening. Drying is based on rotary drum using steam as heating medium. The design of the pyrolysis reactor is assumed to be fixed bed. The gas product from the pyrolysis process is combusted in a separate boiler with heat recovery as steam. Flue gas partially cooled after the combustion process is recirculated and use as heating medium in the pyrolysis. The biochar from the pyrolysis process is quench in a water basin and stored.

Table 10. Main process data for the production of biochar via pyrolysis.

Parameter	Typical value (range)
Moisture content forest residue	25 – 50%
Moisture content saw dust	25 %
Particle size feed to pyrolysis	5 mm
Moisture content feed to pyrolysis	20 %wt.
Char mass yield (% wt. dry biomass) [a]	15–25
Gas mass yield (% wt. of dry biomass) [a]	75–85
Gas LHV (MJ/kg) [b]	8 – 13
Heat production efficiency (%)[c]	85%
Net heat export	2.0 GJ/t (feed to pyrolysis)
Heat demands	
Drying [d]	0 – 1.0 GJ/t (raw feedstock)
Pyrolysis	1.27 GJ/t (feed)
Electric power consumption	
Milling and sieving	18 kwh/ton (raw feedstock)
Pyrolysis and heat recovery	25 kwh/ton (feed to pyrolysis)
Flue gas cleaning	9 kwh/ton (feed to pyrolysis)

Notes: [a] Typical range; [b] Assuming a typical gas composition (%wt. dry) of 43% CO_2, 1% H_2, 46% CO, 6% CH_4 and 5% C_{2+}, with calculated 40-70%wt. H2O; [c] Assumed to be produced by combustion of the gas products with steam production; [d] Based on moisture content in the feedstock of 20-40%wt.

Economic assessment

Tables 11 and 12 shows the distribution of equipment cost and operating cost for each value chain as a function of the feedstock capacity.

VC1. Within the capacity range of 10-100 kt/year of saw dust, the total specific equipment cost varies between 2.9 and 1.7 M€/t/h, with the pyrolysis representing about 1/3 of the total. Excluding the cost of feedstock supply, the operating cost per unit feedstock mass is in the range of 26.2-12.5 €/t, where maintenance costs represent between 60- 50%. Figure 14 shows the estimations of the minimum selling price of biochar produced from saw dust as a function of the feedstock supply cost for plant capacities of 10 and 100 kt/year and biochar mass yields of 15 and 25 % (dry basis). Higher biochar yields imply lower gas production in the pyrolysis process and thus revenues from exporting excess heat leading to an increase of the MSP. Considering that market price for biochar is in the range of 200-300 €/t, the results shown in Figure 14 indicates that this value chain can be economically feasible when cost of saw dust is below 5 €/t for a plant capacity of 10 kt/year and below 35 €/t for plant capacities of 100 kt/y.

VC2. For comparison with VC1, the analysis of this value chain considers the same capacity range, i.e. 10-100 kt/year of forest residues. Due to the need of particle size reduction and drying of the feedstock before pyrolysis, the total specific equipment cost increases compared to VC1, being in the range of 4.4 and 1.6 M€/t/h.

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Excluding the cost of feedstock supply, the operating cost per unit feedstock mass is in the range of 38-17.2 €/t, representing a 50% higher than VC1 mainly due to increase electricity consumption and equipment maintenance costs. Figure 15 shows the estimations of the minimum selling price of biochar produced from forest residue as a function of the feedstock supply cost for plant capacities of 10 and 100 kt/year and biochar mass yields of 15 and 25 % (dry basis). This value chain requires a higher heat demand by the drying process leading to a significant reduction of the heat that can be exported and a lower economic performance than VC1 due to reduced income from heat export. Considering a plant capacity of 10 kt/year, the economic viability can be achieved when the supply cost of forest residues is below 70 €/t. When the plant capacity increases to 100 kt/year, the minimum cost of feedstock supply to reach viability increases to about 90 €/t.

Table 11. Distribution of equipment costs (M€) distribution among main systems for the LLab4 (IBF) value chains based on feedstock processing capacities of 10 / 50 / 100 kt/y.

Equipment	VC1	VC2
Storage and handling	1.0 / 2.3 / 3.3	1.0 / 2.3 / 3.3
Drying and grinding	-	2.3 / 6.0 / 9.0
Pyrolysis	2.1 / 5.0 / 7.3	2.0 / 4.7 / 6.8
Heat export	0.4 / 1.2 / 1.9	0.22 / 0.67 / 1.09
Gas cleaning	0.03 / 0.08 / 0.13	0.02 / 0.05 / 0.09

Table 12. Distribution of unit operating costs (€/t) distribution for the LLab4 (IBF) value chains based on feedstock processing capacities of 10 / 50 / 100 kt/y.

	VC1	VC2
Feedstock supply	20 – 50	50 – 100
Electricity (consumption)	4.8	5.2
Maintenance	17.8 / 8.6 / 6.3	27.6 / 13.7 / 10.2
Other fixed operating cost	3.2 / 1.5 / 1.1	5.3 / 2.6 / 1.9
Net heat export (revenue)	78	34

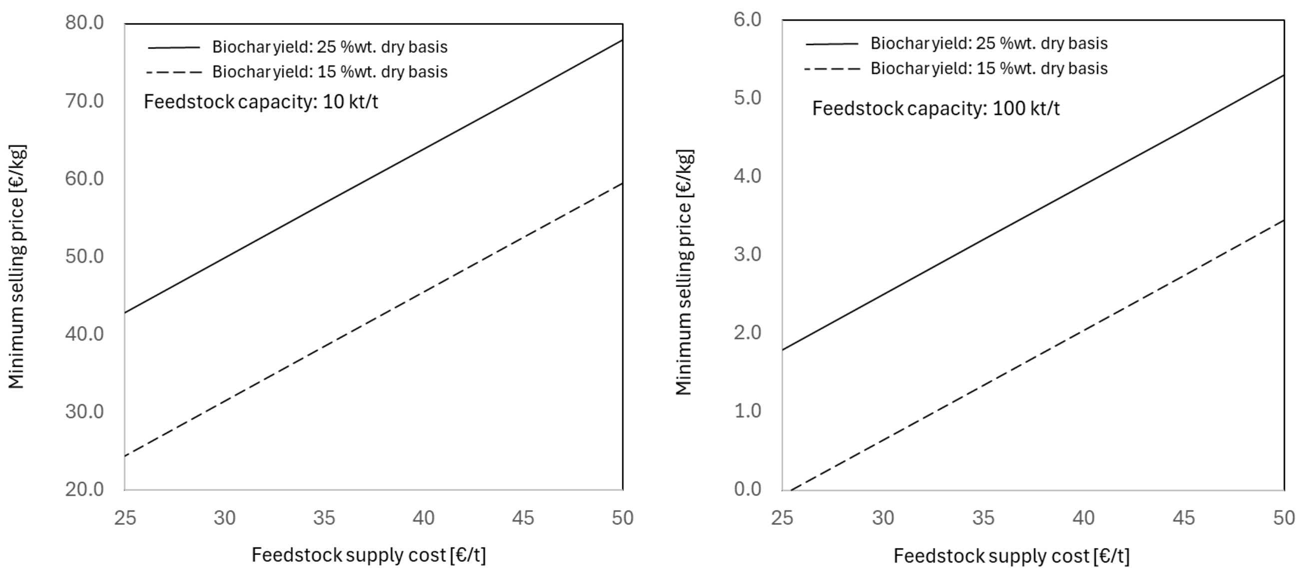

Figure 16. Variation of the Minimum selling price of biochar produced from pyrolysis of saw dust as a function of the feedstock supply cost for a plant capacity of 10 kt/y (left) and 100 kt/y (right), based on biochar yield of 0.15-0.25 on dry mass basis relative.

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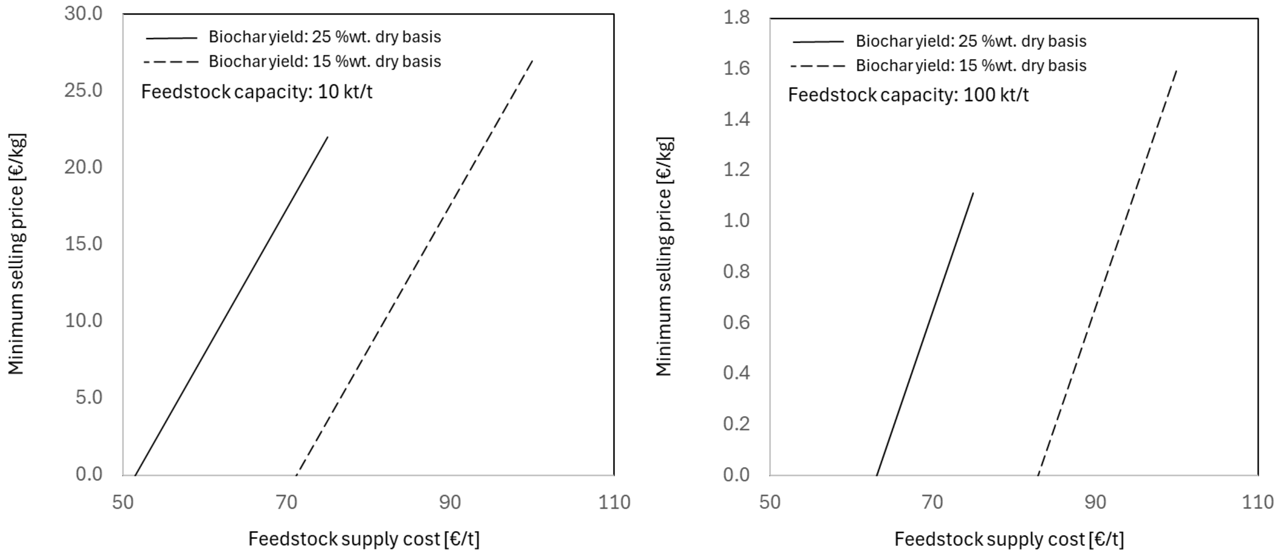

Figure 17. Variation of the Minimum selling price of biochar produced from pyrolysis of forest residue as a function of the feedstock supply cost for plant capacities of 10 kt/y (left) and 100 kt/y (right), based on biochar yield of 0.15-0.25 on dry mass basis relative to raw feedstock. It is assumed that the saw dust has a moisture content of 5o%wt. and requires drying or particle size reduction.

4.2.5 Living Lab 5: Cell Factory Lab (Leader: VTT)

Value chains

VC1: Cultivation of plant cells from concentrated effluent residues derived from production of berries juice (containing sugars and other nutrients). The main processes include 1) sterilization by freezing of the liquid feedstock, 2) preparation of cell growth medium, 3) seed cultivation from selected cell culture line(s), 4) main cell cultivation, 4) cell harvesting and dewatering, and 5) cell product freeze drying.

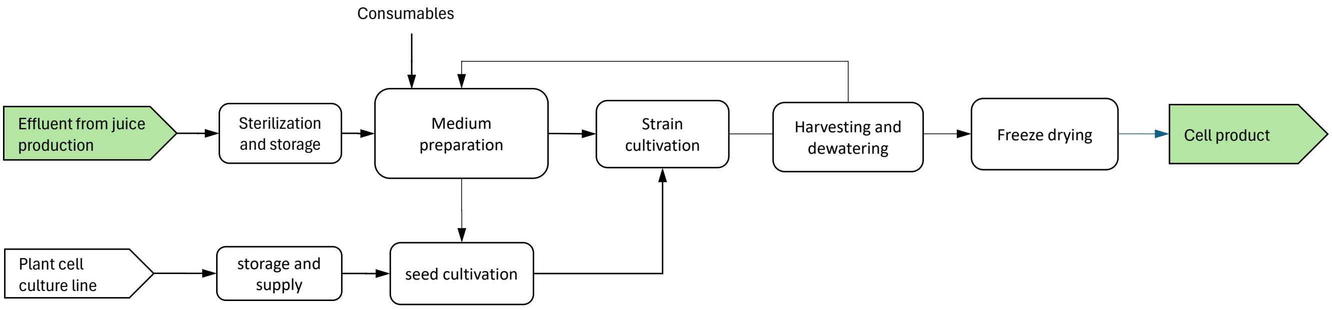

Figure 18. Process block diagram representing schematically the production of cells using effluents from juice production (VC1, VTT).

Technologies

The feedstock is here defined as the side stream effluent from juice production used for cell cultivation, which have a minimum concentration of sugars of 3 g per litre. Before the cell cultivation process, the feedstock requires sterilization at 120 deg. C for 20 minutes in a pressurized tank using saturated steam as heating fluid. Preparation of the medium takes place in an agitated tank where the feedstock is mixed with additional nutrients (other from the carbon source) required for cell growth, which includes micronutrients, macronutrients, vitamins, iron and phytohormones. Both seed and cell cultivation processes take place in separated bioreactors, design as stainless steel tanks equipped with heating jacket, agitator and air injection. Harvesting and dewatering of cultivated cell products is performed by gravimetric separator followed by centrifuge. Further reduction of water is performed by e.g. freeze drying.

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The main operational parameters considered for the processes involved are shown in Table 13. The dried cell product from this value chain is defined as an intermediate ingredient that can be used in other industrial applications such as food or cosmetics production.

Table 13. Main operational parameters considered to evaluate the production of cultivated cells using residues from berries juice production.

Parameter	Typical value (range)
Sucrose content in the feedstock	3 g / litre
Additional nutrients in medium preparation [a]	0.35 g / litre
Culture supply to seed cultivation	10 % wt. dry feed
Sterilization temperature	120 deg. C
Sterilization time	20 min
freezing temperature feed storage	- 4.0 deg. C
Residence time, medium preparation tank	1h
Seed cultivation temperature	25 deg. C
Seed cultivation time	10 days
Air dosing seed cultivation	50 Nm3/h/m3
Strain cultivation temperature	25 deg. C
Strain cultivation time	10 days
Air dosing seed cultivation	50 Nm3/h/m3
Water content after filtering	70% wt.
Cell product yield [b]	0.6 – 1.1
Heat demands	
Sterilization	0.19 MJ/kg
Bioreactors	0.12 MW/m3
Freeze dryer	0.4 MJ/kg (feed)
Electric power consumption	
Refrigeration	2500 kWh/m3 (feed)
Pumping	6.0 kWh/t
Medium preparation	10 kWh/t (feed)
Bioreactors	9.1 kWh/m3
Freeze dryer	4.4 kWh/kg

Notes: [a] Other than the carbon source (sugars), including micronutrients, macronutrients, vitamins, iron and phytohormones; [b] Defined as total dry mass of cell product per mass of sucrose in the input effluent

Economic assessment

Tables 14 and 15 shows the distribution of equipment cost and operating costs for plant processing capacities of 1-100 kt/year based on the input feedstock. Within this capacity range, the total specific equipment cost varies between 8 and 2 M€/t/h, with the sterilization and medium preparation system representing about 45% of the total equipment cost. Excluding the cost of the feedstock and additional nutrients in the medium preparation, the operating cost per unit mass of feedstock is in the range of 90-40 €/t, where the cost of heat and electricity is about 32 €/t. Fixed operating cost including maintenance and labour are dominant for capacities below 5 kt/y. Figure 16 shows the estimations of the minimum selling price of the dried cultivated cell as a function of the feedstock capacity. Excluding the cost of nutrients supply, the MSP of dried cells is in the range of approximately 160-360 €/kg. Including the cost of feedstock and additional nutrients with unit prices varying between 10 and 50 €/t increases the MSP by 40-200 €/t. The market of cultivated plant cells is still almost non-existing, and price levels depends greatly on the application.

Table 1414. Distribution of equipment costs (M€) among main systems for the LLAB5 value chain based on feedstock processing capacities of 1 - 50 kt/y.

Feedstock capacity (10^3 t/y)	1	5	10	25	50
Storage and handling	0.06	0.19	0.30	0.61	0.95
Sterilization	0.07	0.18	0.26	0.44	0.64
Medium preparation	0.13	0.35	0.52	0.9	1.4
Seed cultivation	0.05	0.14	0.23	0.4	0.7

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Cell cultivation	0.23	0.72	1.18	2.2	3.6
Harvesting and dewatering	0.04	0.13	0.21	0.39	0.64
Drying (freeze dryer)	0.13	0.6	1.2	2.8	5.4

Table 1515. Distribution of unit operating costs (€/t) for the LLAB5 value chains based on feed processing capacities of 1/5/10/50/100 kt/y.

Feedstock capacity (10^3 t/y)	1 / 5 / 10 / 25 / 50
Consumables	4.0
Heat	21.5
Electricity	10.4
Maintenance	18.4/ 11.2 / 9.2 / 6.9 / 5.6
Other fixed operating costs	9.2 / 5.6 / 4.6 / 3.5 / 2.8
Labour	30 / 6 / 3 / 1.2 / 0.6

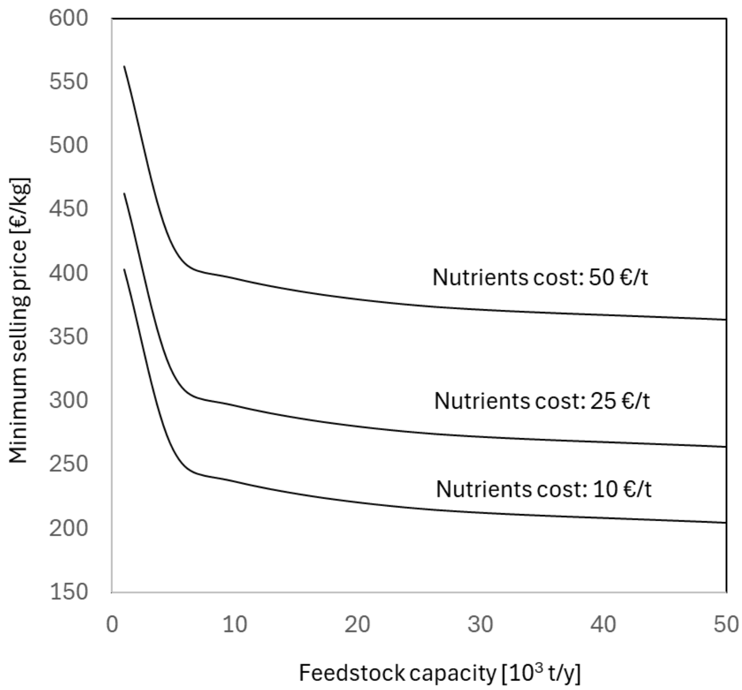

Figure 19. Variation of the Minimum selling price of cultivated cell as a function of feed capacity, based on a required return of investment of 10%.

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5. Risk analysis of Living Labs and Regional Ecosystems

5.1 Approach

In this section, we present a risk analysis focused on the Living Labs (LLabs) and their surrounding regions. We begin with a summary table that consolidates key insights from previous work under the PRIMED project, the value chain mapping and the techno-economic assessment.

5.2 Methodology

For each Living Lab, we quantify **annual feedstock availability** and **current processing capacities**, and we explore **scalability risks and opportunities**. The outputs are segmented by local market categories. For example, in the case of ALC BioLLab, we focus on Lleida and Catalonia as primary markets for Alcarràs-based products. We collected Catalonia-specific demand data and 5–10-year growth forecasts to build various scaling scenarios (ranging from status quo to multi-site expansion).

Each scenario is evaluated against technical, regulatory, financial, and social risk dimensions. We then map risks against potential impacts to visualize phased expansion pathways. Assumptions are grounded in regional policy frameworks, local project ecosystems (with a list of success cases included at the end), and potential strategic partnerships identified to de-risk each development phase.

5.3 Results

5.3.1 Living Lab 1: ALC Bio-Lab

VC1: Direct Aerobic Composting

Category	Details
Feedstock Flow & Capacity	Input: Solid manure (~22,500 t/y), pig slurry solids (~4,500 t/y), pruning wood (~2,000 t/y), additional woody biomass (~50,000 t/y) for structure. Throughput: Current: ~27,000 t/y
Technological Feasibility & Limits	Composting is low-tech and scalable. Risks: Feedstock moisture/nutrient imbalances can reduce microbial efficiency. Inadequate monitoring may lead to incomplete pathogen inactivation, affecting certification.
Competitive Landscape	• Decentralized composting on farms • Direct land-spreading under nutrient regulation Alcarràs model is collective, centralized, and quality-focused, making it unique regionally.
Value Proposition (Lleida, Catalonia, Spain)	• Centralizes slurry solids processing, supporting compliance with nitrate regulations. • Produces high-value organic compost. • Interest from multiple multinational buyers.
Market Applications	• Local farms (soil health improvement) • International buyers (e.g., French farmers) • Future potential: municipalities, gardening retailers, ornamental horticulture.
Stakeholders & Value Chain	• 150 local farm families supply feedstock. • Composting is managed centrally. • Supported by BioHubCAT and local/regional government. • Export interest and market development in progress.
Market Dynamics	• EU demand for organic soil inputs is rising. • Premium compost commands higher pricing.

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	• Market sensitive to input costs and competition from chemical fertilisers.
Known Risks	• **Operational**: Expansion logistics, compost quality monitoring. • **Regulatory**: Compliance with organic and health standards. • **Environmental**: Risk of leachate, odor, if mismanaged. • **Economic**: ~€1.5M investment depends on market uptake. • **Social**: Trust-building and community engagement are essential.

Products/by-products: Premium compost

Current Local Demand

Agriculture (incl. organic farms): Catalonia uses ~300,000 t/year of organic soil amendments, projected to grow with the expansion of organic farming and stricter fertilizer rules. Urban/peri-urban gardening & landscaping: In the Barcelona metro area alone, current compost use meets ~8% of NPK nutrient demand for peri-urban farming; potential share could rise to 21% by 2025 with expanded collection programs

Market Segments

- ***Bulk farms***: ~200,000 t/y
- ***Municipal landscaping & green spaces***: ~50,000 t/y
- ***Retail garden centers / consumers***: ~50,000 t/y

10-Year Demand Growth Estimate

- Average sector CAGR ~6–10% (aligned with EU organic/green economy trends).
- Lleida alone (~10% of regional consumption): ~30,000 t/y growing to ~50,000 t/y by 2035.

Year	Total Demand (Catalonia)
Now (2025)	~300,000 t
2030 (+6% p.a.)	~400,000 t
2035 (annual +6%)	~530,000 t

Scalability & Replicability in Lleida/Catalonia

Scalable to cover a substantial proportion (25–50%) of Lleida's agricultural organic residues with replicable models. Costs fall in the €50–100/t range, with ROI of around 5–7 years (shorter with carbon credits and grants). Generated co-benefits in nitrate mitigation, carbon sequestration, and soil resilience enhance economic viability. Replication is straightforward: community or municipal-based models can be adapted across Catalonia, especially in livestock- or horticulture-intensive areas.

Feedstock Potential & Coverage

- ***Alcarràs current scale***: Currently processes ~27 000 t/yr of solid manure, slurry solids, and pruning wood / ~11% of available region-scale feedstock (~245 000 t/yr total solids including slurry and wood). .
- ***Expansion scenario***: Aims to scale to ~67 000 t/yr, potentially covering ~27% of current feedstock, a sizable contribution, though other composters in the region, like those in Sort or Segrià, cover additional portions of Catalonia's organic residues.
- ***Replication potential***: With appropriate investments and community structures, additional facilities could absorb another 30–50% more of catalyst region feedstock through a network of similar plants.

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Required Investment & ROI Considerations

- ***CapEx benchmarks:***
- Alcarràs plant cost approx. €1.5 M for initial 27 000 t/yr capacity.
- Expanding to 67 000 t/yr likely requires €3–6 M based on EU average (€50–200 per tonne capacity).
- OPEX: ~€15–30/t for labor, bulking material, maintenance, transport.
- ***Revenue potential:***
- Compost at €40–70/t with environmental premiums.
- Carbon credits (€10–30/tCO_2e) and avoided nitrate fines (€15/t) may lift margin.
- ***ROI:***
- At €50/t sale – €20/t cost = €30/t margin → Annual EBITDA ~€800 000.
- With scale expansion and credits, ROI could reach 5–7 years nominally.

Environmental Co-benefits & Monetization

- ***Nitrate regulation compliance***: Centralizing slurry solids reduces groundwater nitrate pollution and regulatory penalties.
- ***Carbon sequestration***: Composting converts organic C into stable soil carbon; depending on certification, carbon offsets (~€10–30/tCO_2e) could provide added revenue.
- ***Waste reduction***: Diverts feedstock from landfills/incineration, avoids waste disposal fees (~€90/t in some Catalan regions).
- ***Water savings & soil health***: Compost improves soil moisture retention, critical in drought-prone Catalonia, adding indirect benefits.

Replicability Drivers & Enablers

- ***Abundant feedstock***: Numerous livestock-dense municipalities in Lleida have similar manure/residue profiles.
- ***Community models***: Sort (Pallars Sobirà) showcases door-to-door plus community composting, adaptable to Alcarràs-style decentralised, multi-farm hubs
- ***Institutional support***: Funding via NextGenerationEU, bioeconomy grants, and Catalan provincial support.
- ***Technology & standards***: Leveraging low-tech windrow systems with basic monitoring, but adding portable sensors, source separation, and pathogen checks to ensure quality.
- ***Local partners***: Companies like Ros Roca (waste tech equipment) and Compost Segrià (organic fertilizer) can support equipment and distribution.

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Scaling Paths: Risk VS Impact

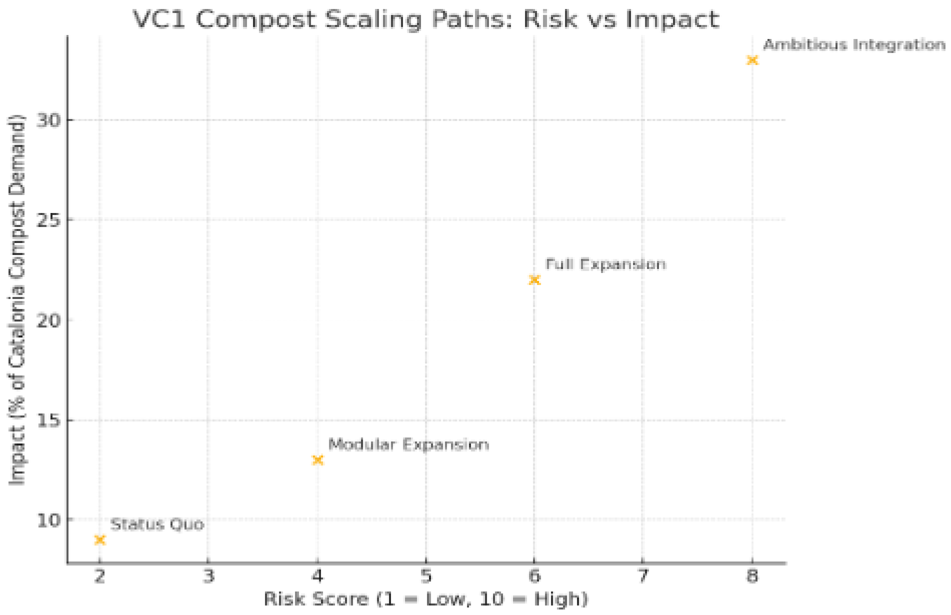

Figure 20. Scaling Paths: Risk VS Impact of the VC1.

The chart above maps four realistic scaling paths for Alcarràs' compost operation, plotting risk (horizontal) against impact (vertical, as a percentage of total regional compost demand):

- ***Status Quo (27 375 t/y, 9% share)***
  - Risk Score: 2; Impact: 9%
  - Maintains current capacity. Very low risk but limited incremental benefit.
- ***Modular Expansion (40 000 t/y, 13% share)***
  - Risk Score: 4; Impact: 13%
  - Adds capacity through modest infrastructure upgrades (e.g., covered static piles). Moderate risk in securing and balancing seasonal feedstock; moderate impact.
- ***Full Expansion (67 000 t/y, 22% share)***
  - Risk Score: 6; Impact: 22%
  - Reaches near the practical limit of windrow technology in Lleida. Higher risk around land use, permitting, quality control, but doubles Alcarràs's market influence.
- ***Ambitious Integration (100 000 t/y, 33% share)***
  - Risk Score: 8; Impact: 33%
  - Extends beyond manure and pruning into municipal green waste, requiring major capex (€6–10 M), complex logistics, and new zoning. Highest impact but substantial execution risk.

A modular expansion step (40 000 t) offers a balanced profile: meaningful market share gain with manageable risk. Pushing toward full expansion is logical once quality monitoring and feedstock contracts are solidified. Ambitious integration could follow, contingent on pilot successes in seasonal blending and municipal partnerships.

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Ground-truth assessment

Realistic Performance Limits

- ***Throughput ceiling***: Windrow-based facilities in Catalonia rarely exceed 80 000 t/y without shifting to in-vessel or aerated static pile systems. Alcarràs's planned 67 000 t/y is near the practical upper bound for passive aeration models- Beyond this, additional investment in blowers, covered bays, and leachate management is needed.
- ***Moisture balance***: Optimal moisture is 50–60%. Local manure can range from 20–75% moisture depending on barn practices. Without high-precision drying or bulking controls, piles risk anaerobic zones, odour spikes, and reduced degradation rates, limiting consistent 8–12-week cycle times.

Key Issues & Barriers

- ***Feedstock variability***: Seasonal shifts in pruning volumes (winter) versus manure loads (spring) challenge continuous operation.
- ***Regulatory thresholds***: Catalan health rules require ≥55 °C for 3 days to certify pathogen kill. Monitoring gaps can jeopardize organic certification.
- ***Land use constraints***: New compost bays require agricultural zoning changes; municipalities like Alcarràs have tight land-use plans.

Opportunities & Mitigations

- ***Modular expansio***n: Introduce covered static piles with controlled aeration to push capacity toward 100 000 t/y without expanding footprint.
- ***Digital monitoring***: Deploy IoT sensors (temperature, O_2, moisture) via local ag-tech startups (e.g., Lleida Tech Hub) to maintain compliance and optimize cycle times.
- ***Co-processing***: Blend in up to 15% municipal green waste under Catalonia's separate biowaste mandate to smooth seasonal feedstock gaps and improve C:N balance.

VC2: Anaerobic digestion Composting

Category	Details
Feedstock Flow & Capacity	Input: Pruning wood (~2,000 t/y), other regional forest/agro residues (potential up to 10,000 t/y initially, scalable). Throughput: Small-scale pilot planned (~2,000–5,000 t/y), expandable.
Technological Feasibility & Limits	Pyrolysis is a moderate to high-tech process requiring consistent biomass quality and drying. Output: Biochar, syngas, bio-oil. Risks: Feedstock moisture, reactor control, and tar management.
Competitive Landscape	• Emerging regional startups and EU-funded demo projects. • Competes with biomass combustion and CHP (combined heat & power). • Few biochar producers in Catalonia; early-mover advantage possible.
Value Proposition (Lleida, Catalonia, Spain)	• Decentralized valorization of woody biomass; aligns with fire prevention and forest management goals. • Circular use of prunings/waste, potential carbon credit revenue.
Market Applications	• Soil amendment (biochar for agriculture) • Carbon sequestration markets (voluntary carbon offsets) • Animal feed additive (pending approval)

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	• Water filtration, green building materials.
Stakeholders & Value Chain	• Local forest and agriculture cooperatives as biomass providers. • Municipalities interested in wildfire risk mitigation. • Technology developers, e.g., SMEs in pyrolysis systems.
Market Dynamics	• EU biochar market growing, supported by new EU Carbon Removal Certification Framework (CRCF). • Local demand limited but growing; early adopters include regenerative farms.
Known Risks	• **Operational**: Reactor malfunction, feedstock drying requirements. • **Regulatory**: Biochar certification, air emissions permits. • **Environmental**: Pyrolysis off-gas must be managed. • **Economic**: High CAPEX (~€1–2M); ROI depends on biochar pricing and carbon credit monetization. • **Social**: Perception of "burning" may create pushback without proper communication.

Products/by-products: Heat/power; digestate

Current Local Demand

- ***Renewable energy***: Catalonia's installed biogas capacity currently generates a portion of the 400–500 GWh/year from 70+ plants, serving farm use or grid electricity.
- ***Digestate***: Used on nearby land; quality varies. ~8.5 Mt of organic materials processed by 2030 will require extensive nutrient re-use coordination.

Market Segments

- ***Farm-scale CHP***: Local utilization of heat & power (~2 MWh per farm)
- ***Electric grid***: Larger installations selling electricity.
- ***Soil amendment***: Digestate application in crop acres (100,000+ ha in priory zones).

Market Growth (2025–2035)

- ***Biogas Strategy*** aims for ~150 plants (x2 growth):
- ***Energy Output***: From ~0.5 TWh to ~2 TWh by 2030 → ~+14% CAGR
- ***Digestate Reuse***: Volume doubles (embedded in farm circular systems); market-share growth at +10–12% annually.

Scalability & Replicability in Lleida & Catalonia

VC2 (Anaerobic Digestion → Heat & Power + Digestate) demonstrates strong scalability and replication potential across Catalonia. With abundant organic feedstocks, supportive policy and financing, and positive environmental/economic returns, the model is viable for decentralized adoption. ROI timelines are competitive given subsidies and digestate revenue, and the co-benefits in greenhouse gas reduction and nutrient management further boost value. Alcarràs stands as a best-practice model ready for replication in similarly structured livestock regions.

Feedstock Coverage & Regional Potential

- **Alcarràs Scale**: Current investment (~€3M via ICF) supports processing ~70,000 t/y of livestock manure from 150 family farms, converting it into heat and power.

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- **Catalonia-wide scope**: Region generates ~9.4 million tonnes of slurry each year, esteemed as "one of the European areas with greatest availability of resources".
- ***Strategic goal***: Catalan Biogas Strategy targets a 10× increase in treated manure, reaching ~4 million tonnes by 2030, with the creation of ~150 plants processing 8.5 million tonnes of organic materials producing 2 TWh/yr
- ***Replicability***: With 72 existing plants, and an aim to add ~12 per year until 2030, similar community/farm-level AD hubs are scalable across high-density livestock zones in Lleida and Central Catalonia.

Capital & Economic Viability

- ***Capital Cost***s: A mid-sized AD facility (30–70 kt/y) typically costs €3–6 M, aligning with Alcarràs's €3 M capex.
- ***Operating Costs***: Estimated at €15–30 per tonne of feedstock.
- ***Revenue Streams***:
- Energy sales: Electricity/heat at ~€40–50 / MWh, with premium potential due to green energy branding.
- Digestate uplift: Returns of €10–30/t as nutrient-rich soil amendments.
- Avoided feed/fertilizer costs and potential carbon credits enhance margins.
- ***ROI Outlook***: Catalonia's distribution network indicates payback periods of 8–12 years; typical IRRs range 6–12%, boosted by grants like €23 M through 2024 and €46 M by 2026 for plant and biomethane network connections.

Environmental & Social Co-Benefits

- ***Nutrient management***: Centralizing slurry reduces nitrate leaching risk and meets EU nitrate directive requirements; 150-plant strategy tackles nutrient overloading.
- ***GHG Reduction***: The Strategy aims to decrease emissions by 350,000 t CO_2-eq annually
- ***Renewable energy***: With a target of 2 TWh/yr from biogas (≈13% of current natural gas demand), the approach aligns with Catalonia's clean-energy shift.
- ***Round-trip benefits***: Alcarràs's digester returns energy to farms and the grid, aiding farm resilience; local economic value for ranchers

Replicability Enablers

- ***Strong policy support***: €23 M + €46 M grants and streamlined approvals foster adoption.
- ***Local model***: Alcarràs and Torre Santamaría (Axpo cooperative) serve as replicable case studies.
- ***Farmer cooperatives***: Leveraging local groups in livestock regions (Lleida, Vic, Plana de Vic etc.) aligns with decentralized biogas strategy
- ***Technology ecosystem***: Providers like CycleØ, FNX, and ICF's EcoGreen line support community-based initiatives.
- ***Feedstock availability***: In Lleida and Central Catalonia alone, over 9 million tonnes of slurry and manure exist annually, a robust, sustainable resource.

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Scaling Paths: Risk VS Impact

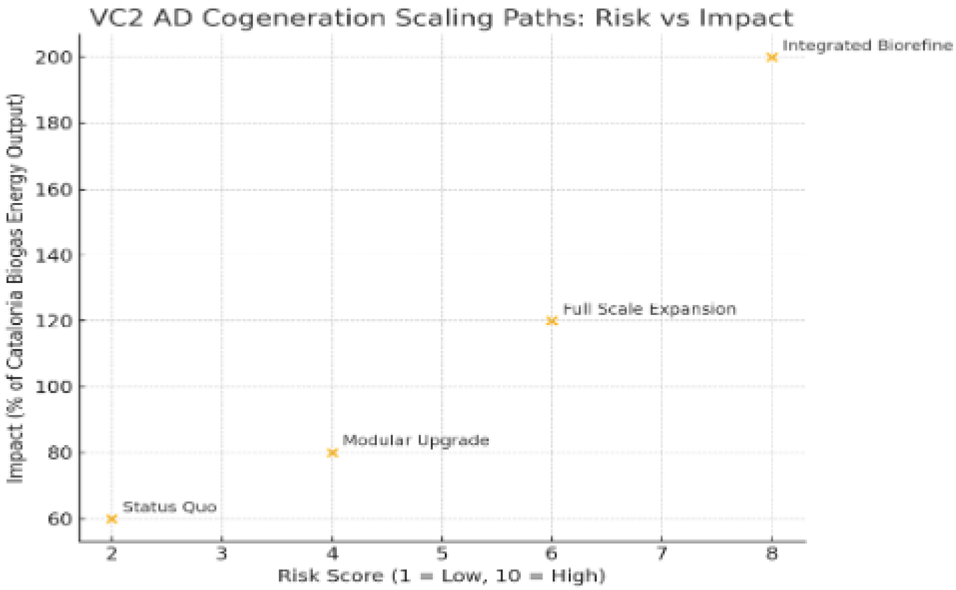

Figure 21. Scaling Paths: Risk VS Impact of the VC2.

The scatter plot illustrates four realistic scaling trajectories for Alcarràs's AD cogeneration hub, showing risk (horizontal axis) against impact (vertical axis as percentage of Catalonia's ~0.5 TWh biogas output):

- ***Status Quo (0.3 TWh → 60% share)***: Risk 2. Maintaining current digester operation carries minimal new risk yet already contributes significantly to regional energy.
- ***Modular Upgrade (0.4 TWh → 80% share)***: Risk 4. Minor expansions (e.g., optimizing engine output, adding heat-to-district links) increase impact with moderate technical and permitting risk.
- ***Full Scale Expansion (0.6 TWh → 120% share)***: Risk 6. Doubling throughput via an additional digester and heat network integration pushes beyond local demand, requiring new partnerships for heat off-take and tighter feedstock contracts.
- ***Integrated Biorefinery (1.0 TWh → 200% share)***: Risk 8. Combining extensive co-digestion, ammonia stripping, pelletized digestate, plus CHP and district heating entails high capex, complex permits, and sophisticated off-takes, yielding the greatest regional impact but also the highest execution risk.

At first, Alcarras can pursue a modular upgrade to achieve 0.4 TWh with manageable risk, enhancing heat utilization through greenhouse partnerships. Once stable, full-scale expansion is considered, pairing with municipal district heating and nutrient recovery systems to secure digestate markets. Reserve the integrated biorefinery concept as a long-term vision contingent on securing large-scale offtake agreements, significant grant funding, and regulatory clearances.

Ground-truth assessment

Realistic Performance Limits

- ***Methane yield:*** Typical pig/cow slurry co-digestion yields ~200–240 m^3 CH_4 per tonne VS (volatile solids). Local slurries average 5–6% VS, so a 70 000 t/y plant can produce ~14 M m^3 CH_4 (≈14 GWh) annually. Attempts to exceed 80 000 t/y risk suboptimal loading rates and digester instability.
- ***Energy recovery***: Reciprocating engines convert biogas to electricity at 35–40% efficiency; heat recovery adds another 45–50%. In Lleida's colder months, heat utilization can drop if no district network is available.

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Key Issues & Barriers

- ***Grid & heat off-take***: Only a handful of local farms have district heating; surplus heat in summer often flared, limiting full energy potential.
- ***Operational upsets***: High ammonia from autumn–winter slurries can exceed 3.5 g NH_4-N/L, inhibiting methanogenesis.
- ***Permit delays***: Odour control requirements under Lleida's provincial ordinances add months to approval.

Opportunities & Mitigations

- ***Seasonal balancing***: Co-digest with up to 10% pruning chips (rich in lignin) to stabilize C:N and improve buffer capacity.
- ***Heat networks***: Partner with nearby greenhouses (e.g., vegetable producers in Segrià) to absorb chill-season heat, boosting utilization to >80%.
- ***Pre-treatment for ammonia***: Install partial ammonia stripping prior to digestion, reducing inhibition and recovering a concentrated ammonium sulfate fertilizer.

VC3: Biomethane from pig slurry

Category	Details
Feedstock Flow & Capacity	Input: Pig slurry (~150,000 t/y potential), agro-industrial residues (e.g., fruit pulp, food waste), co-digestion options. Throughput: Pilot to mid-scale AD facility (~30,000–50,000 t/y).
Technological Feasibility & Limits	Anaerobic digestion is mature but sensitive to feedstock variability and C:N ratio. Biogas and digestate outputs. Risk of inhibition from high ammonia or toxic compounds.
Competitive Landscape	- Some farms operate small digesters. - Industrial-scale AD facilities concentrated near food industry zones (e.g., Girona). - Alcarràs would be first large AD for manure in Lleida region.
Value Proposition (Lleida, Catalonia, Spain)	- Solves pig slurry management challenge in high-density farming area. - Generates renewable energy (biogas) and biofertilizer (digestate). - Supports regional GHG targets and nutrient directives.
Market Applications	- Biogas for grid injection or self-use (heat/electricity) - Digestate for local fertilizer markets - Potential link to green hydrogen (future synergy)
Stakeholders & Value Chain	- Pig producers as key feedstock suppliers - Municipal and energy utilities for grid access - Regional support from climate and energy programs (e.g., ICAEN, BioHubCAT)
Market Dynamics	- Stable long-term outlook due to EU Fit for 55 & RED III directives. - Digestate demand may be seasonal and regulated. - High energy prices increase attractiveness of biogas.
Known Risks	- Operational: Slurry variability, foaming/scaling in digesters. - Regulatory: Environmental permits, digestate classification. - Environmental: Digestate runoff risk; odor complaints. - Economic: Initial CAPEX €3–6M; profitability depends on feed-in tariffs and energy sales. - Social: Public concern over odor, traffic, NIMBY ("Not In My Backyard") opposition possible.

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Products/by-products: Biomethane; digestate

Current Local Demand

- Catalonia now hosts ~8 operational biomethane plants, injecting ~142 GWh/year. Currently represents a small share (<0.4%) of total natural gas use but increasing rapidly.

Market Segments

- ***Industrial users***: Heating, high-temperature processes
- ***Transport fleet***: Heavy-duty/municipal vehicles
- ***Grid injection***: Renewable pipeline supply

5- and 10-Year Projections

- 2027: ~22 operational plants → ~500 GWh/year (Catalonia alone) .
- 2030: Target ~2 TWh/year (×14 growth vs 2025)
- 2035: If growth continues at 20–25% annual CAGR, region could reach ~5 TWh/year—supporting 15–20% of regional gas consumption.

Scalability & Replicability in Lleida & Catalonia

VC3 is highly scalable and replicable across Lleida and Catalonia. Proven case studies confirm the technical and environmental advantages. Backed by strong regional policy, strategic investment, and vast feedstock availability, large-scale biomethane deployment is a realistic next phase in circular bioeconomy. With experienced partners and targeted grants, Alcarràs could lead replication efforts—prioritizing pilot projects before full-scale rollouts to manage risks and community acceptance.

Regional Feedstock & Potential Coverage

- ***Feedstock***: Combines liquid manure (~74,000 t/y at Alcarràs) with slurry and agro-industrial residues—potential feedstock pool easily exceeding 140,000 t/y across nearby farms.
- ***Scale Examples***: Naturgy Vila-Sana plant in Lleida produces ~12 GWh/year from one livestock farm. A larger Torrefarrera project will process ~140,000 t/y to generate ~60 GWh/year, covering ~16,000 homes
- ***Provincial Potential***: Catalonia's AD strategy targets ~2 TWh/year of biomethane by 2030 (~246 MW), enough to supply ~150 plants and reduce 350,000 t CO_2 annually

Capital Costs & Financial Viability

- ***Estimated CapEx***: €10M+ per facility, including upgrading and compression units for ~60 GWh output.
- ***Revenue Streams***:
  - Biomethane sales via grid injection or CNG/LNG vehicle fuel.
  - Digestate marketing as bio-fertilizer.
  - Potential carbon credits.
- ***Market Support***: Catalan government grants (€3M for network injection; €46M aligned to Biogas Strategy) reduce up-front risks
- ***Private investment momentum***: e.g., Naturgy's ~€18M for Torrefarrera; Moeve is investing €600M for 30 plants (~50 GWh each) across Spain, including Catalonia
- ***ROI Prospects***: Large-scale plants (>€10M capex) may achieve IRR in the 10–20% range, depending on incentives and offtake contracts—payback around 7–8 years in strong policy environments.

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Environmental & Social Benefits

- ***GHG Reduction***: Converts methane emissions from livestock slurry into biogenic methane, mitigating CO_2 equivalents. Torrefarrera alone avoids 15,000 t CO_2/year.
- ***Circularity***: Produces renewable energy, returns organic nutrients, and prevents nitrate contamination, supporting EU environmental targets.
- ***Social Impact***: Distributed energy sources enhance regional energy security; creates new skilled jobs; engagement with local cooperatives ensures community benefits.

Drivers Enabling Replication

- ***Policy Framework***: Catalonia's 2024–2030 strategy enables 150 plants via €46M in grants and network support
- ***Technical Validation***: Successful plants (Vila-Sana, Torre Santamaría, Torrefarrera) demonstrate feasibility and profitability
- ***Feedstock Abundance***: Catalonia produces ~9.4 Mt slurry and 2.8 Mt solid manure annually ample for a >10-fold scale-up
- ***Investor Activity***: Moeve, Naturgy, Axpo, Sorigué, Compost Segrià, PreZero, major players funding rollout
- ***Grid Infrastructure***: Nedgia has already connected multiple biomethane plants (e.g., Vila-Sana, Torrefarrera), demonstrating capacity to scale network integration

Scaling Paths: Risk VS Impact

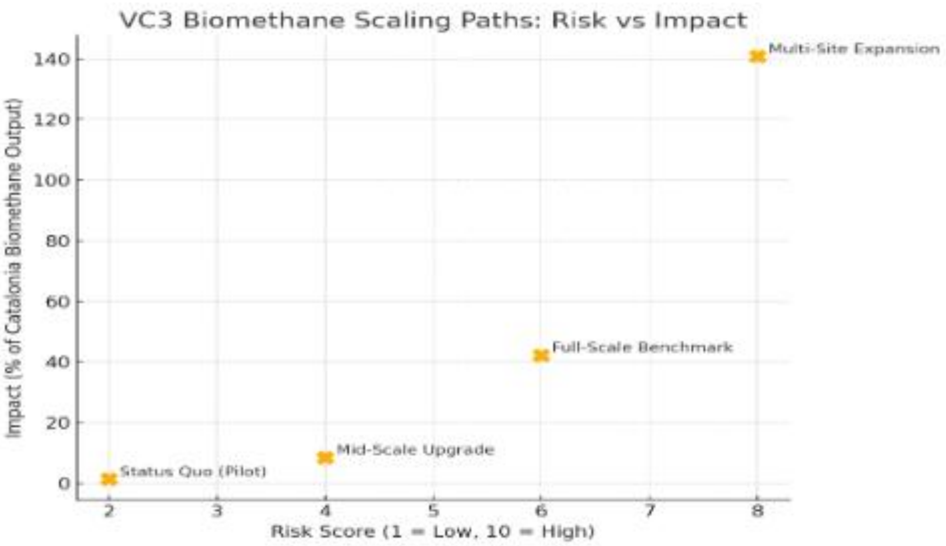

Figure 22. Scaling Paths: Risk VS Impact of the VC3.

The scatter plot above shows four plausible scaling trajectories for VC3, plotting risk against impact (as a percentage of Catalonia's current 142 GWh annual biomethane output):

- ***Status Quo (Pilot, 2 GWh; ~1.5% share)***: Risk Score: 2; Impact: 1.5%. Keeps Alcarràs in pilot injection, minimizing technical and financial exposure.
- ***Mid-Scale Upgrade (12 GWh; ~8.5% share)***: Risk Score: 4; Impact: 8.5%. Mirrors Vila-sana scale. Moderate risk via a small PSA skids and grid tie-in; requires coordination with Nedgia.
- ***Full-Scale Benchmark (60 GWh; ~42% share)***: Risk Score: 6; Impact: 42%, Emulating Torrefarrera's output. High capex, complex permits, but substantial regional impact.

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- ***Multi-Site Expansion (200 GWh; ~140% share)***: Risk Score: 8; Impact: 140% Deploys multiple plants or one large facility akin to Seròs. Very high investment, regulatory hurdles, but positions Alcarràs as a major regional supplier.

Alcarras can start with the mid-scale upgrade to validate operations and secure offtake contracts. Then, progress to the full-scale benchmark once grid connections, financing, and community buy-in are in place. Afterwards, consider multi-site expansion as a long-term ambition, contingent on market growth (towards 2 TWh by 2030 and 5 TWh by 2035) and securing robust grant and private financing packages.

Ground-truth assessment

Realistic Performance Limits

- ***Upgrading capacity***: Small PSA or membrane units top out at ~100 m^3/h; to handle Alcarràs's full potential biogas output (~1 600 m^3/h), multiple parallel trains or larger cryogenic skids are required, dramatically driving CapEx above €10 M.
- ***Injection pressure and quality***: Catalan grid injection demands gas be at 16 bars with <5 ppm H_2S and <2% CO_2. On-site compression to that spec consumes ~8–10% of the biomethane produced.

Key Issues & Barriers

- ***High upfront cost***: Local financing rates (6–8% for rural cooperatives) push payback over 8-10 years without heavy subsidies.
- ***GO feedstock rule***: Spanish GO rules cap vegetal co-digestion at 20%, limiting co-feeding of pruning/residues that could improve yields.
- ***Infrastructure access***: Nedgia's nearest high-pressure line is 5 km from Alcarràs, trench and right-of-way approvals can add 12–18 months and €1–2 M.

Opportunities & Mitigations

- ***Phased roll-out***: Begin with a mobile CNG trailer pilot (100 m^3/h), selling to local fleets; use revenue to de-risk full grid injection build-out.
- ***Lobby for GO flexibility***: Convene a Catalan producer consortium via BioHubCAT to request pilot exemptions for higher-biomass blends.
- ***Public grants & green bonds***: Secure EU Modernisation Fund and/or NextGenerationEU grants earmarked for rural biomethane; combined with green bond issuance (e.g. leveraging local bank CaixaBank's rural fund).

Local and Regional Success Cases

Across Catalonia, a number of projects have blazed trails in organic waste valorization and energy recovery, each offering a distinct governance model, scale and technological twist that helps illuminate where Alcarràs fits into the regional mosaic.

Composting in Segrià and Beyond

Just southwest of Lleida city, the ***Segrià County*** compost plant processes roughly 11 000 tonnes of source-separated municipal organics each year, using open-windrow piles and trommel screens to turn household food

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scraps and landscaping trimmings into a reliable, if mass-market, soil amendment. This facility is overseen by the Consell Comarcal, embodying a public-sector approach to community composting.

Further north, the ***FORM plant at Montoliu*** de Lleida tackles about 15 000 tonnes of organic household waste annually, employing a hybrid static-pile system with covered bays and dedicated leachate tanks. Both Segrià and FORM cater to urban biowaste (selling a generic compost for parks and public gardens),

On-farm, a RAACPUR installation under the ***Grup Carles*** banner demonstrates another path: this compact system treats some 21 600 m^3 of pig slurry directly on the farm, separating solids for fertiliser use and returning cleaned liquid back to fields. Here, nutrient recycling is contained within one operation.

Anaerobic Digestion's Local Front-Runners

In the dairy heartlands near Vallfogona de Balaguer, Axpo Iberia has teamed up with a cooperative of local farmers to run an on-farm anaerobic digester. It converts all the barnyard manure into biogas, powering engines that deliver roughly 12 GWh of electricity per year to farm operations—and feeding any surplus into the regional grid under a PPA. Unlike Alcarràs's multi-stakeholder executive model, this venture is a utility-led setup, optimized for electricity sales with only modest heat recovery. A short drive away, the Torre Santamaría plant operated by Noguera Renovables (a Sorigué–Axpo joint venture) has taken co-digestion to the next level: since 2022 it has been injecting about 26 GWh of upgraded biomethane into the pipeline annually, with expansion underway to more than quadruple that output. This project illustrates the pure biomethane route.

Biomethane Ambitions at Vila-sana, Torrefarrera and Seròs

On the outskirts of Lleida town, the Vila-sana facility operated by Naturgy in partnership with Compost Segrià and Sitra has quietly been injecting around 12 GWh of biomethane into the network each year since mid-2023. Its medium-scale PSA upgrader sits adjacent to the gas mains, a convenience that Alcarràs will need to replicate at greater cost. To the east, the Torrefarrera plant (also a Naturgy-led scheme, this time with Compost Segrià and Servei de Gestió Ramadera) will process some 140 000 tonnes of mixed agri-industrial and livestock residues annually, producing about 60 GWh of renewable gas once fully commissioned. This €18 million investment sets a benchmark for what a regional hub can achieve, dwarfing Alcarràs's pilot-scale ambitions but offering a clear blueprint for phase-two growth. And then there's Seròs, where Enagás has established one of Spain's largest biomethane facilities (300 GWh per year) transforming agri-food by-products at cryogenic scale into grid-grade gas. As a national strategic asset, Seròs sits at the far end of the scale spectrum, while Alcarràs occupies the grassroots niche: a living lab run by farmers, proving the technical and social viability of circular bioeconomy on a human scale before feeding into the grander Catalan energy network.

5.3.2 Living Lab 2: Bio-Silica Lab

VC1: Rice Husk to Pristine Bio-Silica (Thermal route)

Category	Details
Feedstock Flow & Capacity	Input: Rice husk (~20–30 kt/y), sourced mainly from rice-producing areas in southern Portugal. Transported to northern Portugal (CeNTI).
Technological Feasibility & Limits	Mature thermal process (drying, calcination at 500–700 °C, chemical precipitation). Risks: High energy demand in calcination; quality depends on husk uniformity and ash purity; regulatory issues related to ash handling as waste.
Competitive Landscape	• Local: Direct combustion of rice husk for energy (biomass plants).

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	• International: Imports of industrial-grade silica (China, Eastern Europe). • CeNTI's process is among the first in Portugal for bio-based silica valorisation from raw husks.
Value Proposition (North Portugal)	• Diverts agricultural waste to high-value materials. • Supports decarbonization and material circularity. • Enhances technological leadership in sustainable materials in the north.
Market Applications	• Unmodified bio-silica for low to mid-grade applications: fillers in building materials, concrete additives. • Potential future channel: raw input for functionalization (VC3).
Stakeholders & Value Chain	• Rice mills & co-ops (southern Portugal, e.g. COTArroz). • CeNTI (pilot line operation, process control). • Material R&D partners. • Construction material developers.
Market Dynamics	• Increasing EU push to replace synthetic silica with sustainable alternatives. • Initial low-margin market; competitiveness depends on logistics and energy costs. • Export demand possible if cost-effective.
Known Risks	• Operational: Transport costs, variability in husk quality. • Technical: Residual carbon in ash lowers purity. • Regulatory: Waste status of ash and chemicals. • Economic: Profitability hinges on energy price and silica purity.

Products/by-products: Pristine bio-silica

Current Local Demand

- Construction & materials: Northern Portugal (Braga, Ave, Porto) uses several thousand tonnes of silica annually in cement, plaster, and composite materials. Demand for low-carbon fillers is rising slowly, with modest current penetration of bio-based options.
- Agriculture: Limited current demand for silica-based soil amendments, but exploratory uses (e.g., pest resistance, water retention) are under R&D by local agri-coops and universities.

Market Segments

- Eco-construction & cement blending: ~2,000–4,000 t/y (Portugal, potential substitution of imported silica)
- Agricultural soil inputs: <500 t/y (pilot use only)
- Coatings and paints: ~1,000 t/y (regional industrial use)

10-Year Demand Growth Estimate

Driven by EU carbon-neutral construction and green material standards. Potential scale-up supported by construction clusters and green public procurement.

Year	Total Demand (Portugal)
Now (2025)	~3,500–5,000 t
2030 (+7% p.a.)	~7,000–8,000 t
2035 (+7% p.a.)	~10,000–12,000 t

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Scalability & Replicability in Portugal

Feedstock Potential & Coverage

- ***CeNTI Current Scale***: Processes lab/pilot-scale batches (≈2–3 t SiO_2/y) using rice husk sourced from southern Portugal associations (~20–30 kt husk/y capacity).
- ***Expansion Scenario***:
  - Pilot-to-Demo (5–10 t/y): Partnering with a mid-size biomass boiler or rice mill to secure a continuous stream of 200–500 t husk/y could boost output to 50–100 t SiO_2/y.
  - Industrial Scale (100–1,000 t/y): Co-locating a dedicated calcination and sol-gel line near large rice-processing hubs (e.g., Tejo/Sado) could tap up to 5,000 t husk/y, yielding ~1,000 t SiO_2/y.
- ***Replication Potential***: (1) Geographical: Any region in Portugal with >1 kt/y husk (or equivalent agro-residue) could host a VC1 line, e.g., Alentejo (olive pomace), Minho (chestnut shells); (2) Sectoral: The same thermal + sol–gel approach applies to other silica-rich agri-wastes (e.g., oat hulls, sugarcane bagasse ash), broadening replication across Iberia.

Required Investment & ROI Considerations

- ***CapEx Benchmarks***
  - Pilot Unit: €100–200 k for lab-scale furnace, reactors, and drying ovens.
  - Demo Plant (50–100 t/y): €0.5–1 M for a small calciner (500 kg/h capacity), alkaline/acid reactors, effluent treatment.
  - Industrial Module (1,000 t/y): €3–5 M including continuous kiln, automated sol–gel line, and emissions controls.
- ***Revenue Potential***: Pristine bio-silica market prices range €1.5–3 / kg (depending on purity and customer). At 100 t/y → revenues of €150–300 k/y; at 1,000 t/y → €1.5–3 M/y.
- ***ROI***:
  - Demo Scale: Payback in 5–7 years assuming 60% capacity utilization and €2 / kg avg price.
  - Industrial Scale: Payback in 4–6 years with optimized energy use, potential premium for "green" silica, and by-product valorisation (e.g., residual char sold as filler).

Environmental Co-benefits & Monetization

- ***Waste Valorisation***: Converts a largely under-utilized husk (often landfilled or burned) into a marketable material, reducing landfill methane and uncontrolled biomass burning.
- ***Carbon Footprint Reduction***: Substitutes mined or petrochemical silica, cutting embodied CO_2 by up to ~40% per kg of SiO_2.
- ***Monetization***: Carbon Credits under EU ETS for avoided emissions (~0.6 t CO_2-eq per t SiO_2). Circular Economy Grants from Horizon Europe or national RRP funds (covering 30–50% of CapEx).

Replicability Drivers & Enablers

- ***Regulatory Support***: Advancing waste-to-resource frameworks in Portugal to ease ash and husk reuse permits. Green public procurement targets for low-carbon building materials.
- ***Industrial Synergies***: Existing biomass energy plants offering co-location and shared utilities.
- ***R&D & Innovation Networks***: CeNTI's role as an anchor partner in PRIMED and national bio-economy clusters. Technical assistance from ANI and PortugalBIO to de-risk scale-up.
- ***Market Pull***:
  - Emerging demand from construction clusters (prefab concrete) and automotive (Continental's Braga plant) for sustainable fillers.

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- o Early adopters willing to pay a premium for low-carbon materials, helping validate first-of-a-kind demonstrations.

Scaling Paths: Risk VS Impact

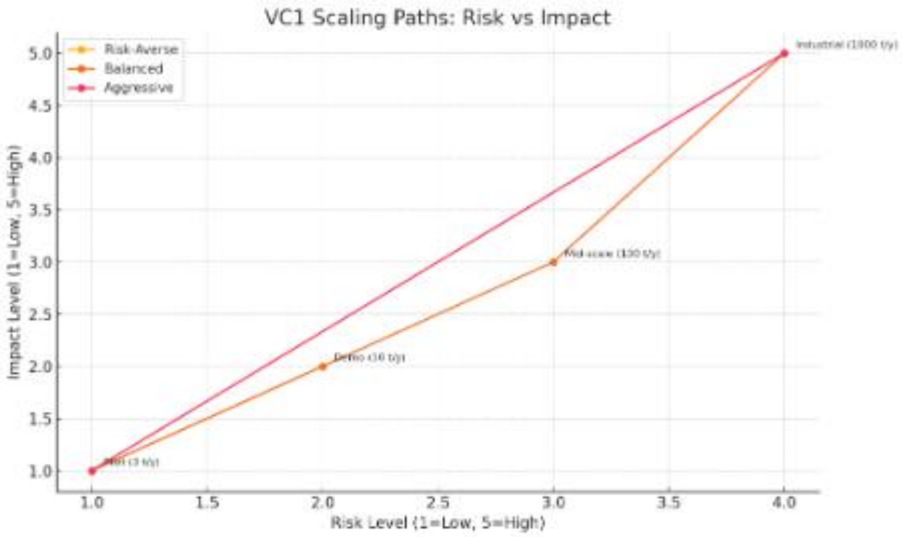

Figure 23. Scaling Paths: Risk VS Impact of VC1 – Llab2.

The chart above illustrates three possible scaling trajectories for VC1 in Northern Portugal, mapped by risk (composite score capturing technical uncertainty, feedstock security, regulatory hurdle, financial exposure, and market adoption risk) against impact (composite score capturing production volume, revenue uplift, and carbon & waste benefits):

- ***Risk-averse path***: Pilot → Demo (3 t/y → 50 t/y) - Low technical and financial risk, moderate impact growth. Ideal for initial de-risking and stakeholder buy-in.
- ***Balanced path***: Pilot → Demo → Mid-scale → Industrial (3 t/y → 50 t/y → 100 t/y → 1,000 t/y). Gradual risk increases with significant cumulative impact. Provides room for learning and process optimization at each stage, aligning investment with market uptake.
- ***Aggressive path***: Pilot → Industrial (3 t/y → 1,000 t/y). Highest risk but fastest route to major impact. Requires substantial upfront investment, strong feedstock and off-take agreements, and robust technical confidence.

Ground-truth assessment

Realistic Performance Limits

- **Silica yield**: 12–18 % of husk mass under optimized lab conditions; industrial yields may plateau at ~15 % after scale-up.
- **Purity ceiling**: ~95 % SiO_2 without additional polishing steps; reaching ≥99 % (electronics grade) requires extra purification and significantly higher cost.
- **Energy use**: ~1.8–2.5 MWh per tonne of silica (mostly in calcination), with limited reduction (<10 %) achievable through heat integration in near-term projects.

Key Issues & Barriers

- ***High energy & emissions***: Calcination at 500–700 °C drives both operational costs and CO_2/NOx emissions.

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- ***Feedstock logistics***: Rice husk must be trucked ~250 km from south to north, adding ~€20–30/t in transport.
- ***Ash handling & waste status***: Post-calcination ash classification as "waste" triggers separate permits and disposal costs if not fully valorised.
- ***Market entry***: Construction and cement sectors have established supply chains for synthetic silica; requires proof of performance and consistent supply.

Opportunities & Mitigations

- ***Heat integration***: Co-locating with biomass boilers can recover flue heat to pre-dry husk, cutting energy use by ~15 %.
- ***Carbon credits & grants***: Monetize ~0.6 t CO_2-e avoided per t SiO_2 via EU ETS, and secure 30–50 % capex grants under RRP or Horizon.
- ***Local co-production hubs***: Partner with Porto-Ave construction clusters to pilot on-site calcination units, reducing transport.
- ***Phased certification***: Target mid-grade markets (concrete, fillers) first before pursuing high-purity electronics grade.

VC2: Rice Husk to Pristine Bio-Silica (Chemical route)

Category	Details
Feedstock Flow & Capacity	Input: Rice husk ash (~10–15 kt/y) sourced from local biomass energy plants in central or northern Portugal. Lower transport and processing intensity.
Technological Feasibility & Limits	More energy efficient as it uses pre-calcined feedstock.Risks: Ash quality highly variable depending on combustion temperature; some ash may contain crystalline silica (less useful); trace contaminants.
Competitive Landscape	• Competes with direct ash disposal or use in low-value concrete fillers. • Few local players valorising ash for silica extraction. • Technology is less proven at scale compared to VC1.
Value Proposition (North Portugal)	• Circular valorisation of waste ash from existing biomass infrastructure. - Reduces dependency on virgin or imported silica. • Contributes to decarbonization goals via lower process energy.
Market Applications	• Unmodified silica for construction sector, binders, and potentially ceramics. • Intermediate feedstock for VC3 functionalization.
Stakeholders & Value Chain	• Biomass energy producers and boiler operators. • CeNTI (process development, lab validation). • Local environmental authorities for waste-to-resource transition.
Market Dynamics	• Fluctuating ash quality poses challenge for standardization. • Rising EU support for secondary raw materials. • Needs stable offtake markets to scale.
Known Risks	• Technical: Crystalline content or heavy metal contamination. • Regulatory: Classification of ash as waste may block reuse. • Market: Lower acceptance vs. traditional additives. • Environmental: Residue handling and leaching risk.

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Products/by-products: High-purity silica

Current Local Demand

- Construction & ceramics: Small-scale local use of ash in cement and ceramics. Demand for chemically extracted silica is currently low but increasing with stricter landfill restrictions and interest from industrial symbiosis zones in the north.
- Waste valorisation: Biomass power plants (Braga, Viana do Castelo) produce rice husk ash with limited current valorisation (opportunity to provide services and reduce disposal costs).

Market Segments

- Cement additives & low-carbon binders: ~1,500 t/y
- Ceramic fillers and glass industries: ~1,000 t/y
- Biomass plant byproduct recovery: ~800 t/y (service market)

10-Year Demand Growth Estimate

Tied to decarbonisation of the construction sector and biomass sector regulation. Functional fillers and co-product reuse are likely to expand with the EU push for a circular economy.

Year	Total Demand (Portugal)
Now (2025)	~3,500–5,000 t
2030 (+7% p.a.)	~4,000–4,500 t
2035 (+7% p.a.)	~5,300–6,000 t

Scalability & Replicability in Portugal

Feedstock Potential & Coverage

- ***CeNTI Current Scale***: Lab-scale R&D: ~1–2 t SiO_2/y using ash from partner biomass boilers.
- ***Expansion Scenario***:
    - Demo (20–50 t/y): Secure dedicated ash streams (500–1,000 t ash/y) from one or two biomass plants in Braga/Viana do Castelo.
    - Industrial (500 t/y): Co-locate extraction units at multiple biomass facilities, aggregating 10,000 t ash/y to yield ~2,000 t SiO_2/y (operating at 25% capacity).
- ***Replication Potential***: Any region with biomass-to-energy plants (e.g. Alentejo straw boilers, Algarve olive-pomace combustors) can adopt VC2 modules. Variant feedstocks (eucalyptus ash, wood-chip ash) can feed the same sol–gel line with minor adjustments.

Required Investment & ROI Considerations

- ***CapEx Benchmarks***
    - Pilot skid (€50–100 k): Small reactors, neutralization tank, filter press.
    - Demo plant (€300–500 k): 100 kg/h continuous solubilizer, precipitation tanks, dryer, effluent treatment.
    - Industrial module (€1–2 M): 1 t/h extraction line, modular reactors, automated solids handling, emissions control.
- ***Revenue Potential***: Market price for mid-grade silica: €1.2–2.0 / kg. Demo (50 t/y) → €60–100 k / year; Industrial (500 t/y) → €600 k–€1 M / year.

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- ***ROI***:
  - Demo: 5–8-year payback at 70% utilization, assuming avoided ash disposal fees (~€20 / t) plus silica sales.
  - Industrial: 4–6-year payback when capturing both silica revenues and waste-treatment savings; premium if sold as "circular" filler.

Environmental Co-benefits & Monetization

- ***Waste Diversion***: Diverts 100–10,000 t/y of ash from landfills, cutting disposal costs and associated CO_2/methane.
- ***Lower Energy Footprint***: Bypasses calcination; estimated 30–50% energy savings vs. VC1.
- ***Effluent Valorization***: Neutralization salts can be recycled (e.g. gypsum coproduct), possibly creating additional revenue streams.
- ***Monetization***:
  - Waste-treatment credits: Avoiding disposal fees (~€20–30 / t ash) improves margins.
  - Circularity incentives: National grants (P2020) and carbon credits for waste valorisation (~0.2 t CO_2-eq per t ash processed).

Replicability Drivers & Enablers

- ***Regulatory Trends***: EU Circular Economy Action Plan pushing for ash reuse; Portugal updating waste regulations to ease permitting for valorisation facilities.
- ***Industrial Synergies***: Biomass plant operators keen to reduce ash handling costs; potential for take-or-pay ash supply contracts.
- ***Funding & Clusters:*** PortugalBIO and ANI offering co-funding for secondary raw material projects. Horizon Europe calls for "Industrial Symbiosis" clusters that support VC2 replication.
- ***Technical Support***: CeNTI's process know-how can be licensed; simple modular skid design facilitates plug-and-play deployments.

Scaling Paths: Risk VS Impact

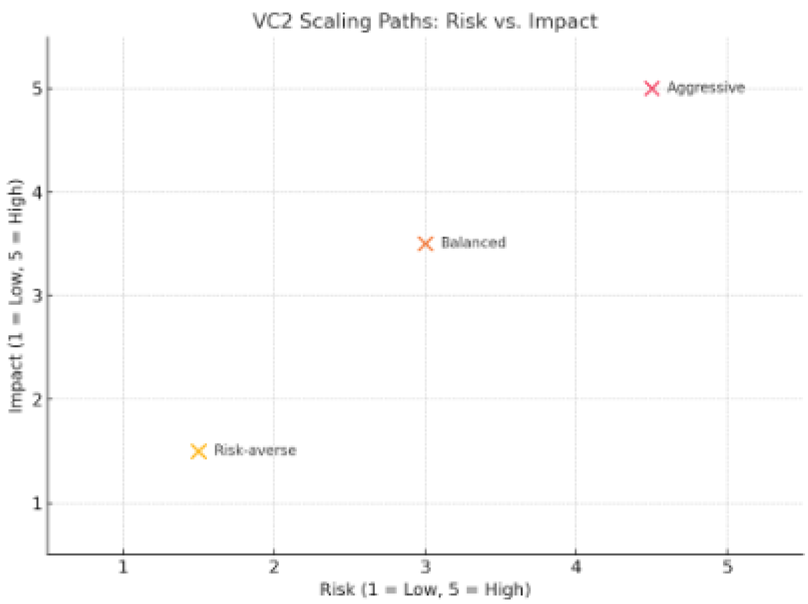

Figure 24. Scaling Paths: Risk VS Impact of VC2 LLab2

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The chart above illustrates three possible scaling trajectories for VC2 in Northern Portugal, mapped by risk (composite score reflecting technical uncertainty, feedstock security, regulatory hurdles, financial exposure, and market adoption risk) against impact (production volume, revenue potential, and environmental benefit):

- ***Risk-averse path***: Pilot → Demo (3 t/y → 30 t/y). Technically conservative and financially manageable. Prioritizes small-batch supply for R&D or specialty applications, with limited market or environmental impact.
- ***Balanced path***: Pilot → Demo → Mid-scale → Industrial (3 t/y → 30 t/y → 150 t/y → 600 t/y). Allows for gradual technical maturation and iterative customer validation, while unlocking significant gains in revenue and landfill/circularity impact.
- ***Aggressive path***: Pilot → Industrial (3 t/y → 600+ t/y). Fastest route to becoming a bulk supplier for construction, coatings, and green agri-inputs. High upfront investment and customer commitment required but enables substantial carbon and resource circularity benefits early on.

Ground-truth assessment

Realistic Performance Limits

- ***Silica yield***: 8–12 % of ash mass (ash typically 20–25 % SiO_2), with yields up to ~10 % practical at scale.
- ***Purity ceiling***: ~90–94 % SiO_2 without extensive acid/base recycling; ash contaminants (K, Ca) limit purity.
- ***Energy use***: ~0.8–1.2 MWh/t SiO_2, mainly for pumping, heating to ~80 °C, and drying—30–50 % lower than VC1.

Key Issues & Barriers

- ***Ash variability***: Combustion parameters vary by plant, causing inconsistent ash mineralogy and silica extractability.
- ***Waste classification***: Raw ash is "waste", requires environmental permits even for valorisation.
- ***Effluent management***: Neutralizing acidic lixiviate produces gypsum or salt by-products that need outlets.
- ***Limited awareness***: Few local end-users recognize ash-derived silica as a drop-in substitute, slowing adoption.

Opportunities & Mitigations

- ***Modular extraction skids***: Deploy standardized 100 kg/h reactors that can be co-located at multiple plants to average out ash variability.
- ***Effluent valorisation***: Sell gypsum coproduct to cement or construction-materials producers, offsetting treatment costs.
- ***Regulatory engagement***: Work with regional environmental agencies to classify valorised ash as "by-product" not "waste," streamlining permitting.
- ***Pilot partnerships***: Collaborate with a local concrete-block manufacturer to demonstrate performance parity and secure first commercial offtake.

VC3: Pristine Bio-Silica to Functionalized Bio-Silica

Category	Details
Feedstock Flow & Capacity	Input: Pristine bio-silica from VC1 and VC2 (~5–10 kt/y potential). Small-volume, high-value process stream.

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Technological Feasibility & Limits	Emerging functionalization techniques (chemical surface treatments, doping with additives). Risks: Surface modification reactions require precise control and may involve hazardous chemicals; upscaling not fully proven.
Competitive Landscape	• Competes with synthetic silica (Evonik, Wacker) in EU. • Novel bio-silica functionalization has limited direct competition locally. • Portuguese industry still early-stage in applying these materials.
Value Proposition (North Portugal)	• Enables high-value applications across industrial sectors. • Differentiates CeNTI as a developer of circular performance materials. • Strong link with regional innovation ecosystem.
Market Applications	• Functional additives for: automotive composites (e.g., Continental, Braga), textile coatings (technical fabrics), battery materials, cosmetics. • Exports likely, as local market is small but growing.
Stakeholders & Value Chain	• CeNTI (R&D and lab-scale functionalization). • Automotive suppliers, textile clusters, battery tech startups. • National and EU R&D funders (e.g., Horizon, PRR).
Market Dynamics	• Rising demand for eco-advanced functional materials. • Niche markets with strong margins but high technical requirements. • Early-stage—market shaping still underway.
Known Risks	• Technical: Scaling surface modification without performance loss. • Market: Uncertainty about user acceptance and qualification. • Regulatory: Use of surface agents and toxicology approval. • Economic: Cost per kg may be high without process optimization.

Products/by-products: Surface-modified bio-silica

Current Local Demand

- Very low, but strategically significant. Demand is emerging in coatings, composites, advanced textiles, and battery research. Northern Portugal is a growing hub for innovation in these fields (CeNTI, INL, Fibrenamics, Universidade do Minho, and companies like Continental, Bosch).
- Active co-development interest from coatings and polymer formulators exists but is still pre-commercial.

Market Segments

- Functional coatings (hydrophobic, barrier, antibacterial): ~500 t/y (R&D, industrial pilots)
- Advanced composites & automotive: ~300 t/y
- Battery materials & energy storage: <200 t/y (early-stage)
- Functional textiles & packaging: ~100–200 t/y (niche)

10-Year Demand Growth Estimate

Driven by EU R&D investments, battery sector expansion, and functional surface technology development. Expected CAGR >15%, especially in coatings and batteries.

Year	Total Demand (Portugal)
Now (2025)	~1,000 t
2030 (+7% p.a.)	~2,000 t
2035 (+7% p.a.)	~4,000 t

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Scalability & Replicability in Portugal

Feedstock Potential & Coverage

- ***CeNTI Current Scale***: R&D batches: ~100–200 kg functional silica/y for pilot testing.
- ***Expansion Scenario***:
  - Demo (1–2 t/y): Install bench-scale functionalization reactors (5–10 kg/batch) to serve local industrial pilots.
  - Industrial (10 t/y): Deploy 100–200 kg/batch continuous surface-treatment units, sourcing 20–50 t pristine silica/y from VC1/VC2 lines.
- ***Replication Potential***: Any region with chemical-processing capability (e.g. Setúbal, Porto chemical parks) can host VC3 modules. Functionalization recipes are agnostic to raw silica source, which enables replication across Europe.

Required Investment & ROI Considerations

- ***CapEx Benchmarks***
  - Lab skid (€100–150k): Glass-lined reactors, dosing pumps for silanes/biocides, spray or tray dryers.
  - Demo unit (€500–800 k): 20 kg/h surface-activation line, solvent recovery, safety systems.
  - Industrial plant (€1.5–3 M): 200 kg/h continuous functionalization reactors, automated loading/unloading, integrated QC lab.
- ***Revenue Potential***: Specialty silica prices: €5–15 / kg (depending on function). Demo (2 t/y) → €10–30 k / year; Industrial (10 t/y) → €50–150 k / year (early volumes), growing as scale improves.
- ***ROI***:
  - Demo: 6–9-year payback, given high initial R&D costs and slow market uptake.
  - Industrial: 4–7-year payback once anchor clients (e.g. Continental, technical textile firms) sign offtake agreements.

Environmental Co-benefits & Monetization

- ***Material Efficiency***: Adds high-value function without large additional energy inputs.
- ***Chemical Recycling***: Solvent and silane recovery loops reduce VOC emissions and raw-material waste.
- ***Downstream Sustainability***: Products enable end-users to reduce chemical loads (e.g. less frequent coating re-application), extending product life.
- ***Monetization***:
  - Eco-labels & Premium Pricing: “Bio-functional” claim can command 10–30% price premium.
  - Innovation Grants: Access to SME Instrument funds, PRR innovation vouchers, and green innovation tax credits.

Replicability Drivers & Enablers

- ***Market Pull***: Industrial clusters (mobility, textiles, energy storage) in the North actively seeking advanced materials.
- ***Regulatory & Certification Support***: Growing demand for REACH-compliant, RE-usable chemistries; positive alignment with EU Green Deal and new materials regulation.
- ***Modular Design***: Standardized reactor skids and treatment modules enable “copy-paste” expansion to other chemical parks or industrial zones.

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Scaling Paths: Risk VS Impact

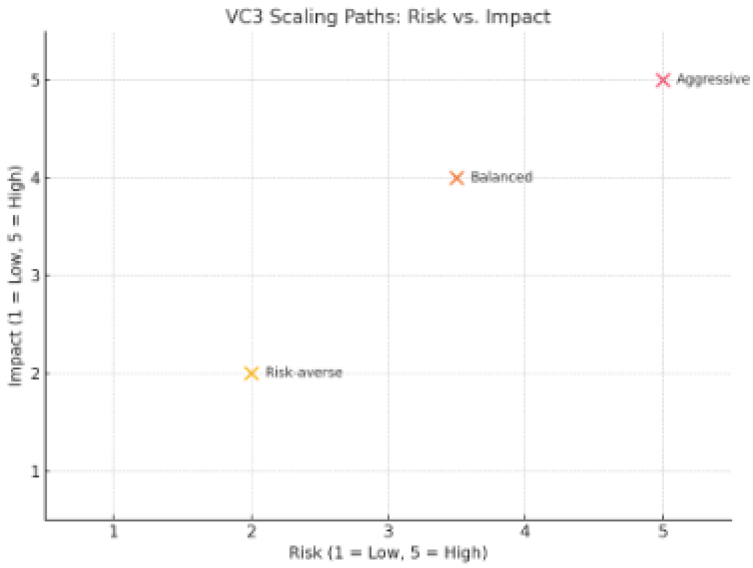

Figure 25. . Scaling Paths: Risk VS Impact of VC3 LLab2

The chart above maps three possible scaling trajectories for VC3 (in Northern Portugal, using the same composite scoring method as VC2:

- ***Risk-averse path***: Pilot → Limited prototyping (2 t/y → 20 t/y). Focuses on controlled applications such as R&D composites or academic-industry collaborations. Risk is relatively low but so is the systemic impact.
- ***Balanced path***: Pilot → Demo → Application-scale rollout (2 t/y → 20 t/y → 100–200 t/y). Aligns with gradual validation in electronics, automotive, or packaging applications. Unlocks moderate impact while balancing cost, technical maturity, and adoption challenges.
- ***Aggressive path***: Pilot → Industrial (2 t/y → 500+ t/y). Fast-track scale-up to deliver functionalized silica for regional and EU-level composites markets. Highest risk due to technical customization needs and buyer integration hurdles but enables CeNTI to anchor a high-value innovation ecosystem in Portugal's materials sector.

Ground-truth assessment

Realistic Performance Limits

- ***Batch size***: 50–100 kg/batch in pilot reactors; continuous lines could reach 200–300 kg/day with modular design.
- ***Functional loading***: Surface modification <10 wt % active agent (e.g., silanes, biocides) before agglomeration or performance loss.
- ***Cost floor***: ~€5–8/kg of functionalized silica at small scale; economies of scale may reduce cost by ~30 % at 10 t/y.

Key Issues & Barriers

- ***Chemical handling & safety***: Use of volatile silanes or biocides requires specialized ventilation and worker training, raising CapEx.
- ***Product consistency***: Ensuring uniform surface coverage in each batch is challenging. Minor deviations can impair hydrophobic or antimicrobial performance.
- ***Regulatory approval***: Certain functional additives (e.g., nano-biocides) may trigger REACH or biocide-product registration, adding time and cost.

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- ***Market qualification***: End-users (e.g., Continental, coatings firms) require multi-month validation cycles before approval.

Opportunities & Mitigations

- ***Solvent recovery loops***: Implement closed-loop solvent/vapor recovery to reduce emissions and raw-material costs by ~20 %.
- ***In-line analytics***: Deploy real-time particle-size and surface-chemistry sensors to guarantee batch consistency and speed up QC.
- ***Pre-certification tracks***: Engage with notified bodies early to pursue low-toxicity silane chemistries that expedite REACH registration.
- ***Anchor client programs***: Co-develop proprietary formulations with one or two "lead adopters" under joint IP agreements to secure early revenue and references.

5.3.3 Living Lab 3: Liguria Bio-Lab

VC1: Fish By-catch → Agricultural Biostimulant (Fermentation)

Category	Details
Feedstock Flow & Capacity	Input: Unmarketable fish by-catch from Ligurian coastal fisheries. Volume depends on seasonality and fishing zones. Requires rapid processing (<24h).
Technological Feasibility & Limits	Fermentation is technically feasible at small scale. Risks: protein variability affects product consistency; logistics constraints (mountainous/coastal roads); spoilage risk if delayed.
Competitive Landscape	• Imported fish-based fertilizers • Seaweed biostimulants • Synthetic fertilizers • The model is unique in valorizing local fish discards with a circularity narrative.
Value Proposition (Liguria)	• Provides added income stream for small-scale fishers • Creates circular input for regional agriculture • Aligns with regional agroecological branding ("Liguria DOP")
Market Applications	• Terrace olive and citrus groves • Greenhouse vegetables in Piana di Albenga • Potential for organic agriculture and floriculture across Liguria
Stakeholders & Value Chain	• Fisher cooperatives • Fermentation operators (mobile or centralized) • Farmers • Local support from regional innovation hubs (e.g., FILSE)
Market Dynamics	• Organic input demand rising in Italy (~€300M/y) • Premium biostimulants can command higher prices • Requires product standardization for broader uptake
Known Risks	• Operational: spoilage risks, seasonal variability • Regulatory: ABP classification risks • Economic: viability depends on scale/logistics • Social: community trust needed for cooperative pooling

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Products/by-products: Fish-based Biostimulant (Fermented)

Current Local Demand

- Agriculture: Liguria's coastal and inland agriculture is characterized by high-value, low-volume production (e.g., olives, citrus, wine grapes). Demand for biostimulants is limited but growing, particularly in organic and terraced farming systems seeking to improve resilience to drought and pests. Existing use of organic fertilisers is fragmented and often imported (e.g., seaweed or fish emulsion from Northern Europe).
- Floriculture & nurseries: The Albenga plain hosts Italy's second-largest cluster of ornamental plant producers. There is moderate interest in sustainable inputs, especially those improving root development and resistance to stress. Adoption is hindered by lack of standardized, locally certified biostimulants.

Market Segments

- ***Terrace and hillside farming*** (olive, vines, citrus): ~1,000–1,500 t/y potential substitution of synthetic/chemical fertilisers with organic alternatives.
- ***Greenhouse vegetable***s (Albenga): ~500–800 t/y estimated potential use, especially in transition to IPM/organic.
- ***Nurseries and ornamental producers***: ~300–500 t/y, particularly for rooting agents and plant tonics.

10-Year Demand Growth Estimate

Growth driven by EU Farm-to-Fork strategy, increasing organic certification, and regional branding. Uptake depends on regulatory clearance and demonstration of agronomic performance.

Year	Total Local Demand
2025	~1,800–2,500 t
2030 (+8% p.a.)	~2,700–3,700 t
2035 (+8% p.a.)	~4,000–5,400 t

Scalability & Replicability in Liguria

Feedstock Potential & Coverage

- ***Current Potential***: Small-scale fishers in Liguria land several hundred tonnes per year of non-commercial by-catch, discards, and processing residues. The fragmented landing sites (e.g., La Spezia, Savona, Imperia) complicate centralized sourcing.
- ***Expansion Scenario***: Pilot Scale (50–100 t/y product): Collecting ~300–500 t/y of fish residues from 3–4 fishing cooperatives. Mobile fermentation units co-located at port or cooperative hubs could ensure freshness.
- ***Demo Scale*** (500–1,000 t/y): Requires regional fishery waste collection network and basic preprocessing (grinding, acidification). Could serve much of Liguria's organic/peri-urban agriculture.
- ***Replication Potential***: Replicable in coastal regions with small-scale fisheries (e.g., Campania, Puglia, Sicily), each producing 500–2,000 t/y of by-catch. Could extend to other protein-rich waste streams (e.g., mollusk shells, shrimp heads, crustacean processing waste) using the same fermentation principles.

Funded by the European Union

Required Investment & ROI Considerations

- ***CapEx Benchmarks***:
  - Pilot Unit (50–100 t/y): €150–250k for shredders, fermentation tanks (5–10 m^3), pH control, and odor management.
  - Demo Plant (500–1,000 t/y): €0.8–1.5M including preprocessing, controlled fermentation, and basic formulation/filling line.
  - Industrial Scale (2,000–5,000 t/y): €3–4M including full automation, effluent treatment, and cold chain logistics.
- ***Revenue Potential:***
  - Market prices range from €1.0–2.0 / kg, depending on nitrogen content and certification (organic use). At 500 t/y → €500k–€1M/y. At 2,000 t/y → €2–4M/y.
- ***ROI***
  - Demo Scale: Payback in 5–8 years at 60–70% capacity utilization and €1.5 / kg selling price.
  - Industrial Scale: Payback in 4–6 years if supported by certification, contracts with agri-coops, and low-cost feedstock sourcing.

Environmental Co-benefits & Monetization

- ***Waste valorisation***: Utilizes protein-rich discards that are otherwise dumped or turned into low-value fishmeal. Helps reduce marine pollution.
- ***Carbon footprint reduction***: Avoids emissions from landfill or incineration; replaces synthetic nitrogen-based inputs (~2.5–4 kg CO_2-eq saved per kg fertiliser)
- ***Monetization***: Potential inclusion in circular economy credits (e.g., Italian NRRP support for bioeconomy demonstrators). Horizon Europe or Interreg Med funds may support community-led resource valorisation models.

Replicability Drivers & Enablers

- ***Regulatory support***: Italy's waste reuse laws allow fish residues to be processed under certain ABP (Animal By-product) categories if used in agriculture. A clear classification and sanitary control protocol is needed.
- ***Industrial synergies***: Fishermen's cooperatives can anchor collection; existing agri-coops and fertilizer blenders (e.g., in Piana di Albenga) can integrate product into supply chains.
- ***R&D networks***: Collaboration with Ligurian universities (e.g., University of Genoa), CREA, and regional innovation clusters (e.g., Blue Economy Hub in La Spezia).
- ***Market pull:***
  - Organic agriculture growth and pressure to reduce synthetic inputs.
  - Brand advantage for "Ligurian sea-to-soil" bioproducts linked to PDO crops.
  - Municipal green procurement (e.g., for parks) may support initial demand.

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Scaling Paths: Risk VS Impact

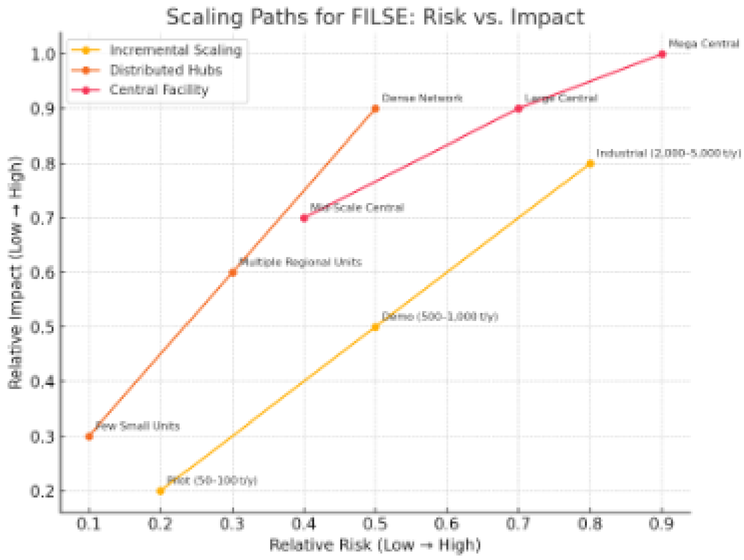

Figure 26. Scaling Paths: Risk VS Impact of VC1 LLab3.

The chart above maps three distinct scaling paths for FILSE's fish-bycatch biostimulant value chain, plotting relative risk (x-axis) against relative impact (y-axis). Risk and impact are quantified by scoring each scaling stage across four equally-weighted dimensions (operational complexity, capital intensity, regulatory uncertainty, supply-chain fragility for risk; throughput, geographic coverage, economic value-added, and environmental benefit for impact).

Incremental Scaling

Start small with a single pilot fermenter at one cooperative, then progressively step up capacity in rounds, from a few dozen tonnes per year up to several thousand. Best for organizations with limited funding, cautious governance, or early-stage technology readiness looking to de-risk before large investments.

- ***Stages & Features***:
  - Pilot (50–100 t/y): Deploy a single mobile or containerized fermenter at Santa Margherita harbour. Test stakeholder coordination, logistics and preliminary agronomic trials.
  - Demo (500–1,000 t/y): Add a second fermenter or upgrade tank volume; bring in 2–3 additional fishers' cooperatives as suppliers. Formalize quality-control protocols; begin modest sales to local farms.
  - Industrial (2,000–5,000 t/y): Invest in custom-built, on-shore fermenter hall; integrate preprocessing (grinding, buffering) and packaging lines. Secure long-term offtake agreements with agri-co-ops and extension services.
- ***Pros:***
- Minimizes upfront capital and operational complexity.
- Ideal when regulatory pathways are still fluid.
- Builds credibility stepwise, easing stakeholder buy-in and co-investment.
- ***Cons:***
- Slow to reach meaningful regional impact or economies of scale.
- Per-unit costs remain high at a small scale; may rely on subsidies longer.
- Risk that pilot learnings don't translate neatly to larger configurations.

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Distributed Hubs

Establish multiple small-to-medium fermenters co-located with fishing cooperatives across several Ligurian ports—creating a network of "micro-plants" rather than one central unit.

- ***Stages & Features:***
    - Few small units: 2–3 sites, each processing ~100 t/y; keeps transport short and leverages local buy-in.
    - Multiple regional units: Scale to 4–6 sites, each ~200–300 t/y; standardize equipment and protocols across hubs.
    - Dense network: 8–10+ sites covering all major landing points; aggregate marketing under a regional "Blue Bio-Liguria" brand.
- ***Pros:***
- Keeps feedstock fresh, fewer spoilage losses and lower odor risk.
- Engages cooperatives directly, spreading ownership and local benefits.
- Builds resilience: if one site has issues, others continue.
- ***Cons:***
- Higher cumulative CapEx and O&M overhead (multiple sites to manage).
- Complexity in standardizing quality across disparate locations.
- Requires stronger coordination, training and remote monitoring systems.

Central Facility

Consolidate all feedstock into one or two large-scale fermentation plants strategically located (e.g., near Genoa) to maximize economies of scale.

- ***Stages & Features:***
- Mid-scale central (500–1,000 t/y): First dedicated facility with on-site preprocessing, multi-tank fermenters, basic QC lab.
- Large central (2,000–3,000 t/y): Expand tank farm, install automated mixing, thermal control and formulation lines.
- Mega central (5,000 t/y+): Full automation, integrated waste-water treatment, on-site packaging, and dedicated logistics hub.
- ***Pros:***
- Lowest per-unit cost once at scale.
- Easier to implement uniform quality controls and certifications.
- Better suited for national distribution and larger contracts.
- ***Cons:***
- High initial CapEx and longer payback horizon.
- Elevated logistics risk must transport perishables from coast in <24 h.
- Single-point failure risk: if the facility goes offline, the entire network stalls.

Ground-Truth Assessment

Realistic Performance Limits

At pilot scale, a single 5–10 m^3 fermenter can process roughly 50–100 t of wet fish discards per year, yielding about 25–35 % liquid biostimulant by weight. Each fermentation batch requires 7–10 days (including settling and formulation), capping vessel turnover at approximately 30–40 cycles annually. Beyond ~500 t/y (demo scale) or ~2,000 t/y (industrial scale), vessel volumes exceed 100 m^3 or require multiple units, adding engineering complexity. Cold-chain storage further limits shelf life: unformulated fermentate retains full activity for only 4–

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6 weeks under refrigeration. Finally, to avoid spoilage and odor issues, all feedstock must reach the fermenter within 24 h, practically constraining sourcing to a ~50 km radius unless mobile units are deployed.

Key Issues & Barriers

- ***Feedstock variability***: Species mix and protein solids in by-catch fluctuate by season and location, making it challenging to deliver a consistent NPK and amino-acid profile.
- ***Logistics & timing***: Liguria's narrow coastal roads and unpredictable weather can delay transport, risking spoilage or community odor complaints.
- ***Regulatory uncertainty***: Local authorities may apply EU Animal By-Products rules (Regulations 1069/2009 & 142/2011) more stringently than the Waste Framework Directive intends, potentially classifying the fermentate as a hazardous waste rather than an agricultural input.
- ***Technical scale-up***: Moving from bench- or batch-scale (<10 m^3) to >100 m^3 fermenters demands robust mixing, pH and temperature control systems, and local expertise is limited.
- ***Market acceptance***: Farmers in Liguria are unfamiliar with fish-based biostimulants and require convincing field-trial data, organic certification, and hands-on training before adoption.
- ***Financing & skills***: FILSE and the fishing cooperatives have strong coordination capabilities but lack in-house business development experience and clear ROI cases to attract private investors for demo or industrial units.

Opportunities & Mitigations

- ***Standardizing feedstock quality***: Implement rapid on-site assays (e.g., refractometers or protein test strips) to guide batch blending into standardized "lots" before fermentation.
- ***Overcoming logistics bottlenecks***: Mobile fermentation containers can park directly at landing sites during peak seasons, eliminating long hauls. Schedule these units on weekly circuits, in collaboration with port authorities for priority docking and refrigerated support.
- ***Clarifying regulatory pathways***: Early engagement with regional veterinary and waste-management agencies can co-create a compliant ABP-Category 3 protocol under the Waste Framework Directive. Prepare a concise sanitary dossier detailing microbial kill-steps, quality controls, and end-product safety, to fast-track local approvals and avoid misclassification.
- ***Building farmer trust and adoption***: Partner with Slow-Food Liguria and agricultural research institutes to run side-by-side trials on terraces and greenhouse plots.

5.3.4 Living Lab 4: BioEire Lab

VC1: Biochar Production via Pyrolysis of Forest and Sawmill Residues

Category	Details
Feedstock Flow & Capacity	Input: Forestry residues (branches, tops) and sawdust from sawmills in Tipperary and surrounding counties. Sawmill residues are more consistent in quality and moisture content. Forestry residues may require chipping and drying. Feedstock volumes are seasonal and spatially dispersed, transport cost sensitive.
Technological Feasibility & Limits	Pyrolysis is commercially available (TRL 8–9). Mobile or small-scale modular units exist. Process is technically mature for both dry sawdust and pre-treated forest residues. Limits: drying infrastructure needed for forest biomass; varying ash content may affect biochar properties; heat valorization needs integration.

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Competitive Landscape	• Wood residues already used for pellets, bedding, combustion. • Competing biochar applications are emerging but still limited. • Local demand for biochar is underdeveloped. • Few producers currently active; carbon credit market still immature.
Value Proposition (Tipperary)	• Adds value to low-grade forestry by-products. • Potential to support soil carbon and water retention on livestock farms. • Aligns with Ireland's Climate Action Plan and Just Transition in Midlands. • Supports circular use of local biomass streams.
Market Applications	• Soil amendment for silage and grassland systems. • Bedding additive in dairy operations to reduce ammonia. • Compost and organic fertilizer improvement. • Potential niche use in water filtration or green infrastructure.
Stakeholders & Value Chain	• Forestry owners (Coillte, private landowners) • Sawmills (ECC Timber, etc.) • Energy and biomass cooperatives (e.g., Tipperary Energy Agency) • Farmers (livestock/dairy), agricultural consultants • Bioeconomy Campus at Lisheen, Teagasc, BiOrbic
Market Dynamics	• Growing national interest in regenerative and climate-smart agriculture. • CAP subsidies for carbon farming could boost biochar market. • Few established buyers; requires awareness-building and standardization. • Initial sales may rely on local demonstration pilots.
Known Risks	• Operational: feedstock logistics, drying bottlenecks, continuous supply challenges. • Regulatory: end-of-waste and product certification lacking. • Economic: market demand uncertain without incentives; small-scale operations may struggle. • Social: low awareness among farmers, need for agronomic trials and outreach.

Products/by-products: Biochar

Current Local Demand

- ***Agriculture***: Tipperary's mixed livestock and grassland-based farms are increasingly open to alternatives that improve soil health and fertility. Biochar usage is emerging in pilot trials for soil remediation, nutrient retention, slurry treatment, and as a peat substitute.
- ***Forestry & green infrastructure***: Interest in utilizing biochar for filtration, erosion control, and nursery media is growing, bolstered by awareness from the Irish Bioenergy Association and Interreg projects
- ***Environmental sectors***: Biochar is being recognized at national level for carbon dioxide removal and alternative green waste management under Ireland's Climate Action Plan.

Market Segments

- Grassland and silage farms: Users of slurry, with potential substitution of peat in fertilizers.
- Dairy farms: Use as bedding additive to reduce ammonia emissions and improve animal health.
- Composters and municipal services: Integration into compost or green waste treatment systems..

10-Year Demand Growth Estimate

Anticipated rise in demand fueled by Inclusion in Ireland's Climate Action Plan and carbon farming incentives. CAP shifts toward regenerative practices and peat reduction. Increasing pilot-scale awareness and educational outreach.

Year	Estimated Demand (t)
2025	1,000–1,500
2030	2,500–3,500
2035	5,000–7,000

Scalability & Replicability

Feedstock Potential & Coverage

- Abundant supply from forestry residues and sawmill by-products (Coillte, private forests, sawmills) across Tipperary and adjacent counties.
- High consistency in sawdust feedstock; forest residues require chipping/drying.
- Local workshops confirm sustainable season-round availability, though low density limits logistical radius.

Required Investment & ROI Considerations

- ***CapEx Estimates***:
  - Pilot (≤100 t/y): €200–300 k for a modular pyrolysis unit, dryer, and screening line.
  - Demo (1,000–2,000 t/y): €1–2 M, including enhanced feedstock handling and steam boiler.
  - Commercial (>5,000 t/y): €3–5 M with automated systems and quality control modules.
- ***Revenue Potential:***
  - Markets for soil amendment, bedding, compost: €200–400/t.
  - Carbon credits may add €50–100/t.
- ***ROI:***
- Demo-scale: Payback projected in 5–7 years with 60–80% capacity use.
- Commercial: 4–6-year ROI with carbon incentives and broader market reach.

Environmental Co-benefits & Monetization

- Carbon sequestration: ~2–4 t CO_2e removed per tonne biochar applied.
- Avoids methane from alternative disposal, supports climate objectives.
- Recovers low-grade feedstocks, prevents inefficient burning.
- Co-benefits monetization: Potential under Ireland’s carbon farming policies; contributions to water management and air quality improvements.

Replicability Drivers & Enablers

- Feedstock access: Established forestry operations and bioenergy actors in the region.
- Infrastructure: Nearby Lisheen Campus and Teagasc pilots demonstrating viability.
- Policy support: Inclusion in Climate Action Plan and CAP incentives
- Stakeholder synergy: Connections with forestry landowners, farmers, and research clusters.
- Mobility & modularity: Mobile pyrolysis units enable flexible deployment across farms and forests.

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Scaling Paths: Risk VS Impact

The scatter plot below maps four realistic scaling trajectories for IBF's biochar operation in Tipperary, plotting risk (horizontal axis) against impact (vertical axis as percentage of local biochar demand, estimated at ~5 000 t/year): ⊠

- ***Status Quo Pilot (100 t → 2% share)***: Risk 2: Maintaining a single modular pyrolysis skid requires minimal additional capital (€250 k) and faces negligible permitting or feedstock risk. It delivers only a small introduction of biochar to Tipperary soils but lays the groundwork for stakeholder engagement and process validation.
- ***Modular Expansion (500 t → 10% share)***: Risk 4: By deploying several mobile units and basic drying capacity, IBF can reach around 10% of the regional market. Technical and logistical challenges grow (seasonal drying, feedstock transport) but remain manageable. Early revenues and farmer buy-in justify this step.
- ***Demonstration Plant (1 500 t → 30% share)***: Risk 6: A fixed facility with integrated chipping, steam recovery, packaging, and carbon-credit certification (CapEx ~€1.5 M) significantly boosts impact. Permitting complexity and quality-control demands rise, as does the need for offtake agreements, but success here proves the commercial model.
- ***Commercial Hub (5 000 t → 100% share)***: Risk 8: A fully automated biochar hub, complete with advanced emissions control, heat export lines, and full EBC certification, commands the entire local market and enables exports. This transformative scale carries the highest execution and market risks but offers maximum impact and carbon-farming revenues.

At first, IBF could pursue Modular Expansion, gaining ~10% market share with moderate risk and solid demonstration value. Once supply contracts and offtake channels are in place, progressing to a Demonstration Plant will de-risk the commercial model and attract larger grants. The Commercial Hub remains a longer-term vision, unlocked by pilot successes, policy incentives, and robust feedstock partnerships.

Ground-Truth Assessment

Realistic Performance Limits

- ***Throughput ceiling***: Modular pyrolysis units realistically cap at 500 t/year each without major re-engineering; a fixed 1,500 t/year demonstration plant is near the upper practical limit for a single-line pilot before economies of scale demand multi-line or continuous-flow reactors.
- ***Yield variability***: Dry-feed conversion yields hover around 30 ± 5% biochar per tonne; wetter forest residues (< 15% moisture) can depress yields by up to 10%.
- ***Energy self-sufficiency***: On-site heat recovery can cover 60–70% of drying and reactor energy needs; beyond that, external fuel or grid electricity is required, raising opex.

Key Issues & Barriers

- ***Feedstock consistency***: Sawmill sawdust is uniform, but logging residues vary in composition and size, demanding flexible pretreatment and risking process upsets.
- ***Regulatory uncertainty***: Biochar remains in a gray zone under Irish waste and agricultural regulations—end-of-waste criteria and product classification are unclear, hindering market confidence.
- ***Market familiarity***: Few farmers understand biochar's agronomic benefits; without demonstration plots and agronomic data, uptake stalls.

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- ***Capital access:*** Mid-scale plants (~€1.5 M CapEx) sit in a tough financing gap—not small enough for small grants, not large enough for commercial lenders without subsidies or offtake guarantees.

Opportunities & Mitigations

- ***Feedstock blending protocols***: Develop standard operating procedures for mixing sawdust with forest residues at optimal ratios (e.g., 70:30) to stabilize moisture and ash content, smoothing reactor performance.
- ***Regulatory engagement***: Work with DAFM and EPA to fast-track biochar end-of-waste guidelines, leveraging emerging EU biochar certification frameworks as reference.
- ***Farmer-led trials***: Partner with Teagasc and local cooperatives to run funded on-farm trials, publishing clear ROI and soil health data to drive wider adoption.

VC2: Lactic Acid (from Whey Permeate & Dairy Sludge)

Category	Details
Feedstock Flow & Capacity	Input: Whey permeate and dairy sludge from large dairy processors in Tipperary (e.g., Tirlán, Dairygold). These side streams are continuous and reliable, though volumes may vary by season and plant operations. Existing concentration and treatment systems may be leveraged.
Technological Feasibility & Limits	Fermentation of whey to crude lactic acid is well-established (TRL 7–9). Polymer-grade purification is more complex and capital-intensive. Risks: feedstock variability in sludge; scaling challenges; integration into existing plant infrastructure; energy costs for purification.
Competitive Landscape	Whey currently used for protein recovery, animal feed, or AD. • No local lactic acid or PLA production in Ireland; all imported. • Competes indirectly with fertilizer, feed additives, and plastics value chains. • Bio-based chemicals market is still nascent nationally.
Value Proposition (Tipperary)	• Enables circular valorization of dairy side streams. • Positions Ireland as a bio-based chemical producer. • Adds value within regional dairy clusters. • Fits with Lisheen Bioeconomy Campus objectives and circular bioeconomy strategy.
Market Applications	• Crude LA: silage inoculants, animal feed acidifiers, composting additives. • Purified LA: food-grade additives, bioplastics (PLA), cosmetics ingredients. • Most refined applications target export or national buyers.
Stakeholders & Value Chain	• Dairy processors: Tirlán, Dairygold, Arrabawn • Technology providers (fermentation, membrane separation) • Researchers: Teagasc, BiOrbic, Shannon ABC • Bioeconomy platforms: Lisheen Campus, Enterprise Ireland • Agri-input distributors, packaging and cosmetic producers
Market Dynamics	• PLA demand growing in EU due to single-use plastic bans. • Bio-based chemicals still dependent on imports. • Rising interest in agroecological inputs and low-carbon materials. • Policy alignment under EU Green Deal and Irish Bioeconomy Action Plan.

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Known Risks	• Operational: high capital cost of downstream purification; integration with dairy lines. • Regulatory: unclear status of sludge-based products for non-energy uses. • Economic: crude LA may have limited local value; purified LA requires scale and export. • Social: acceptance of “waste-to-product” approaches in food and cosmetic markets may be slow.

Products/by-products: Lactic Acid

Current Local Demand

- Dairy sector innovation: The AgriChemWhey project at Lisheen aims to convert whey residues to lactic acid and PLA-grade material
- Industrial interest: Plant protease and ingredient processors in Tipperary and beyond keen to explore crude lactic acid for feed, silage, and biostimulants.
- PLA and chemicals: No current domestic production, but demand is forecast to grow with EU bans on single-use plastics

Market Segments

- Crude lactic acid (~50%): For silage inoculants, animal feed acidifiers, composting aids.
- Food-grade lactic acid: For food and beverage processors (limited local use; primarily export).
- PLA feedstock: Bioplastic manufacturers across Ireland and the EU.

10-Year Demand Growth Estimate

Europe-wide CAGR for lactic acid is ~7.8% p.a. Tipperary's demand will likely mirror Europe's bioeconomy momentum. We assume initial Tipperary demand for lactic acid (crude + polymer-grade) starts around 1,500 t/year in 2025.

Year	Crude LA (t)
2025	1,000–2,000
2030	3,000–5,000
2035	5,000–8,000

Scalability & Replicability

Feedstock Potential & Coverage

Tipperary's concentration of dairy processors (Tirlán, Dairygold, Arrabawn) produces over 30,000 t/year of whey permeate and sludge, easily captured for fermentation. Centralized infrastructure at processing sites enables reliable, year-round feedstock flow with minimal seasonal disruption. Across Ireland, dairy by-product output exceeds 100,000 t/year, supporting expansion into biorefinery clusters nationally.

Required Investment & ROI Considerations

- ***Pilot Scale*** (75 t/y): Fermenters and basic downstream setup, ~€350k CapEx; primarily for demonstration, with potential breakeven in 7–9 years via feed/silage market sales.

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- ***Demo Scale*** (2,000 t/y): Full fermentation chain and separation into lactic acid and gypsum, ~€4M CapEx; revenue ~€3M for crude LA and €0.4M for gypsum, resulting in 6–7-year payback.
- ***Commercial Scale*** (20,000 t/y+): Integrated biorefinery delivering polymer-grade LA and PLA precursor, ~€25M CapEx; revenues ~€35M from mixed-grade LA and co-products; payback in 4–6 years.
- ***Opex*** (~€1–1.5/kg LA) can be offset by energy generated on-site and value from co-products.

Environmental Co-benefits & Monetization

- Effluent reduction by converting high-BOD dairy waste into value-added products, avoiding treatment costs.
- GHG savings through replacement of conventional disposal and imported lactic acid. AgriChemWhey estimates emissions reduction between 18,000–89,000 t CO_2e annually.
- Co-product use: Gypsum for agriculture, biomass for energy.
- Monetization via circular economy subsidies (~€50–100/t waste valorized) and grant support (Just Transition, BBI-JU).

Replicability Drivers & Enablers

- The Lisheen Campus' AgriChemWhey pilot serves as a functional template.
- Co-location with dairy plants reduces logistics, utilities share and fosters economic efficiency.
- Institutional backing: Teagasc, Enterprise Ireland, BiOrbic, and Tipperary County Council provide technical, funding, and regulatory leverage.
- EU directives on single-use plastics and Irish bioeconomy strategies encourage PLA emergence.
- Commercial networks: Connections to dairy cooperatives, technology providers, and packaging/cosmetics industries support distribution and scale.

Scaling Paths: Risk VS Impact

The next chart shows four scaling paths for IBF's lactic-acid biorefinery in Tipperary, plotting risk versus impact as a percentage of estimated 2025 regional demand (~1 500 t/year):

- ***R&D Campus Pilot (75 t → 5% share)***: Risk 2: Hosted at Lisheen for ~€350 k, this stage refines fermentation parameters and engages dairy partners. Risk remains low, but market impact is minimal, serving primarily to validate technology.
- ***Pilot Expansion (500 t → 33% share)***: Risk 4: Installing fermentation and basic separation equipment at a dairy processor (CapEx ~€1–1.5 M) taps one-third of local lactic-acid demand. Utility integration and process consistency introduce moderate risk, but early revenues from silage additives and gypsum by-product justify the move.
- ***Demonstration Biorefinery (2 000 t → 133% share)***: Risk 6: A fully integrated 2 000 t/year plant (€4 M CapEx) produces crude and partially refined lactic acid, displacing existing imports and supplying feed, food, and industrial buyers. Technical scaling and offtake agreements become central challenges, but meeting over 100% of local demand establishes commercial credibility.
- ***Commercial Biorefinery (20 000 t → 1 333% share)***: Risk 8: A national-scale facility converting whey into PLA-grade lactic acid and precursors (CapEx €25 M+) would far exceed regional demand, serving export markets. Logistics, certification, and capital coordination represent the greatest risks but promise the highest returns and leadership in the European bio-chemicals sector.

IBF's optimal path starts with Pilot Expansion, capturing one-third of Tipperary's demand while keeping risk moderate. Success there builds confidence and investor interest for a Demonstration Biorefinery, which in turn

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lays the groundwork for eventual Commercial Biorefinery rollout once European offtake partnerships and funding are secured.

Ground-Truth Assessment

Realistic Performance Limits

- ***Throughput bandwidth***: Single fermenters at Lisheen can handle up to ~500 t/year without advanced CIP (clean-in-place) automation; demonstration facilities at 2 000 t/year must integrate multi-tank sequencing to avoid downtime.
- ***Product purity***: Crude lactic acid (~50% purity) is straightforward; achieving > 90% polymer-grade purity requires continuous ion-exchange and distillation steps, each with ≥ 95% recovery but significant energy and water demands.
- ***Co-product recovery***: Gypsum recovery hits ~85% of theoretical yield; lost product in centrifuge and wash water streams represents ~15% opportunity loss.

Key Issues & Barriers

- ***Integration complexity:*** Retrofitting dairy plants for side-stream extraction, heat integration, and wastewater diversion involves both technical and operational hurdles, plus possible production interruptions.
- ***Utility constraints***: Steam, cooling water, and power at creamery sites are often reserved for core processes; securing sufficient utilities for fermentation and purification creates negotiation challenges.
- ***Market channels***: While silage and feed additives have local buyers, scaling into food or PLA markets requires new certifications (e.g., QPS, food-grade standards) and extended quality-management systems.
- ***Financing scale-up***: Facilities in the €3–5 M range sit between typical R&D grants and large commercial loans; demonstrating bankable offtake contracts is critical but often circular.

Opportunities & Mitigations

- ***Phased utility agreements***: Negotiate staged off-take and utility usage agreements with processors, starting with low-intensity pilot loads and ramping to full-scale once fermentation yields are proven.
- ***Energy integration***: Use anaerobic-digestor biogas (already present at many creameries) to supply process heat, reducing external energy costs and co-locating circular resources.
- ***Tiered product strategy***: Initially target crude lactic acid for silage and feed markets (lower purity, faster revenue), then invest in incremental purification toward food and PLA grades as offtake contracts materialize.

5.3.5 Living Lab 5: Cell Factory Lab

VC1: Plant cells cultivation with concentrated effluent

Category	Details
Feedstock Flow & Capacity	Input: Liquid potato side-streams and berry-juice effluents sourced from processors in Ostrobothnia and other Finnish regions. • Potato streams available year-round in moderate volumes; consistent quality but subject to seasonal processing peaks. • Berry effluents seasonal, high sugar content but variable acidity.

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Technological Feasibility & Limits	• TRL 4–6 (pilot scale): Lab-proven growth media formulation and small-bioreactor cultivation at VTT. • Sterilization and microbial-control methods validated at scale. • Harvesting requires centrifugation or membrane, costly at scale. • Drying and downstream formulation for powder ingredients add complexity; heat-sensitive bioactives risk degradation.
Competitive Landscape	• Conventional fermentation: Yeast/algae-based ingredients are established and sourced more cheaply. • Side-stream valorisation via animal feed, biogas, compost in place. • Emerging precision fermentation and other cellular-ag tech spin-offs in Helsinki compete for VC and R&D attention. • Ingredients from cell culture face higher regulatory and CAPEX.
Value Proposition (Espoo)	• Transforms low-valuewaste into high-value novel ingredients. • Positions Espoo/VTT as Nordic hub for cellular agriculture and circular bioeconomy. • Reduces imports, enhance Finnish food self-sufficiency. • Captures emerging premium market willing to pay for sustainably sourced "lab-grown" bioactives.
Market Applications	• Novel foods: Texturizers, colorants, phytonutrients, etc. • Cosmetics & nutraceuticals: Antioxidant extracts, specialty proteins, bioactive compounds. • Research reagents: Plant metabolites for pharmaceutical R&D.
Stakeholders & Value Chain	• VTT scientific team: R&D, process development, scale-up planning. • Potato and berry processors providing side-streams. • Food manufacturers (novel-food start-ups), cosmetic firms. • Nordic VCs, industry funds (e.g., Tesi, FoodTech VC). • Support actors: Aalto University (tech transfer), biowaste / biogas plants (ammonia sourcing), regional innovation agencies
Market Dynamics	• EU functional-foods market growing ~6 % CAGR. • EU Novel Food Regulation imposes 3–4 yr approval and up to €1 M fees, a major barrier. • Public procurement exploring sustainable foods as early adopters.
Known Risks	• Regulatory delay and costly EFSA approvals • Bioreactors, GMP facilities require significant investment.

Products/by-products: Biomass & Bioactive Extracts

Current Local Demand

- ***Novel Food & Functional Food Industry***: Helsinki-region start-ups and food tech companies are piloting plant-cell-based ingredients as sustainable alternatives to conventional extracts (e.g., colorants, texturizers, micronutrients). Small-batch trials in Espoo's "smart cafeterias" at Aalto University and VTT pilot kitchens are validating texture and flavor profiles.
- ***Cosmetics & Nutraceuticals***: Nordic beauty brands (e.g., in Helsinki and Turku) are exploring clean-label, lab-grown botanical actives for anti-oxidant serums and botanical peptides. Dietary-supplement formulators are assessing high-purity cell-culture–derived phytonutrient concentrates for gut-health capsules.
- ***R&D & Analytical Markets***: University and pharmaceutical research labs around Espoo require consistent, contaminant-free plant metabolites for assay development, driving small-scale purchases of standardized cell-culture extracts.

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Market Segments

- ***Functional-Food Manufacturers***: Producers integrating novel texturizers, colorants, or nutrient boosters into bars, beverages, and dairy alternatives.
- ***Cosmetic Formulators***: Brands seeking sustainably sourced bioactives (e.g., flavonoids, phenolics) for serums, creams, and masks.
- ***Nutraceutical Companies***: Firms developing concentrated plant-cell extracts for capsules or powders targeting immunity, inflammation, or beauty-from-within.
- ***Research & Testing Facilities***: Academic and pharma labs purchasing cell-culture–grade compounds for bioactivity screening and assay standardization.

10-Year Demand Growth Estimate

Anticipated uptake driven by regulatory approvals (EU Novel Food clearances), increasing consumer demand for sustainable ingredients, and cost reductions from scale-up.

Year	Estimated Demand
2025	5 – 10
2030	25 – 40
2035	60 – 85

Scalability & Replicability Analysis)

Feedstock Potential & Coverage

- ***Volume Availability***: Potato side-streams: from ultiple medium-sized processing plants in Ostrobothnia generate ~1,000–1,500 m^3/year each. Aggregated across 5–8 processors, total annual volume could exceed 6,000 m^3, enough to support several 100-L bioreactors running continuously. Berry-juice effluents with seasonal peaks (~200–500 m^3 per facility) yield ~1,000 m^3 over the summer; can be stored (frozen/pasteurized) for off-season use.
- ***Geographic Coverage & Logistics***: Centralized collection hub in Espoo requires ~400 km rail or refrigerated-truck routes. Co-location with VTT and cold-storage facilities reduces spoilage. Potential satellite mini-hubs near major processors (e.g., Seinäjoki or Oulu) could preprocess (sterilize, concentrate) feedstocks before bulk transport, lowering costs.
- ***Feedstock Diversification***: Beyond potatoes and berries, similar facilities could tap oat mill filtrates, sugar-beet vinasses, or brewery spent-yeast streams—broadening regional coverage and smoothing seasonality.

Required Investment & ROI Considerations

- ***CapEx:***
- Pilot-scale unit (TRL 5–6): €0.5–1 M for modular bioreactor, sterilization, dewatering, and QC lab.
- Commercial-scale facility (TRL 7–8): €3–5 M for 10,000 L reactor array, GMP clean rooms, freeze-dryers or spray-dryers, and cold storage.
- ***OpEx:***
    - Feedstock preprocessing (sterilization, concentration): €100–150/tonne.
    - Energy & utilities: €200–250/tonne biomass produced.
    - Labor & QC: ~€150–200/tonne.
- ***Revenue Streams & ROI:***

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- Premium novel ingredients: €5,000–10,000 per tonne of high-purity extract; bulk cell-biomass powders at €1,500–2,500/t.
- Break-even horizon: 5–7 years post-investment, assuming 50% capacity utilization and two long-term off-take agreements (e.g., one F&B, one cosmetic brand).
- Sensitivity levers: Yield improvements (+20 %), energy efficiency gains, and additional co-products (e.g., spent-cell biomass for animal feed) materially shorten ROI.

Environmental Co-benefits & Monetization

- ***Circularity***: Diverts agro-food effluents from wastewater treatment, reducing BOD/COD loads and methane emissions.
- ***Resource efficiency***: Uses existing side-streams rather than virgin crops, saving land, water, and fertilizers.
- ***Reduced transport impacts***: By localizing feedstock valorization, cuts logistics emissions versus shipping to distant biogas or composting sites.
- ***Monetization pathways***: Waste-treatment cost savings: Partner processors could pay lower disposal fees if VTT-hub accepts their effluents. Brands may pay a sustainability surcharge (5–15 %) for "upcycled" inputs.

Replicability Drivers & Enablers

- ***Technical Standardization***: Modular bioreactor units and standardized pretreatment protocols can be packaged as "feed-and-grow" kits for other regions.
- ***Regulatory Templates***: Early EFSA dossiers and compliance roadmaps can be adapted by replicants, reducing time and cost to novel-food approval elsewhere.
- ***Ecosystem Synergies***: Espoo's model of integrating university labs, tech centres (VTT), and pilot kitchens can be emulated in other knowledge hubs.

Scaling Paths: Risk VS Impact

The following is a 2x2 Scaling Pathways Matrix for VC1, plotting Risk (low to high) against Impact (low to high). Each pathway reflects a different strategy for VTT or regional actors to expand the platform.

A. Core-Finland Expansion (Low Risk, High Impact)

VTT establishes multiple modular bioreactor hubs in Finland's key agro-processing regions—Ostrobothnia, Turku and Seinäjoki—leveraging existing energy, cold-storage and logistics infrastructures. Public-private partnerships (e.g., Business Espoo, regional development agencies) co-fund shared pilot facilities. Standardized pretreatment and quality protocols ensure consistent output across sites. Off-takers include functional-food SMEs, cosmetic formulators, and municipal pilot kitchens. This approach amplifies circularity within Finland, attracts further R&D grants, and builds a strong domestic market before broader EU replication.

B. Niche Product Focus (Low Risk, Low Impact)

VTT maintains a single, well-controlled pilot line in Espoo, producing limited volumes of high-purity cell-culture extracts tailored for premium niches—cosmetic serums and R&D reagents. Capital and operational costs remain modest, and regulatory pathways (e.g., "research-only" exemptions) further de-risk the venture. Revenues stem from a handful of strategic partnerships, enabling gradual IP development and proof points without heavy scaling commitments. Impact on systemic circularity is modest, but financial stability and IP retention are prioritized.

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C. Export-Led Replication (High Risk, High Impact)

Building on Finnish success, VTT licenses turnkey “train-and-deploy” packages—including bioreactor designs, pretreatment recipes, and regulatory dossiers—to partners in Germany, Italy and the Baltics. Each location adapts modules to local feedstock (e.g., sugar-beet vinasse, brewery effluents). While potential climate and circularity gains across the EU are substantial, this path means navigating diverse regulations (EFSA vs. national), disparate consumer markets, and complex logistics. High initial investments and coordination challenges raise risk, but EU funding alternatives and cross-border alliances can mitigate barriers.

D. Tech-Only Licensing Model (High Risk, Low Impact)

VTT focuses purely on IP licensing—selling patents or out-licensing the cell-culture platform without direct involvement in operations or market development. Licensees (e.g., large CPG firms, biotech entrants) take full responsibility for facility build-out and commercialization. VTT’s role is limited to patent enforcement and nominal royalty collection. While this path requires minimal ongoing CapEx from VTT, it offers low control over quality, environmental co-benefits or social impact, and success depends heavily on licensee execution capabilities.

Ground-Truth Assessment

Realistic Performance Limits

- ***Throughput bandwidth***: Single 500 L bioreactors at VTT pilot can process ~150 m^3 side-stream/year (at 70% uptime) without full CIP/SIP automation; scaling to a 5,000 L array (×10 volume) pushes capacity to ~1,500 m^3/year but requires multi-tank sequencing and automated cleaning to avoid 15–20% downtime.
- ***Biomass yield & product titers***: Current pilot yields of 2–3 g dry cell mass/L·day (~30% carbohydrate conversion) translate to ~2 t biomass/year per 500 L reactor; optimized strains in bench scale achieve 5 g/L·day (~60% conversion), but maintaining that at pilot scale is unproven.
- ***Product purity & co-product recovery***: Crude cell-biomass powders (20–30% active metabolites) are readily obtainable; elevating purity to > 80% bioactive extract demands sequential solvent or membrane steps (each ≥ 90% recovery) that cumulatively incur ~25% yield loss. Spent biomass (70–80% of wet weight) can be valorized to animal feed or biogas, but actual recovery is ~60–65% of theoretical.

Key Issues & Barriers

- ***Feedstock variability & logistics***: Seasonal fluctuations in potato wash water (±20% sugar content) and berry effluent availability (summer-only) lead to inconsistent media performance. Long-haul refrigerated transport (~400 km) adds €0.05–0.10/kg in logistics costs and risk of spoilage.
- ***Regulatory hurdles***: EFSA Novel Food approval cycles (3–4 years, €0.5–1 M fees) block market entry; parallel cosmetics or nutraceutical filings each introduce additional data requirements and timelines.
- ***Capital & operating costs***: A 5,000 L commercial array plus downstream (centrifuge, dryer) demands €3–5 M CapEx. Finnish energy (€0.15/kWh) and labor (€35–40/h) drive OpEx to ~€450/t biomass, challenging unit economics against fermentation incumbents (€200–250/t).
- ***Market & stakeholder alignment***: Premium ingredient pricing (€1,500–10,000/t) must compete with €500–1,000/t yeast- or algae-based extracts.

Opportunities & Mitigations

- ***Satellite preprocessing hubs***: Install small pasteurization/concentration stations near Ostrobothnia processors to stabilize sugar levels (+/−5%), cut transport volumes by 40%, and reduce spoilage risk.

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- ***Modular, CIP-enabled bioreactors***: Deploy plug-and-play 1,000 L units with automated cleaning to halve downtime (< 5%) when sequencing multiple tanks.
- ***Energy & heat integration***: Co-locate with biogas or data-centers in Espoo to capture waste heat for sterilization and drying, cutting process energy by ~25% and reducing OpEx by €50–75/t.

6. Value chain analyses and co-design of value chain synergies

6.1 Approach

This section of the deliverable presents “Task 3.3: Co-design of Bio-Based value chain map, synergies and governance structuring for each LLab”. It enhances and extends prior analysis done in “Deliverable 2.2 Analysis of the state-of-the art of bio-based value chains creation” by exploring the current and future development of bio-based value chains, their synergies and governance structuring for each LLab. For better cohesiveness amongst the different parts of this deliverable, we tackle the co-design of bio-based value chain maps and synergies in this section, and address governance structuring in section 8. We have adopted a multi-actor mapping of different bio-based value chains for each LLab. The mapping includes all the activities identified in the life-cycle including feedstock availability from primary producers and primary and secondary sources of bioproducts, technology and innovation flows.

We present a multi-actor and life-cycle perspective on sustainable and circular value creation based on SWOT analysis. The analysis visualizes and foresees the strengths, weaknesses, opportunities and threats attributable to each bio-based value chain. We include the analysis of feedstock and multi-regional supply chain, gaps in sustainability schemes and multi-sector application to different industrial sectors.

6.2 Methodology

6.2.1 Data collection

Building further on the preliminary value chain mapping interviews conducted with leaders of each LLab done in WP2, in WP3 we have conducted follow-up discussions to identify most important value chains and the stakeholders that are the most critical to each LLab at the current stage of their evolution and for the future developments. These stakeholders were then selected for multi-stakeholder workshops which were co-facilitated by LUT researchers and the LLab leaders.

Multi-stakeholder workshops: Seven workshops were conducted for the five LLabs, with three being organized in-person, three being organised online and one being organized in the hybrid mode.

A semi-formal structure was followed for the multi-stakeholder discussions, with specific preliminary questions based on the main targets of Task 3.3 serving as starting prompts, and workshop participants being encouraged to carry the discussion forward. The following questions, which were discussed and agreed upon along with the LLab leaders, were used to guide the flow of the workshops:

- Who are the main value chain actors for the relevant value chains?
- What are the main strengths, weaknesses, opportunities and challenges inherent in the material and knowledge flows between the value chain partners?
- What are current gaps and opportunities in accounting for the end-of-the-life stage of the product?
- What are some gaps and opportunities in the sustainability schemes that affect the relevant value chains?

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- What are the main projects and partnerships you envision for the next 3-5 years across the value chain and how can they be developed?
- How will these future projects affect the governance of the value? Would it be possible to create a model of governance of the value chain in this Living Lab?
- What should the future models of governance between the relevant stakeholders look like? How should this work: via creation of an organization, network governance or a cooperative?

The workshop participants were also provided with some preparatory material to prepare for the workshop, which included an overview of the relevant LLab and value chain(s), along with the above listed questions.

Interviews: Follow-up interviews were also conducted with several stakeholders for more comprehensive insights on aspects of the LLab and their value chain(s).

LLab field research: We have done field research visits to Llab 1 (Spain, December 2024), LL2 (Italy, February 2025) and LL3 (Ireland, May 2025) with the goal to gather ethnographic and direct observation data. Each visit was conducted by two researchers and lasted from 3-5 days. We visited the main biorefineries in each LLab, met and interviewed all the main stakeholders, business partners, public authorities, universities and researchers. We recorded all the interviews and visit and transcribed the data. We adapted to the cultural and language for each LLab.

In Finland, we have directly followed the development of LLab 5 as we are located in the same country.

6.2.2 Data analysis

Debriefs were conducted after each workshop and interview between the researchers and extensive notes taken during the workshops were discussed. To aid the preparation of this deliverable, workshop recordings and transcripts were also reviewed, and data was extracted from them and condensed into the following findings. We codified the data to understand the main topics, emerging business projects, growing interactions between the lead partner and all the stakeholder in the value chain map to explore future value chain developments, synergies. We also explored during the workshops and interviews the current and future trends of value chain governance.

To map each value chain within different LLabs, our analysis includes:

- Key actors and activities
- Feedstock availability
- Multi-sector industrial synergies
- Gaps in relevant schemes
- SWOT analysis

We present the results in the next section.

6.3 Results

6.3.1 Living Lab 1: ALC Bio-Lab (Leader: Alcarras Bioproductors)

ALC Bio-Lab consists of three value chains connected to the same feedstocks: solid and liquid pig slurry and cow manure, which are supplied by 150 farming families in Alcarràs. These families are also shareholders and members of the farmers' association that created SAT Alcarràs Bioproductors. They own the business and the land where the biorefineries – Biocompost and Biogas/bio-methane - and the Bio-Polygon are located.

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1. The first value chain consists of valorisation of solid cow manure and pig slurry into bio-compost and is currently dealing with expanding commercialisation of their end-product.
2. The second value chain consists of valorisation of liquid cow manure and pig slurry into biogas that will be co-generated on a first digester. The plant is converting the generated biogas into electricity to sell into energy markets and is also commercialising combined heat and power (CHP). In the second stage, they are currently finalizing the construction of the second digestor that will allow the biogas upgrading and bio-methane compression/cooling storage and distribution. This will add value by generating bio-methane as compressed natural gas (GNC) or liquid natural gas (LNG). The same cow and pig farmers provide the feedstock for both value chains.
3. The third value chain, the Bio-Polygon, consists of creating an industrial bioeconomy hub around the facilities of the first two value chains, to facilitate cross-fertilisation and utilisation of by-products, end-products and knowledge resources (originating from the first two value chains) across co-located partners working synergistically. The operationalisation of this value chain has been recently approved by local authorities and the LLab is in the process of exploring and negotiating agreements with potential partners in the hub. The bio-polygon is located on the land owned by the farmers' association.

The discussions that were facilitated amidst the stakeholders of this LLab focused on all the aforementioned value chains, since significant overlaps and synergies exist between the three. Thus, the following analysis has been undertaken keeping a cross-sectional and systemic-level approach in mind, with several themes being discussed across all value chains because of the significant interlinkages and commonalities that exist amongst these. In ALC Bio-Labs the main feedstock providers, the farmers are also shareholders and own the three business units connected to the three value chains, the facilities and the land.

Three in-person workshops were conducted with 19 stakeholders on 9th December 2024. These stakeholders included actors from the Lleida region and some of them in Catalonia:

- 4 end-user managers
- 3 university professors (University of Lleida and Polytechnic University of Catalonia)
- 3 board members/shareholders/feedstock providers (members of the farmers' association)
- 2 feedstock provider representatives/shareholders (members of the farmers' association)
- 2 executive team managers of Alcarras Bioproductors SAT
- 2 commercial partner managers for national and international markets
- 1 Catalan leader /facilitator (Director of BioHubCAT [BioHubCatalonia])
- 1 local administrator/policy-maker (mayor)
- 1 Catalan industry cluster representative, Manager of Bioenergy cluster of Catalonia
- 1 technology consultant

Further data was also collected during two site visits and presentations on the operational facilities. Follow-up interviews were also conducted with the 2 end-user representatives, 1 executive representative and with the technology consultant over the course of December 2024-January 2025.

Key actors and activities

Primary producers: Providing feedstock, investing in and governing the three business units

The cow and pig farmers from two farmer associations in the Alcarras village (Lleida region) pooled their resources and created a joint farmers association with the goal of buying the land on which the facilities of Alcarras Bioproductors are now located. In 2022, they built the composting plant to solve the cattle dejections' challenge. In 2024-2025 they are building the biogas and upgraded biomethane digestors.

In 2022, the business was named ALC Bioproductors. The formal business is a SAT, that is an *Agricultural Transformation Society*, a civil society organization that has an economic-social purpose related to the

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production, transformation, and marketing of agricultural, livestock or forestry products, the implementation of improvements in the rural environment, agricultural promotion and development, as well as the provision of services.

General Assembly: All the 150 farmers families meet formally (in annual general meetings) and informally, to discuss issues related to governing the business, most importantly decisions on where the returns and further investments should be channelised across the three value chains and on instating new roles in the executive team that looks after the day-to-day operations of the business.

Board of directors: The general assembly of 150 farmers selected and voted for 10 farmers to act as the board of directors. In 2018, the board of directors started leading the bio-compost business. The board is now divided in two boards, one for bio-compost and one for biogas. In 2022, they selected and voted for another 10 farmers to act as the board of directors for the biogas business. To set up the current changes on the governance of Alcarras Bioproductors, they are formally reviewing the by-laws/statutes of farmers association to formally differentiate the three business and two board of directors.

Investment in two biorefineires - Bio-Compost and Biogas: Out of the 150 families, some invested in the construction of the biorefineries. While some families participated in both projects, others invested in only one. Between 2020 and 2022, 71 families from Alcarràs invested in the biocompost facility. In 2023 and 2024, 41 families invested in the biogas project, which involved building two anaerobic digesters to generate thermal energy and biogas that will be converted into bio-methane.

Executive team: Day-to-day business operations

They board of directors have created an executive team to manage the three business, bio-compost, biogas and bio-polygon. The executive team is based on a Chief Executive Officer, Operational manager of bio-compost, Technology and operations manager of biogas, Financial and accounting manager and administrative manager.

They also have service providers such as commercial partners for the national and international markets and technology consultants and providers. The executive team works with them to allocate massive effort in understanding how to extend the markets by understanding client needs, bringing them to the bio-compost and biogas facilities and fostering a sense of familiarity with the spirit of the business by narrating the story of the LLab, including how it originated to address a critical environmental problem that was being faced by the farmers of the region. LLab members cite this as a key reason behind the success they have seen in the market in being able to sell their bio-compost product at a premium price.

Local administration and leadership: Funding and expanding stakeholder connections

The government bodies of Alcarras municipality, Diputacio de Lleida (regional administration) and Generalitat of Catalonia have allocated funding for bioeconomy development. A main institution is the creation of the facilitating bodies like BioHubCatalonia (BIOHUBCAT), that has become a crucial channel and main support of projects like Alcarras Bioproductors. BIOHUBCAT is the one-stop shop dedicated to generating economic value from renewable organic resources in Catalonia. It is a place where companies and entrepreneurs can find the solutions they need to take the next step. BIOHUBCAT connects and promotes public and private infrastructures, capacities and services to facilitate project execution. It also promotes initiatives to cover the gaps in this global map of innovation services. BioHubCatalonia supports Alcarras Bioproductors as a lead project in Catalonia.

As the local stewardship increased, the Generalitat of Catalonia has launched the Bioeconomy Strategy of Catalonia 2030 as the tool to promote the sustainable growth and development of the Catalan economy by facilitating the production and use of renewable biological resources. The Bioeconomy Strategy has supported the development of the LLab and is now using its example as an exemplary reference in other regions of Catalonia, to reproduce other such stories across the region.

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At municipal and regional level, municipalities and the Diputacio of Lleida have strongly supported the growing of bioeconomy as a driver for regional development. They have attracted EU funding to develop bioeconomy projects in Lleida. A main project was BIOHUB LAB, funded by European Regional Development Fund, and located on a set of Lleida municipalities. Alcarras was one of them..

Local leaders, within the local administration and bioeconomy development bodies and bioenergy cluster of Catalonia, have also played a crucial role as network actors, imagining opportunities, co-creating action pathways with the LLab members and helping them connect to other actors that could complement their vision.

In 2025, the Diputatio of Lleida has created *Lleida, Terra d'oportunitats*, a policy that support a place-based arena for transformative innovation to accelerate systemic change towards just and smart ecological transition through systemic investment and new business models. *Lleida, Terra d'Oportunitats* is the result of collaborative work by the region's key institutions since 2018, aimed at addressing demographic challenges by transforming the current economic model into a green and digital economy based on local resources and potential. Through a shared agenda, systemic changes are being implemented to achieve a collaboratively constructed vision of the future.

The institutional alliance, the future-oriented vision as a benchmark, the shared agenda as a working methodology, the governance model managing the agenda's dynamics and processes, and the territorial ecosystem supporting transformative innovation collectively position Lleida as an ideal environment for ideating, prototyping, and scaling systemic solutions. In this vision, Lleida becomes a region that, through strong collaborative networks, leverages its strategic location and endogenous resources, capacities, and potential to develop a competitive and sustainable model of a green, circular, and highly digitalized economy. This model strengthens strategic sectors and fosters the emergence of new sectors and business models within a supportive environment equipped with the necessary infrastructure and services. The aim is to generate the levels of well-being and prosperity needed to retain and attract population and talent, while actively contributing to the achievement of the Sustainable Development Goals (SDGs) and advancing the ecological and digital transitions promoted at the European level. Alcarras Bioproductors is a main successful project of *Lleida, Terra d'oportunitats*.

Commercial partners: Finding and expanding into new markets

Since 2022, Alcarras Bioproductors have constructed a set of strong partnerships to develop their biorefineries, value chain and business models. Alcarras Bioproductors have commercial partners to distribute and sell the bio-compost in the national markets, including one that pelletises the same for more efficient logistics. The LLab has also been able to reach farmer networks in France and sell their bio-compost to them. Now, it is in talks with a potential commercial partner in France to professionalise this process further and deepen their presence in the French agricultural market.

Alcarras Bioproductors is also in talks with an international commercial company (that provides agricultural solutions to markets across several countries around the world, including in Asia, the Middle East and Africa), to potentially become another bio-compost commercial partner that can help them tap into distant markets that would normally be out of their reach. To sell bio-compost in these markets, they are studying how they can pelletize their bio-compost for more efficient logistical handling and are currently at the testing and market screening phase.

End-users: Providing different markets for end-products

The LLab sells their bio-compost to some local farmers in and around the Lleida region as well as to some farmers in France. It has other potential end-users in mind, including municipalities and private gardens, who can use the bio-compost for enhanced plant growth and quality within their premises.

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For the biogas, the LLab is selling electricity to spot electricity markets, and is also considering selling heat and power production to some companies such as the national gas grid and energy utilities. They are also considering distributing the biofuel though a local gas station. They are also exploring selling the biofuel to the nearby farmers who can use it to fuel their tractors and other machinery. All these end-products could also be sold to other companies that could become a part of the envisioned circular bio-industrial park, the Bio-Polygon. Finally, they are also exploring how to create a farmers bioenergy cooperative, an “energy community” under the Generalitat de Catalunya, in order to self-consume the heat and power production in their own farms.

For the Bio-Polygon, which would surround the LLab’s existing facilities, they are exploring and negotiating agreement with key partners that could use their bio-compost, heat and power and natural gas as main inputs to create biochar and other products. The board of directors is working on exploring possibilities for this and advancing the agenda for an eco-circular industrial park. The potential end-user relationships are yet to be explored further.

External consultants: Providing expertise on technological and regulatory aspects

The LLab works with an external technological consultant and other experts who bring expertise on the suitable choice of technology and the technology provider. They have recently signed an official agreement with this technological consultant to assess the suitable pathway for further technological development of the bio-methane value chain.

Further, the LLab is trying to consolidate a local industrial hub, the Bio-Polygon, where other companies can set up their facilities, with both the LLab and the other companies being able to use end-products and by-products from each other’s processes to enhance their own operations and end-products. To comply well with safety requirements of the local municipality which discourage organic waste management within industrial areas, they have hired an urban planning expert to create a suitable layout for the Bio-Polygon which can meet the regulatory requirements and facilitate the Bio-Polygon’s permitting process.

Feedstock availability

The composting plant at the LLab is supplied with approximately 22,500 tonnes of solid cow manure, 4,500 tonnes of solid pig slurry and 2,000 tonnes of vegetal residues (from local fruit tree pruning activities) each year. This is well aligned with the bio-composting plant’s annual capacity of 27,000 tonnes. However, in April 2024, the plant was operating beyond its capacity, processing a quantum of feedstock that was equivalent to processing 30,000 tonnes of feedstock annually. Thus, the feedstock availability has been assessed and forecasted to be adequate in the near future, leading to the business having made plans to expand the capacity of the plant.

The farmers also produce approximately 12,000 tonnes of liquid cow manure and 62,000 tonnes of liquid pig slurry each year. To valorise this waste, one biogas digester is in the process of being constructed and operationalised. A second phase has been planned for technology upgradation with a second digester. The combined capacity that has been planned for in the biogas plant is 126,000 tonnes. The liquid animal waste will also be combined with 10,000 tonnes of vegetal residues (from pruning and gardening activities) for process enhancement.

Feedstock traceability also exists within the business, with a GPS system that has been integrated into the feedstock collection operations. The system maps and stores data on the latitude and longitude of the geographical point from where the feedstock is collected, type and quantity of feedstock as well as the journey of the feedstock from the sourcing site to the processing facilities. This system is also integrated with the register of the Catalan government to ensure that waste management is being done as per regulatory standards.

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Multi-sector industrial synergies

Workshop participants highlighted the criticality of collaborating with different actors in the value chain instead of competing with one another, especially given the emergent nature of the organic bio-compost ecosystem, the inception of the biogas refinery and the Bio-Polygon in the region.

Despite the LLab and end-users producing products that could be considered competitors in the market (e.g. bio-compost, bio-compost pellets and biochar-enhanced fertilisers), they discussed how they are not just interdependent in terms of using each other's products to innovate on their own, but are all newer and smaller players as compared to the inorganic fertiliser giants who are ahead of them in terms of both volumes and pricing. Thus, at this nascent stage, they find it critical to find synergies amidst themselves to strengthen their products and become more collaboratively competitive in existing and new markets.

Local municipalities' and food companies' biowaste: The board of Alcarras Bioproductors has been discussing the possibility of partnering with municipal waste management authorities and regional food companies to source bio-based waste from them. This additional feedstock will help in filling up the capacity of the digesters and can not only be processed to make larger quantities of bio-compost and biogas, but also to enhance the quality of these end-products.

Fertiliser pelletisation: The LLab is in talks with two potential partners, with whom they are discussing conversion of their bio-compost to pellets. This is useful because the pelletisation process makes the end-product more compact and easier to transport to other, especially more distant, regions. Therefore, pelletisation could be one way in which the LLab approaches its commercialisation and market scaling, by minimising logistical costs.

Biochar: The LLab highlighted their aspiration to enter the biochar market at some point using their biomass, since they see expanding opportunities in this market. However, instead of making inroads into this market themselves, they are discussing opportunities with an existing end-user that is already working with biochar, using biochar and the LLab's bio-compost to make an enhanced agricultural fertiliser. The LLab sees strength in this collaboration because of the end-user's advanced research capabilities, years of existing international experience in the biochar field as well as their advantageous positioning amidst other players, e.g. having taken up an active role in consolidating a national association for biochar producers. Given the critical volume of biomass that the LLab possesses, they perceive this collaboration with the biochar research centre to yield value in new markets that would have been difficult for them to enter into alone.

Digestate separation for nutrient extraction: Since anaerobic digestion technologies are used for both bio-compost and biogas value chains, these technologies produce a process by-product called digestate, which is currently under-utilised (only the liquid fraction of the digestate is stripped, transported by trucks to the farmers' lands and used for nutrient irrigation). The LLab is in talks with technology consultants to explore options of separation processes and technologies to extract nutrients like nitrogen and phosphorus from this digestate, which can then even be sold in agricultural markets for irrigation purposes as well as for various chemical industry applications. The LLab has also been talking to a company to buy the solid fraction of the digestate and create their own end-product, and there is a likelihood for this company to locate themselves nearby. For the liquid fraction of the digestate, the LLab has been exploring possibilities for a membrane manufacturer to use this in their processes.

Power and heat production for the electricity grid: Currently, the first solid digestate of biogas is able to produce heat and power (CHP) that Alcarras Bioproductors sells to the energy grid in Spain. The main processes include collection and transport of the pig slurry and cow manure to the biogas production plant, followed by anaerobic digestion for production of biogas, direct combustion of biogas in a reciprocating engine for production and electricity with recovery of heat from the combustion flue gas. However, the prices of the electricity to the grid are low and does not result yet in benefits for Alcarras Bioproductors. The digestate from

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anaerobic digestion is dewatered and use directly for production of compost using agricultural residues as substrate.

Regional industrial hub: The LLab sees the potential for several different players to be able to use both their end-products as well as by-products. Thus, they aim to consolidate a local industrial hub based on resource use synergies, a project which they have named the Bio-Polygon. Adjoining its existing facilities, the LLab owns some land, which it aims to rent out to companies with whom it finds resource use synergies. The idea is to find companies that can make use of the substrates, digestates and other by-products that are generated during the LLab's processes, as well as for the LLab to make use of others' end- and by-products to enhance their own processes and products. Additionally, the LLab's biogas end-product can also act as an energy source for the other companies. The LLab is in talks with, for instance, the aforementioned biochar research company to establish their facility in the Bio-Polygon to make use of the animal waste feedstock that the LLab collects from its farmer members, as well as to enhance the quality of their bio-compost using the biochar that the company produces. Another potential partner company that is working on extracting protein from insects, has been identified and negotiations are in progress.

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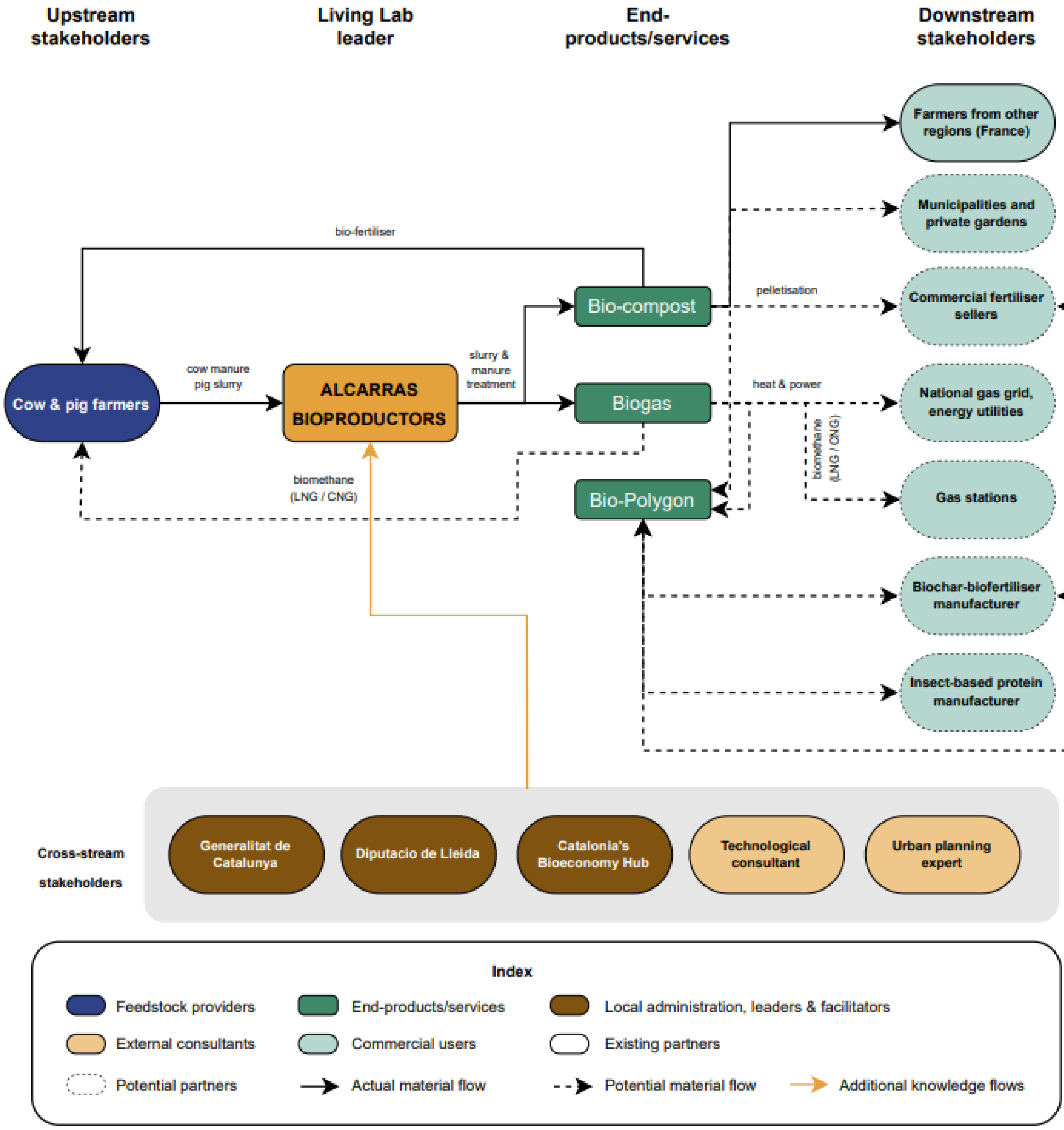

Figure 27. Multi-stakeholder value chain map and synergies for LLab1

Gaps in relevant schemes

Local municipality regulation on organic waste management and processing in industrial areas: The local municipality has regulations that discourage the processing of organic waste within an industrial estate, a major barrier for the consolidation of the Bio-Polygon, where the LLab aims to have several partner companies that can make use of each other's waste streams and end-products to enhance their processes and products. The LLab is in talks with the municipality along with local leaders to find relevant adjustments to these rules.

Long bureaucratic processes: LLab members deemed the regulatory approval processes for the Bio-Polygon as being long drawn out and having delayed the progress they are able to make on the industrial hub, most critically, establishing contractual relationships with interested partners since these bureaucratic uncertainties have led to certain potential partners losing interest in co-locating at the Bio-Polygon.

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SWOT analysis

Strengths

Solving farmers' waste problem: The farmers who are now owner-shareholders of the business previously had to deal with their animal waste on their own farms. Each individual farmer had to tackle this problem, with most choosing to dump the waste into deep manure pits on their own agricultural land, leading to groundwater pollution, eventual regulatory intervention and even monetary fines. The Alcarras Bioproductors business solved this problem of waste disposal by creating a valorisation opportunity for the waste that is being produced during the farming activities by using the waste as a feedstock. Further, because of the pooling of efforts and resources, the handling of the waste has also been centralised and is collected by trucks that belong to the LLab, a collective mechanism that has reduced the individual effort that each farmer had to put in previously for disposing the waste.

Promotion of local organic agricultural practices: The bio-compost produced by the LLab has been sold to several local farmers and has enabled fertilisation of farmlands without the use of inorganic chemical fertilisers. The LLab sees this promotion of the local soil health as a larger ecosystemic benefit that ensures sustenance of the local agriculture for the future. This contribution is even more crucial in light of the European Commission's Farm to Fork strategy, which aims for a 20% reduction in chemical fertiliser usage across the Union by 2030.

Monetary benefit to feedstock providers: The business of the LLab has been successful enough that it has started moving from merely a waste management solution to a profitable business model. The bio-compost end-product is bringing in enough revenue that the initial costs have been recovered and now, the farmers who had been providing their cow manure and pig slurry to the composting plant for free, are soon going to start receiving monetary compensation of 2 euros per tonne of feedstock they provide, thus opening up an additional avenue of income generation for them.

Premium bio-compost end-product: The bio-compost being produced by the LLab is being sold as a premium product, having been priced at up to 70% higher than some competitor products. The high quality of the product is managing to sustain sales at this price premium, with some farmers in France responding very well to it, since France is considered a premium agricultural market and organic bio-compost is in high demand over there. There is also some sense of customer loyalty towards the product due to its high quality, with farmers that try this product, appreciating it and becoming recurring customers.

Local/regional production and consumption: Stakeholders of the LLab identified its story as marking a key turning point in the journey towards the region progressing towards the bioeconomy, setting an exemplar for how products can be locally/regionally sourced, manufactured and consumed, reducing dependence on external economic flows amidst geopolitical and market transitions and uncertainties. Stakeholders appreciated that the new reality that is being crafted by the LLab demonstrates an example of how local bio-based production and consumption patterns are possible and even profitable, which could potentially encourage other regional actors to also work towards similar initiatives, thus facilitating a larger transition for the region as a whole.

Increasing shareholder confidence: After the market success of the bio-compost and the business turning profitable, the farmer shareholders have become more confident of the business, a shift that is visible in the discussions in the shareholder general assembly meetings. While previously, the farmers were conservative in discussing financial options, avoiding big monetary allocations which they considered risky and only supporting marginal investments, they have now started considering and discussing bigger and riskier investments into the business, confident in the business' ability to procure the requisite capital and make profitable use of it, such as upgrading the biogas digester equipment in the second digester even though the commercialisation of the biogas has not started.

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Regional, national and international exemplarity: The story of the LLab is known far and wide, not just as a story of successful community action within agriculture, but as one of the potential of bioeconomy as well. The LLab hosts farmer groups from all over Europe who want to study the model of the LLab and wish to replicate the same in their regions. The LLab members explain to these groups that their strength is in the community and in being able to look past their differences to consolidate an organisation, chart out a mission and eventually, procure funding. They cite their togetherness as a community as the starting point for their success story.

Reinforcement of agriculture as a livelihood of the future: The heart of the LLab's business intertwines deeply with agriculture, with the biowaste generated from the animal husbandry activities serving as not just feedstock for generation of several new end-products but also for community engagement and collaboration. The same livelihood of agriculture that was previously responsible for generating waste that was polluting the groundwater reserves, is now creating new economic and social value in the region. The stakeholders emphasized repeatedly that it is this reinforcement of keeping alive the farmlands' future, that is and should always remain at the core of the LLab's business, since this case is a shining example of how being rooted in agriculture, local communities can generate new ideas, bring together several actors and create value.

Weaknesses

Limited commercialisation of bio-compost: Up until now, there has been limited focus on commercial strategizing for the business, with no systematic market research or planning for exact market segments to be targeted to sell the end-product. This has ended up in limited market success in local markets amidst several competitors, even though the bio-compost has managed to perform well in external markets, such as amidst farmers in France. Several stakeholders highlighted this as the primary concern for the business to sustain in the future.

Challenges of commercialising the biogas: A main challenge of the biogas business is creating the infrastructure to bring the end-product to the customers. The biogas facilities are located five kilometres away from the bio-methane relevant natural gas grid and there is no transmission infrastructure connecting the two. The investment to, let's say, build gas pipelines, is significant, but the feasibility for either Alcarras Bioproductors or the gas grid to do it without any additional support, is limited. Further, applying for credible carbon credit certification may have very specific requirements and the LLab needs to ensure that adherence to these requirements does not hinder the development and, eventually, the commercialisation of the biogas.

Challenges of constructing an operational and systemic approach to the Bio-Polygon: Some weaknesses appear in the exploration and negotiation of the bio-polygon due to the lack of knowledge and capabilities about the synergies in the envisioned circular bio-industrial park. It is important to understand all the synergies between different business while ALC Bio-lab is still creating and developing the other two businesses, bio-compost and biogas. It requires very different type of actions, negotiations and knowledge that should be developed at the same time.

Opportunities

Executive team professionalisation: The executive team explained that currently, they have somewhat flexible profiles, where they often have to take on tasks that they are not trained for, such as reading and interpreting legal documents and applying for bureaucratic approvals. Team members expressed inadequacy in the roles present within the organisation, such as for marketing, branding and commercialisation. More hires with specific competencies may be needed to take on specialised responsibilities and for work allocation to be structured better through, for instance, departmentalisation, which is currently lacking.

Creation and expansion of markets: Several stakeholders highlighted the need for increased market activity in the bio-compost value chain, as well as scoping out and validating potential market opportunities for the biogas value chain. Working together with a commercial partner for bio-compost was seen as aligning well with

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expanding market priorities. Many felt that internationalizing could open up new customer segments and opportunities for the LLab to tap into. Others discussed that looking for specific market segments that would be receptive to a premium bio-compost product, could provide a much needed focus and directionality for the commercial strategy. The LLab is already in talks with at least two potential commercial partners. One of these has a significant international presence (a representative from it also participated in one of the workshops), to scope out how they could collaborate and sell one of the LLab's end-products, the bio-compost, to farmer networks in different countries.

For the biogas value chain, ideas have been floated for biogas' utilisation as biofuel in trucks (including the LLab's own waste collection trucks) and other vehicles by setting up or partnering with a local gas pump, alongside selling electricity to the grid. The requisite infrastructure for the latter may be considered lacking and a huge capital investment may have to be incurred to set up pipelines connected to the grid. Alternatively, the gas could be compressed and liquefied and transported to the grid. The LLab has also applied for Guarantees of Origin (GO) certification that can then bring further revenue and is also considering application for carbon credits sale in the carbon markets. The operational and financial viability of these ideas needs to be determined to find an optimal go-to-market strategy for the biogas value chain.

Advancing data capabilities: The executive team explained that to generate more revenue from the bio-compost product, they need to make their processes more efficient. However currently, they have very limited understanding of the intermediate flows within the process, leaving them with inadequate knowledge to make efficiency-related interventions. Thus, they expressed the need for new systems that can trace, monitor and store information about all flows and processes within the production system, that can eventually enable process optimisation. This system will also help in getting a better understanding of the by-products and residues generated in the process, enabling the channelisation of these resources to suitable valorisation opportunities.

Customer awareness: One of the reasons that stakeholders cite for the LLab's bio-compost not selling much in the price-sensitive local markets, is the lack of awareness amidst potential customers about how this product is different from other competitor products in terms of its quality and the output it can yield. Initiatives to increase such customer awareness can be undertaken, with a systematic branding effort, a story outlining the origin of the product as being farmland-based instead of from the chemical industry and simplified data to back up claims on the premium quality of the output and what it can deliver to its users.

Threats

Premium price point and potential market competition: Due to the high quality of the bio-compost being produced by the LLab, it is being sold at a much higher price than most competitors in the market. This exposes the LLab to potential market fluctuations: since they are reliant on a customer base which is currently limited to very specific regions, market disruptions affecting any of these regions could lead farmers to cut costs and look for cheaper alternatives, significantly dampening the sales of the LLab's product. The high product price could also thwart efforts to expand into newer markets, with customers having limited incentive to depart from existing trusted players to try out a brand that is new, not trusted and yet, expensive. This makes even more sense given that the primary target audience would be farmers, who prioritise keeping cultivation costs at the minimal. Thus, there might be a need to tentatively lower the product price while entering new markets, at least up until they manage to capture a stable position in the market.

Big financiers' competing priorities: Some owner-shareholders (who are also the primary producers providing feedstock for the business) expressed their reservations about future financing of the business by big external financiers who are not rooted in the local agricultural and communal context that underpins the Alcarras story. They are concerned that seeking such financing sources has the risk of strategic profitability concerns overpowering the farmers' interest. The owner-shareholders want the business to remain connected to the original spirit of solving the farmers' waste problem and prioritise that over maximising monetary returns. Such

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prioritisation might leave the business with limited financing options, where future growth might have to be fuelled solely via self-financing, public funding and grants.

6.3.2 Living Lab 2: Bio-Silica Lab (Leader: CeNTI)

Value chains Bio-Silica Lab consists of three interlinked value chains:

1. The first consists of valorising rice husk to make bio-silica, a bio-based substitute of silica, which is an industrial component.
2. The second consists of valorising ash from biomass combustion in industrial biomass digesters to make bio-silica.
3. The third value chain consists of modifying the aforementioned bio-silica for different properties, a customisation that may be required for different industrial applications. These properties include antimicrobial nature, hydrophobicity and flame retardancy.

The discussions that were facilitated amidst the stakeholders of this LLab focused primarily on the first and third value chains due to their relatively advanced stages of development vis-a-vis the second value chain. Different stakeholders focused on different parts of the value chains depending on their roles: for instance, feedstock providers focused more on the first value chain while potential end-users focused on the third value chain and the specific customisations of bio-silica that could ensure viable utilisation of bio-silica in their industrial processes. Thus, the following analysis has been undertaken keeping in mind that the third value chain builds on top of the first two, with several themes being discussed across them because of significant interlinkages and commonalities that exist amongst these.

One online workshop was conducted with 14 stakeholder representatives on 21st March 2025. These stakeholders included:

- 5 scientist representatives from the LLab
- 3 end-user cluster representatives (industrial clusters of automotive, textile and battery)
- 2 potential end-user representatives
- 2 end-user company representatives
- 2 feedstock provider representatives (rice producers' associations)

Further validation data was gathered via interviews with LLab principal manager and researcher.

Key actors and activities

Scientific researchers: Innovating new value by applying technical expertise

The creation of this LLab was only possible due to the deep involvement of CeNTI (a leading R&D Institute in Portugal on Nanotechnology and Advanced Materials) researchers with the frontiers of the scientific community, which enabled them to extract the knowledge on conversion of biomass to bio-silica in the scientific literature, to explore it in the lab. CeNTI scientists tested out several bio-based feedstocks at the lab scale, choosing to eventually focus on rice husk due to it demonstrating the highest silica yield rate per unit mass of feedstock. It was their extensive know-how on silica-based particles to be incorporated in end-products, that pushed them to develop multifunctional bio-silica particles (with antimicrobial, hydrophobicity and flame retardancy properties) and publish a patent (Patent ID: WO2024009250A1 Functionalized Silica Particles, Obtention and Uses Thereof).

Primary producers and food processing factories: Providing feedstock

The LLab has sourced rice husk for its lab-scale valorisation processes from a few different rice farmer associations. These rice farmer associations are a viable source for feedstock supply because they not only aggregate the rice produce from their farmer members, but also have the requisite machinery to peel the husk from the rice grain. This rice husk has traditionally been used for animal bedding in nearby farms or incineration for energy production, and thus, the rice farmer associations have been excited about this new scientific exploration of their bio-waste by the LLab. The LLab has also been in talks to source rice husk from some food companies' factories that buy the rice (with the husk) from rice farmer associations and undertake the husk peeling themselves.

Potential end-user companies and clusters: Providing and promoting different markets for bio-silica

The LLab has identified the textile, automobile and battery industries as examples of key market segments where silica is used in the manufacturing process, thus presenting an opportunity for bio-silica to substitute synthetic silica. At least one end-user, specialising in making three-dimensional(3D) biotissue analogues, has already been involved in testing the bio-silica application in their manufacturing, a process that is ongoing. The end-user clusters, representing the aforementioned industries, self-identified themselves as being crucial intermediaries that can serve as a key contact point for disseminating information and enthusiasm amidst their several members regarding bio-silica and the feasibility of replacing synthetic silica in their manufacturing processes.

Feedstock availability

Based on their knowledge of Portugal's annual rice production being at 160,000 tonnes, a rice farmer association representative estimated rice husk to reach an annual quantum of 30,000 tonnes, most of which is not valorised currently. Thus, they expressed confidence in this sufficient supply of rice husk being easily able to foster a fully-grown, industrial-scale value chain, at least as far as the supply of feedstock is concerned.

Rice production in Portugal is primarily concentrated in the river basins and estuaries, where abundant water is available. The most prominent rice fields are found along the estuaries of the River Sado (notably around Alcácer do Sal), the River Mondego (covering areas such as Coimbra and Figueira da Foz), and the River Tejo (with key production zones around Lisbon). Rice husk can be sourced from these regions either from rice milling companies or from agricultural cooperatives/associations (as long as they have the necessary machinery to peel the husk from the rice grain).

Discussions have been ongoing with several stakeholders, including the Portuguese Environmental Agency, where the need has been highlighted for a shared open-access platform listing the biomass availability (types and quantities) and mapping them to the regions from where they can be sourced. The possibility of the regional commissions to lead the process of this mapping has been discussed, however this exercise has not started as yet.

Multi-sector industrial synergies

Interdependent goals and collective industrial standards: An end-user highlighted that the adoption of a novelty like bio-silica may be facilitated by an industry-wide effort instead of a company-level effort. After all, it is common for some companies to feel hesitant to adopt something innovative if it is seen as a significant deviation from wider acceptable industry standards. Thus, to prevent further pushback along their value chains, it is beneficial for the entire industry, be it that of textiles or automotives, to come together and discuss the potential bio-silica has for being integrated into their processes. This can also be fruitful in meeting larger sustainability-related goals that have been set at the industry-wide level, have a specific timeline and are difficult to work towards independently within just one company.

Inspiring collective understanding of by-products for collective valorisation: An end-user cluster representative, who was inspired by the LLab's story of valorising rice husk that was considered as waste,

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explained how a lot of waste is generated within their industry itself, the value of which remains untapped. Thus, they called for deeper collaboration and cooperation between members of the same industry, as well as across industries, to contribute to knowledge on the different waste products that may be generated in different value chains. They ideated that this could enable different actors, including scientific organisations like the LLab as well as those within the same industry, to look into recovering value from such waste streams and utilising them in their processes.

Gaps in relevant schemes

Restricted waste processing rights: An end-user cluster representative explained how it may be a challenge to get to integrate bio-silica in their industrial processes in the near future because of national regulations which restrict any entity other than waste management authorities from dealing with waste. A license can be applied for separately to get such rights, but this approval process is tedious and takes a long time, thus discouraging the maturation of this value chain at the industrial scale.

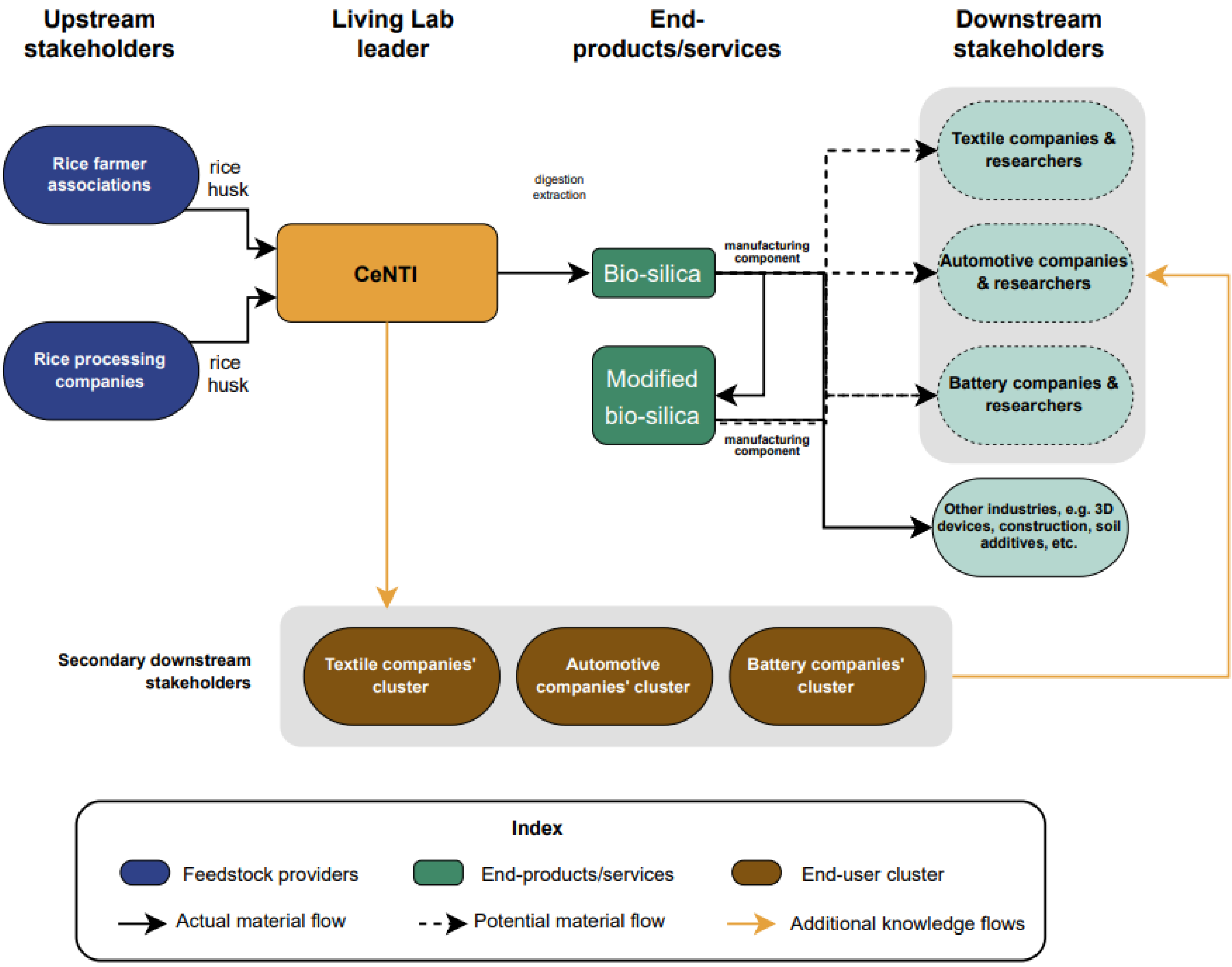

Figure 28. Multi-stakeholder value chain map and synergies for LLab2.

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SWOT analysis

Strengths

Potential value addition for primary producers and food industry: Rice farmer association representatives expressed that there is enthusiasm amongst the rice farmers for the novel bio-silica material since it is valorised from rice husk, which they perceive as something that could bring them additional revenue in the future, even though they have not seen such benefits as yet due to this technology not having been scaled to an industrial level in Portugal. Similar benefits may apply to food processing factories that buy the rice from the associations as it is and carry out the rice husk peeling.

Ensuring feedstock traceability and standardisation: LLab researchers explained how they have a vast database of their experimental trials with different batches of feedstock, wherein they record both traceability as well as material properties of the valorised bio-silica. Having experimented with different varieties of rice husk from different parts of the world, the LLab researchers have concluded that the resulting bio-silica has a similar material profile across the different varieties, which serves as a crucial step towards having a standardised end-product for industrial application. Regardless, the LLab researchers will be able to provide specific information regarding feedstock batches for quality monitoring and traceability purposes. An end-user cluster representative underscored traceability as being valuable for their members in light of the upcoming EU Digital Product Passport implementation.

Weaknesses

Laboratory-to-industry lag: One of the LLab researchers explained how often, the laboratory research is advanced and is ahead of the technology that industries are implementing. However, in some cases, the lag gets sustained for even longer if equal efforts are not made to disseminate not just the advancements that are being made in the lab, but also how they can be brought to the factories. The researcher acknowledged that the LLab should increase its information dissemination activities concerning bio-silica and have interactive workshops with industry partners or their cluster representatives more often.

Potentially limited benefits to primary producers due to industrial feedstock sourcing: As the rice farmer associations explained, very often, many associations do not have the requisite machinery for peeling the rice husk and sell their rice as it is to food processing factories. Such factories may typically be sourcing the rice from several different associations and thus, have significant bargaining power. Therefore, an industrial actor who wishes to source large quantities of rice husk, may turn to food processing factories because of the quantum of feedstock they handle and the predictability of supply. Any monetary benefit accruing from such a transaction may not trickle down to the rice farmer associations who actually produced the rice husk in the first place.

Opportunities

Process optimisation beyond the laboratory scale: LLab scientists have validated their process at the pilot scale, demonstrating its practicality in a controlled research environment. However, the calcination of rice husk remains a bottleneck due to the limitations imposed by CeNTI's high-temperature oven, which has a capacity of 216 L. This restricted capacity results in a time-consuming process. Moreover, as a research centre, CeNTI's production throughput is limited to pilot scale. To understand industrial-level viability in more detail, they wish to test the process with more sizeable machinery. They are now seeking a partner who would be willing to collaborate with them on the same by allowing them to test out their process, especially the rice husk burning process, in an industrial boiler. They have been in talks with a couple of willing companies, however the volume of rice husk needed for even a trial run in an industrial biomass boiler is far beyond what the LLab researchers have worked with up until now. Thus, they are in the process of configuring the logistics of this process, amidst resolving some other concerns.

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Catering to emerging future needs of industries: LLab scientists discussed how the end-users may encounter challenges and market demands in the future that they may have not anticipated as yet, in response to which their products may be required to exhibit dynamic capabilities and adaptabilities. By demonstrating bio-silica as a novel customisable material, the LLab has positioned itself to tap into futuristic opportunities within industries that may or may not exist as yet, by reimagining and developing bio-silica as a palette to which different properties can be added.

Deepening engagement with end-users: The LLab scientists emphasised that an end-product that is novel brings forth a lot of uncertainties and reservations from companies about its cost, efficacy, ease of adoption and benefits. To alleviate any concerns potential end-users may have about these aspects, the LLab emphasised the need for expanding collaboration to multiple actors and undertaking information dissemination initiatives. An end-user cluster representative also mentioned that relevant certifications may also help in boosting credibility and trust for the end-users.

Threats

Conservative industrial standards: An automotive industry end-user cluster representative explained how their industry is conservative in terms of being very price-sensitive for the material inputs, as well as being risk-averse and non-experimental about the material characteristics of the inputs they feed into the production process. Although the times are changing and everyone has started acknowledging that new materials need to be explored, the LLab may still encounter some initial hurdles in the uptake of their novel bio-silica by automotive end-users.

Economic comparability to synthetic material: An end-user cluster representative emphasised that the preliminary concerns that their members will have will be centred around not just the economic viability, but also the predictability of bio-silica, i.e. will bio-silica be cheaper than synthetic silica? Will it be available all-year round or will it be affected by the seasonality of rice production? Can an annual contract for bio-silica supply be consolidated with predictability of required volumes? If these questions are left unresolved, industries may hesitate to replace their synthetic silica with bio-silica.

6.3.3 Living Lab 3: Liguria Bio-Lab (Leader: FILSE)

Liguria Bio-Lab works on several value chains valorising fish industry side-streams, by-products, old fishing nets as well as agro-food industry side-streams, for different end-products. However, within the scope of this work package, they chose to focus on the value chain consisting of valorising fish by-catches from the Liguria region to make an agricultural biostimulant for enhancement of crop output. The biostimulant will be produced at the location of the cooperative in Santa Margherita de Liguria harbour using a fermentation-based technology.

One hybrid workshop was conducted with 9 stakeholder representatives on 24th February 2025, with the 3 LLab representatives joining in-person and the rest joining via the online medium. The list of attending stakeholder representatives can be found below:

- 3 LLab representatives (from the leader FILSE)
- 1 scientific expert
- 1 technological provider representative
- 1 regional innovation hub representative
- 1 university researcher
- 1 marine protection agency representative
- 1 slow food non-profit representative

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Further data was also collected from site visits and interviews (mostly in person but some online) conducted with all the aforementioned stakeholder representatives as well as with some additional stakeholders that included 4 potential end-user farmers, 2 regional waste management company representatives, 1 potential end-user researcher, 1 aquaculture company representative, 1 fishers' cooperative representative, 1 logistics partner representative, 1 scientific researcher and 1 policy partner representative. These interviews were conducted between February and March 2025.

Key actors and activities

FILSE: Fostering regional development by connecting and facilitating diverse expertise for value creation

The bioeconomy in Liguria is driven by a set of organizations working on collective action for regional development and resilience deeply rooted in its ecological systems and nature-based resources. The creation of the Liguria Bio-Lab is inspired by concern for and engagement with the development needs of the Ligurian region. Being a predominantly coastal region, a huge portion of the Ligurian economy is fuelled by its fish /fishery industry. Thus, FILSE wanted to create value for the region using the resources that exist within the fishing community itself. This rootedness in local needs and resources enabled FILSE and other critical partner organisations (such as researchers from the Universities of Genoa and Turin) to mobilise requisite expertise from within the local community itself, to reimagine and valorise "waste" from the fishing industry. Now that the value chains are starting to emerge, FILSE is continuing its critical role in coordinating between different value chain actors, facilitating procurement of relevant resources and inspiring further new partnerships.

The LLab includes a set of stakeholders supported and driven by FILSE, with the scientific implementation of the value chain being driven by the lead scientific expert, supported by the fishers' cooperative and a technology development company that is based at FILSE's Business Innovation Center. Each of them plays a central role in this emerging value chain.

Primary producers: Providing feedstock and building bioeconomy entrepreneurship

Currently, the main primary producers and providers of the feedstock (fish by-products) is the cooperative of fishers in Santa Margherita Ligure, located in the Liguria region. They have agreed to provide their by-catches (unintended smaller fish catches that cannot be sold in the fish market and have traditionally been considered as "waste") for processing and conversion into an agricultural bio-stimulant. Furthermore, they have agreed to locate the fermenter equipment for this process at Santa Maria Ligure harbour, where the main office/market of the fisher's cooperative is located. This proximity to the fishing spots is crucial to prevent decay of organic matter due to long transportation times. They expressed enthusiasm for future investments into more conversion equipment if the ongoing prototyping phase is successful, since they are hopeful that the agricultural biostimulant can serve as an additional source of revenue for them. They are currently analysing the logistical and legal implications of situating the equipment near the harbour versus on one of the fishing boats.

Value chain leader: Bringing technical expertise and inviting relevant actors

The lead scientific expert of this value chain was brought in by the LLab due to their scientific background which led to them imagining, conceptualising and developing this value chain. The expert describes themselves as being a biologist as well as a farmer. The Liguria Bio-Lab's work on fish, combined with their own life as a farmer, inspired them to find synergies between the two, thus creating the concept of valorising fish by-catches to create an agricultural biostimulant. They have utilised their scientific expertise to operationalise the fermentation process, test and validate this concept at the lab scale and on some crops, and are now guiding the modelling of the equipment that the LLab is developing for this value chain. Their farmer background presented a rich network of very diverse farmers spread throughout the spectrum of different technological integrations, whom they are now inviting to test and validate their biostimulant end-product.

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Technological provider: Modelling and building the conversion equipment

The technological provider for this LLab is a technology consultant company that is working on developing the fermenter equipment for the fish by-catches to be valorised into an agricultural bio-stimulant. They are in constant contact with the aforementioned lead scientific expert to align on several fronts: understanding the different stages of the conversion process, determining exact specifications and capacities for each stage and developing the larger model of the equipment, customised to be somewhat small, portable and easy to use for the fishers. The pilot fermenter has only recently been funded by the PRIMED project.

Potential end-users: Testing end-product efficacy and creating a potential market

The LLab has been in talks with a diverse range of agriculturists to test out and validate the end-product of the value chain, the agricultural biostimulant. These include farmers who use minimal equipment and zero technological interventions to practice subsistence terrace farming on the mountains of Liguria, a greenhouse farmer who cultivates their crop using newly developed aeroponics technology and a floriculture research institute that conducts research on different flowering species and their qualitative and quantitative responses to different interventions. These primary producers and researchers have expressed excitement for testing out this new biostimulant on their crops to assess its efficacy.

Legal consultant: Clarifying regulatory aspects and helping to scope value chain compliance

The LLab has partnered with a legal consultancy to provide policy and regulatory insight into how legal issues surrounding animal by-products should be tackled in the development of this new value chain. This consultant also acts as an interpreter and a bridge between the local, national and European-level regulatory landscape, bringing forth discrepancies and suggesting relevant changes that the LLab and its partner institutions can push for, in alignment with the needs of their value chain.

Slow food non-profit: Spreading awareness regarding bio-based sustainable consumption

The LLab has partnered with a slow food non-profit that promotes sustainable and healthy food consumption practices amongst consumers. The non-profit is very excited about the new biostimulant that is being developed in this value chain, deeming the theme of valorisation of bio-waste to cultivate better food and potentially replace inorganic chemical interventions, as being aligned with its organisational mission. They have agreed to disseminate awareness about the developments in this emergent value chain, especially once the end-users start using it as a regular practice, to consumers. They also have partnerships with restaurants and food companies, and have expressed willingness to reach out to them and foster new connections between them and the farmers who agree to use this biostimulant.

Feedstock availability

The cooperative of fishers in the Santa Margherita Ligure is the first active supplier of feedstock for this value chain. Stakeholders mentioned sufficient and predictable supply of fish-based feedstocks for the respective value chains as critical for the success of these value chains. The LLab has reported that there are some other fishers' communities and cooperatives in Liguria region that have been contacted and may be interested in replicating the process. Other potential source of feedstocks may include aquaculture companies and fish processing companies in the region. Yet, sufficiency of feedstock in the region to foster fully matured and scalable value chains, cannot be determined at this stage since the different sources and quantities of feedstocks have not been systematically studied, mapped and documented. This is a critical first step that can be undertaken at the regional level, to be able to forecast which kinds of feedstocks may be available in the future, in what quantities and thus, which value chains can be modified or sustained as they are.

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Multi-sector industrial synergies

Unifying discussions across different fish-based value chains: LLab representatives explained how they wish to have joint discussions for the different fish industry-related value chains by engaging the relevant actors in a collective strategy-making process. They expect that this process could lead to them uncovering more synergies and enabling cross-fertilisation at different stakeholder levels. For instance, each of the feedstock providers is currently focused on providing for a single value chain. But it may be possible that the aquaculture company, alongside providing side-streams like fish skin, fins and bones for bioplastic and cosmetics production, may also be able to provide fish by-catches for biostiumlant production. Similarly, other side-streams and by-products that are not currently utilised, may be of use to one or more of these value chains and should be discussed openly to facilitate such synergistic resource exchange. This same discussion can be replicated in finding end-use application synergies amongst the different value chains, for instance, the fish-based biopackaging from one value chain may be valuable in developing suitable packaging and coating for the biostimulant.

Bringing ecology expertise to fish-based businesses: LLab representatives mentioned how they wish to be mindful and respectful of ecological processes and patterns of the marine ecosystem while birthing these new value chains from within the fish economy. They only wish to carry out their activities of developing these fish by-products' based value chains if the core fishing activities are renewable and sustainable, and not if these are leading to overfishing. Further, with climate change and marine ecosystem acidification, there may be new changes in fish species as well as migration patterns that the LLab wants to take into account when developing value chains for the future. Thus, they expressed their desire for co-develop these value chains for the future alongside an ecologist who has expertise on marine ecosystems, especially of the Ligurian region, to take into account the dynamic changes affecting the fish and their living environments.

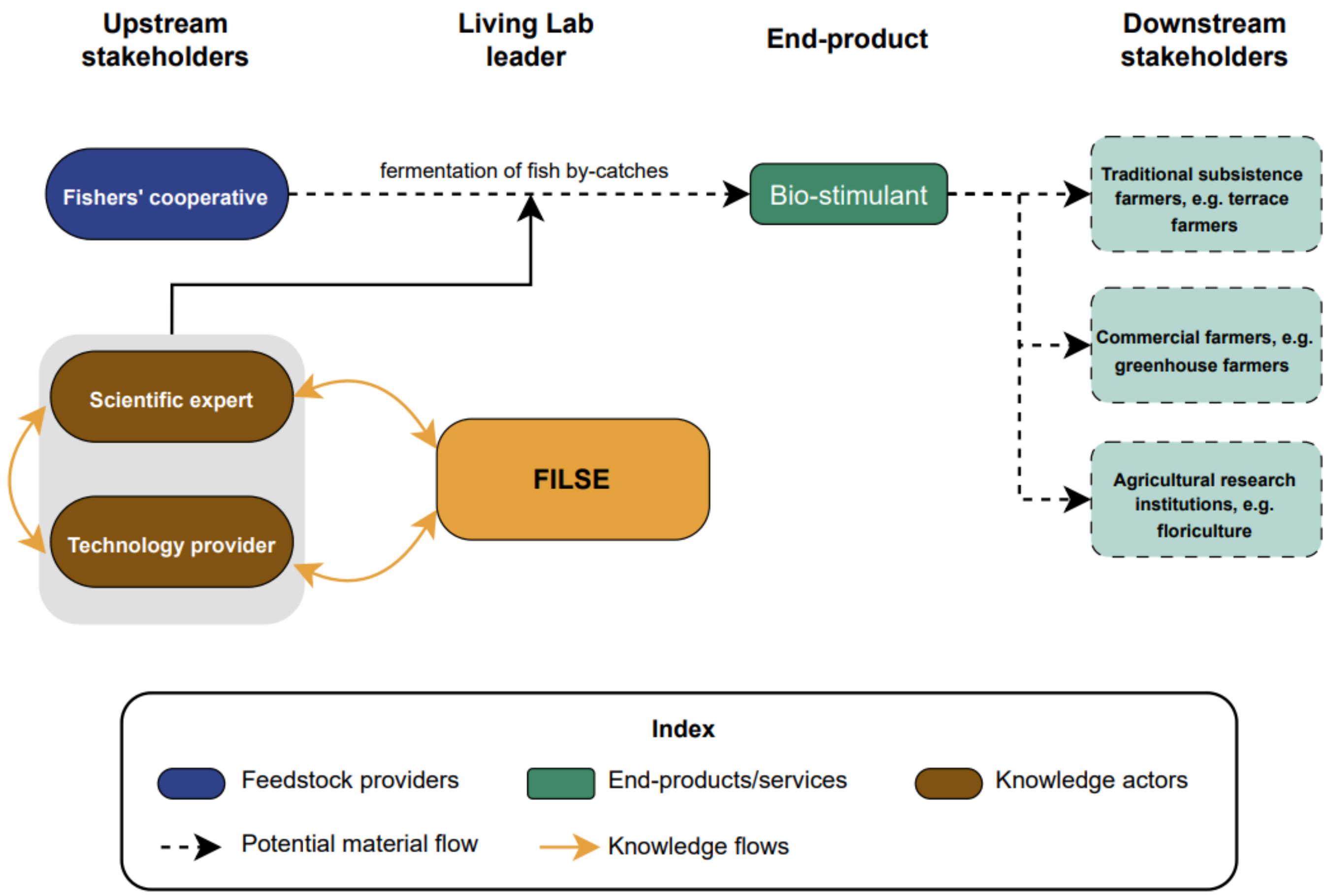

Figure 29. Multi-stakeholder value chain map and synergies for LLab3.

Gaps in relevant schemes

Differing interpretations of waste streams at regional, national and local levels: At the EU level, there are two relevant regulations and one directive that affect this value chain: regulation 1069/2009 (Animal By-products Regulation), regulation 142/2011 and the Waste Framework Directive. Taken together, the regulations define what an animal by-product is, provide the classifications for different kinds of animal by-products and recommendations for country-level approval processes for management of these by-products including transportation, certification and traceability issues. However, the Waste Framework Directive approaches the same by-products and other waste streams with a broader scope that allows for them to be valorised for the creation of new products, as is the case in this value chain.

At the Italian level, the Animal By-products Regulation has been adopted as a guideline, leaving room for each local authority to interpret the regulation and enforce it as per their understanding. Since the Waste Framework Directive is not enforceable as a regulation, the government has been even less active with this. This leads to the local authorities categorising animal by-products based on the Animal By-products Regulation, even though some authorities have also deviated from that. This leads to strict and restrictive processes being imposed in the spirit of the Animal By-products Regulation (which even deals with hazardous animal by-products), even though for valorisation-based value chains, the Waste Framework Directive should be promoted as a supporting and enabling system.

In addition to this confusion between two different EU schemes for different purposes, the local enforcement differs even within an authority from one case to another, due to lack of standardisation. For instance, in the Liguria region, some approvals have been granted easily, whereas others require extensively detailed applications, sometimes going into more detail than the EU regulations recommended. These inconsistencies have led to lack of standardised information on which level of regulation to follow and how to prepare adequately for the approval process.

Commercialisation of waste-originated end-products not permitted: Even though the Bio-Liguria Lab and other related actors in the region are undertaking research to valorise animal by-products and side-streams, these research entities are ending up having to destroy because approvals are only granted for research purposes and further approvals for commercialisation of these products is not granted.

SWOT analysis

Strengths

Collaborative and inclusive approach for regional development: LLab representatives described their work as being steered towards developing a collective force in the region, which they referred to as “one region, one strategy”. They aim to be inclusive in the scope of the work they do and the actors they bring in, engaging with and fostering interlinkages between private (such as primary producers, technology providers and end-users) and public actors (such as regional regulatory bodies who have jurisdiction over by-products related legislations).

Community embeddedness: Showing us around their incubator in Genova’s industrial area (wherein the technological provider for this value chain is also situated), the LLab representatives explained their “physical connection” with the “real economy” of industrial actors as being “strongly impactful” and not as “a distant administrative actor”. They expressed pride in how this strong connection manifests itself in enthusiasm and curiosity from the companies whenever they have new initiatives, wherein they see that their “event rooms are full of participants”.

Ecological embeddedness and conservation: Value chain partners discussed how their motivation to engage in bioeconomy-related work stems from their love for the local nature and surroundings, how they were pulled back from abroad by the call of their land and its beauty. Agreeing with this spirit, one actor reminded us that it is essential that this natural ecosystem is sustained, that one form of economic exploitation is not replaced by another. Therefore, the value chains being developed by the LLab should only valorise what happens to be generated as by-products in economic processes and that these new value chains should not lead to further overfishing to ensure feedstock supplies. Similarly, the preservation of local agricultural soil quality, which is being promoted by the LLab's biostimulant, was also highlighted as integral for the ecosystem to keep thriving.

Promoting sustainable agricultural practices: The biostimulant being produced by this value chain is not just bio-based (being produced from fish by-catches, which are caught anyway without the burden of additional fishing activities) and safe to apply from a farmer's health perspective, but also promises qualitative improvement in crop yields, thus being able to replace conventionally used inorganic chemical fertilisers. Further, LLab representatives explained that they were told by the farmers that there are not many comparable products like this that deliver qualitative, even nutritional, improvements in crops, thus hinting at how the biostimulant may have to deal with only limited market competition. This product, alongside weaning off agriculture's dependence on fossil-based chemicals, may also improve soil and thus, ecosystemic health of farmlands.

Promoting healthy consumption practices: The preliminary lab tests of the biostimulant show positive results on crop yields along several parameters, including nutritional profiles for certain crops. Thus, this value chain is supporting cultivation of safe (from chemical stimulants) food that is high in nutritional value, which will ultimately contribute to healthy food consumption.

Weaknesses

Uncertainty regarding operationalising the value chain: Currently, the LLab is considering two main options for the operationalisation of its value chain. The first option involves extending the small-scale model currently used in Santa Margherita's fishers' cooperative by constructing small, decentralized fermentation facilities in various hubs across the Ligurian region. In this model, feedstock would be supplied directly by the local fishers, being brought straight from the sea to the fermentation units. However, the price of an individual fermenter may be a prohibitive for every cooperative to invest in without financial assistance and the lack of critical scale may yield low volumes of the biostimulant that eventually do not make this initiative profitable for them.

The second option involves pooling in resources of various cooperatives and building one or more medium-sized fermentation facilities centralized in strategic locations to achieve technological and thus, economic scale and efficiency, that makes the value chain profitable based on the demands of the markets and the costs. This model would require establishing a logistics network to transport feedstocks from the fishers in multiple villages to the central facility. Health and safety regulations are a key constraint, as the side-streams must reach the fermenter in less than 24 hours to remain usable. These logistical aspects could lead to additional costs.

These issues have not been discussed and a viable operational model has not been determined, which could lead to significant uncertainties and hesitation for other stakeholders to get actively involved in the process. Thus, a techno-economic assessment is necessary to evaluate the appropriate scale for the fermentation facility and to determine the feasibility of the biostimulant production volumes under each model. This can also be complemented with a market analysis for the biostimulant, regionally but beyond as well.

Limited business knowledge and capabilities: Amidst the principal stakeholders of this value chain (including the scientific lead, fishermen, farmers and the technology developer), no one has in-depth prior experience in entrepreneurship and business development. Yet, it is important to train the team on business and market knowledge and capabilities. FILSE is trying to bring these skills and capabilities to the table with their experience as an incubator. However, further development is needed with more analysis and assessments of future prospects for the business, such as market analyses, business model analysis, business plan and investment plan.

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Lack of funding and investment. A main challenge for the LLab is the lack of clear investment and funding on how to move the pilot to the commercialization and markets. Investment or funding is needed to build a commercial scale fermentation facility. This approach, regarding how to attract more investment and public funding to bioeconomy businesses in Liguria, is discussed by FILSE and other regional associations.

Opportunities

Additional livelihood for fishing community: Fishermen identified this new value chain as creating value from their fish by-catches, which they previously have had no use for and have not been able to monetise. The valorised end-product, an agricultural biostimulant, can be sold to cultivators, thus generating an opportunity for the fishermen to tap into an additional revenue source.

Procuring certifications: The LLab has already started considering getting certifications for their biostimulant, deeming it necessary for their market success in the agriculture market, where soil and crop additives have high standards of qualifications and certifications. This, they believe, will build end-user trust and credibility regarding the efficacy of the biostimulant, thus encouraging better market enthusiasm for the product.

Engagement with additional value chain actors: Stakeholders expressed that for the true potential of this value chain to be realised, actor engagement should go beyond just feedstock providers and immediate commercial users (like cultivators), and instead, should take an ecosystemic approach by considering actors such as municipalities, university researchers (who can provide crucial facilitator and knowledge resources respectively) as well as actors further down in the value chain, such as restaurants and endpoint consumers since they are the ones making the final decision on where to source their consumption from. This engagement can be done by participatory demonstration of the results from the biostimulant testing, with a higher focus on metrics that matter to the end consumers, such as taste and eco-consciousness, facilitated by intermediaries like non-profits working on sustainable consumption.

Threats

Limited funding sources: The LLab members mentioned that the ongoing prototype development would have been difficult without the PRIMED funding. Discussions around further funding sources have been very limited, with the focus on process and technology development overshadowing resources being allocated to procuring financing. This could potentially stall the continuity and scaling of the value chain. Instead of adopting an approach where the scientific specifications of the process are configured before funding is applied for, these two can be parallel processes, wherein both go hand-in-hand and feed into one another. Both private and public sources of funding need to be looked into carefully.

Difficulty of end-product standardisation: Since the LLab is dealing with fish-based waste that is produced and collected from different sources, there may be varying states of biological decomposition of the by-catches, especially if by-catches are to be collected from several different fishermen who operate differently. These uncertainties may be elevated if different fishing spots yield different kinds of by-catches, a problem which may sometimes be exacerbated due to migration patterns of fish, which may further get affected by seasonality and climate-related changes. These uncertainties may make it difficult to pre-determine fixed quality and quantity metrics for the end-product before the processing starts, thus hindering standardisation of the end-product. This standardisation and predictability is essential for the end-users to be able to develop reliable application practices, instead of having to change, for instance, the dosages of the biostimulant in each application. Such lack of standardisation and the application difficulties associated with it, may hinder sufficient uptake of the biostimulant by larger markets, especially by commercial players.

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6.3.4 Living Lab 4: BioEire Lab (Leader: IBF)

The BioEire Lab consists of two value chains.

- The first includes valorisation of forestry industry-related side-streams for conversion into biochar and bioenergy using pyrolysis technology.
- The second includes valorisation of dairy industry-related side-stream for conversion into biochemicals using fermentation technology.

The LLab offers pilot-scale facilities for testing and validation of these processes in the National Bioeconomy Campus in Lisheen, Ireland.

The first value chain is at an emergent stage of development, with at least one end-user and several local stakeholders having been involved. There have been some delays in involving the relevant stakeholders for the dairy industry-related value chain. Due to this PRIMED project Work Package requiring a specific maturity level of the value chains due to its deep engagement with the value chain stakeholders, BioEire Lab chose to focus on only the forestry-based value chain and will work with the dairy-based value chain after a suitable end-user selection in PRIMED's Second Open Call.

Two workshops, one online and the other in-person, were conducted with 10 stakeholder representatives on between March-May 2025. These stakeholders included:

- 3 LLab representatives
- 3 end-user representatives
- 2 county administration representatives
- 1 representative from a technical assessment partner
- 1 end-product cluster representative

Key actors and activities

IBF scientific team: Providing infrastructure and technical expertise for bioeconomy piloting, helping to co-create new value chains

The Irish Bioeconomy Foundation (IBF), the leader of the BioEire Lab, have brought together resources from several national and EU-level funding channels, to start building the National Bioeconomy Campus in Lisheen, Ireland. Their own facilities are at an advanced stage of development, with them having several bioreactors based on different technologies like pyrolysis and fermentation. These bioreactors are pilot scale-sized and the team's objective is to invite relevant stakeholders, such as startups, university and company researchers, to test their bioeconomy-related technical ideas (that they have already validated at the laboratory level) at the pilot scale at these facilities, to get requisite process feedback before they advance to the commercial scale. Along with the infrastructure, IBF also provides their own technical team to guide the users throughout the process, from potential feedstock procurement sources, the equipment utilisation to the analysis of the testing results.

IBF also plays an active and strategic role in shaping the early development of innovative bio-based solutions by engaging in collaborative discussions with technical entities and startups. These interactions help refine ideas and guide them toward testing and market readiness. For example, IBF is involved in exploring the valorisation of sitka spruce into high-value biochar. This product concept envisions two market pathways: one involves pre-loading biochar with microorganisms at the production stage for premium urban gardening applications, while the other envisions farm-level compost loading, offering a cost-effective solution for large-scale agricultural use. This downstream diversification of end product applications not only targets distinct markets but also creates opportunities to link forestry and dairy value chains. In particular, dairy farmers may benefit from the dual functionality of biochar in water filtration and soil enhancement. While the second route presents specific

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technical and regulatory challenges, IBF's continued facilitation of stakeholder dialogue is instrumental in addressing these hurdles and unlocking cross-sectoral collaboration and application.

A third promising extension under discussion involves the on-site utilisation of biochar, which can be enriched using various organic wastes collected regionally for a biogas facility currently undergoing community engagement and planning. This locally enhanced biochar will offer immediate application potential on the grounds of the Tipperary National Bioeconomy campus, where soil regeneration efforts are needed. Further applications may include ecological restoration in nearby peat-extracted fields, where traditional harvesting continues under community-led practices.

In parallel, a fourth emerging partnership envisions integrating pre-loaded biochar into national green corridors as part of ongoing municipal collaboration for decarbonisation. However, discussions are still in the early stages, and the initiative positively reflects growing momentum and multi-level cooperation to embed biochar into Ireland's broader climate and land-use strategies.

End-users: Utilising piloting infrastructure, bringing forth other end-users and financial sustenance

The objective of the LLab is not just for end-users to come to the LLab's facilities and utilise their pilot-scale bioreactors, but for them to also give the LLab feedback on the process and how they could develop the facilities further, especially since the facilities are currently at a very early stage. Involvement with these end-users also keeps the LLab at the frontier of scientific developments in the bioeconomy, thus giving them the edge of technological foresight through discussions with these end-users, which could help them anticipate future infrastructure needs better for the pilot scale. It is also hoped that a network effect will be created and propagated by the end-users, who can recommend the pilot facilities to other potential end-users, who can then come and use the facilities for their pilot-scale testing purposes. Finally, the LLab hopes that at some point, once they have engagements with a critical threshold of end-users, the facilities could be financially self-sustained by utilisation fees from end-users, which would be a significant advancement from status quo, wherein the facilities are being maintained and run mostly because of grant funding in making the pilot plant financially sustainable.

End-product clusters: Encouraging piloting by member companies

The LLab deems it crucial to maintain close ties with clusters of end-product companies, such as on biochar and bioenergy, since these are the companies that they plan to attract to their facilities for pilot testing. Indeed, it is not just early-stage startups that would need pilot testing: companies that wish to advance their processes or bring forth a new product could also benefit from testing their ideas at a pilot scale before they set up their own facility to commercialise the idea. Thus, end-product clusters can become a hotspot for information dissemination and encouragement to member companies to utilise the infrastructure and knowledge resources offered by the LLab for scaling up the bioeconomy

Technical assessment partners: Evaluating end-product characteristics and ensuring piloting success

The LLab also feels the need to have a technical assessment partner who can evaluate the quality of the end-product generated from the piloting process. This partner's role differs from IBF's scientific team in terms of the scope of assessment: while the IBF scientific team is well-equipped to deliver crucial feedback on the technical process itself, the technical assessment partner will look into the end-product and assess its specific marketable characteristics, especially with respect to a specific commercial application. For instance, the current technical assessment partner that the LLab has for the forestry residue-to-biochar value chain (Arti Char), will analyse the biochar to assess its qualitative properties for soil amendment, since that is the primary market that the end users will be targeting is aiming to target.

County council and local communities: Administrative compliance including community engagement

The LLab collaborates actively with the Tipperary County Council on aligning their efforts with the local administrative requirements as well as the county-level goals for decarbonisation and bioeconomy development. This county-level perspective and targets leads to a better directionality and steering of the LLab's growth, in terms of where they need to be in terms of immediate, long-term and intermediate targets.

The County Council also pushes for community engagement in the initiative, something that is also at the heart of the LLab itself, given that one of their goals is to create jobs for the local community with the National Bioeconomy Campus.

There are regular trilateral consultation meetings with IBF, the County Council and the community, where the community expresses their concerns about developments at the Campus (e.g. smells and fumes from the feedstock, possible mishaps at the bioreactor facilities, feedstock trucks blocking the relatively narrow roads) and IBF discusses how these concerns can be alleviated. The County Council also has mechanisms in place wherein they are required to put out a full public proposal for an upcoming project and the community can raise its objections. These objections have to be worked upon and unless there is full consensus on the project, the project is not allowed to go to the next stage. This has also necessitated IBF's engagement with the community, so that the National Bioeconomy Campus stays aligned with the County's and community's priorities.

Feedstock availability

Lurra Bio, the selected end-user from the first PRIMED Open Call for end-use validation, has proactively established relationships with feedstock suppliers through their forestry cooperative networks. The Living Lab has taken a hands-on and iterative approach to identifying optimal biomass inputs by trialing various forestry-related feedstocks in collaboration with Lurra Bio. These include sitka spruce, bark waste, ash-tree residues, and sawdust from multiple forestry processes. Technical partners will evaluate feedstocks to measure performance metrics and select the most promising options based on the outcomes of post-analysis.

While these efforts have laid a strong foundation, a broader-scale mapping of feedstock availability remains a key opportunity for further development. Such mapping would be essential for the long-term commercialisation of the value chain. In addition to estimating the volumes of forestry-based residues, understanding their geographic distribution and designing efficient logistics networks are critical—particularly given the fragmented and decentralised nature of Ireland's forestry sector. Stakeholders have acknowledged the potential of national-level initiatives, actively involving forestry and farmer associations and aimed at supporting coordinated blending and supply of diverse feedstocks, which could significantly strengthen value chain reliability and scalability.

Multi-sector industrial synergies

Local administrations' involvement with biochar-based soil amendments: The bioenergy cluster representative explained how some local authorities are already working on developing and facilitating biochar-based soil amendments for agricultural purposes. They expressed that there is strong potential for the LLab and the end-user to work in collaboration with these authorities to bring their scientific expertise to the administrative and policy developments that are in progress, as well as become an implementation partner for these initiatives.

Carbon sequestration technology: Biochar has been known to have carbon sequestration properties through pyrolysis. Its subsequent integration into agriculture as a soil amendment can further contribute to carbon sequestration and obtain carbon credits, the LLab end-user is considering further technological applications that can use the biochar that LurraBio plans to be producing primarily for carbon sequestration through the valorisation of spitka spruce. These considerations are a significant step in the larger context of biochar receiving

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increasingly higher merit in the policy landscape of the Carbon Removal Certification Framework (CRCF) and the EU having consultation meetings about expanding the certification portfolio from merely carbon removal and biogenic storage to biochar applications as well.

Biochar applications in dairy farms: The LLab and end-user have been discussing ideas for applying their biochar to dairy farmers' fields in two ways. Firstly, biochar bags can be used for filtration purposes in the fields, by filtering irrigation runoff to procure clean water that can be reused in farm processes. Secondly, the saturated biochar from the aforementioned process can be mixed with the animal slurry and applied to the fields, yielding higher crop growth in the farmlands as compared to just using the animal slurry by itself.

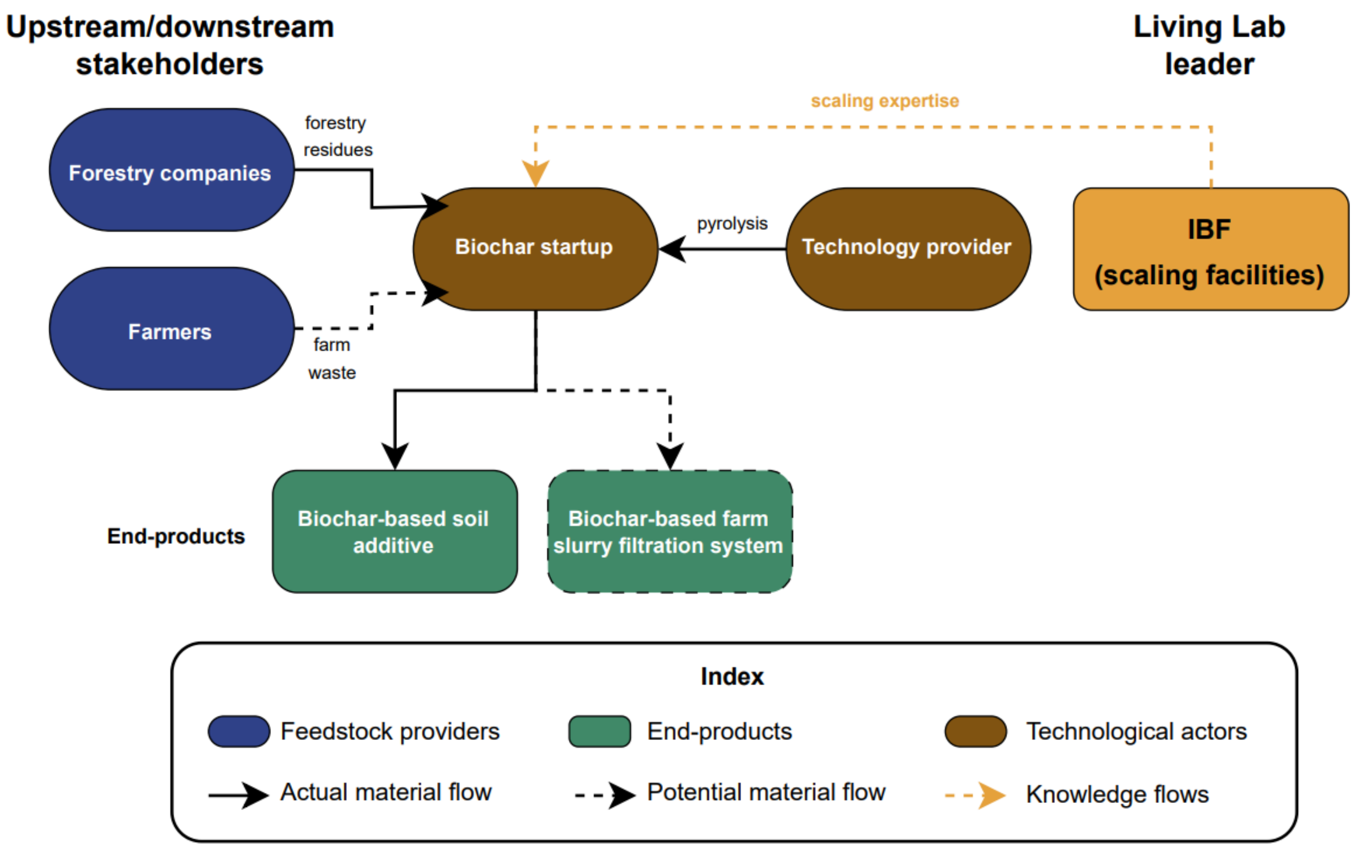

Figure 30. Multi-stakeholder value chain map and synergies for LLab4.

Gaps in relevant schemes

European Biochar Certification Group specifications: If the LLab end-user wishes to obtain certification for its biochar from the European Biochar Certification Group, they will have to adhere to very specific requirements, such as having the heavy metal contamination level as below a specified threshold. Further, whenever there is a change in the feedstock variety or quality, the certification process has to be applied for again, which becomes prohibitively expensive. Ensuring consistency is difficult without securing sources of large supply. However, partnerships with upstream providers are currently under preliminary exploration.

Such certifications are not just hard to receive, but adherence to these specifications is not immediately known through the valorisation process. Testing and characterization from external technical entities can serve to be a very expensive process and ultimately, the results may still turn out to be unsuitable for certification, considerations that can discourage applying for certification in the first place.

To navigate these restrictions, the LLab end-user has ambitions of trying out different feedstock valorisations to find an optimal recipe which complies with these specifications. Other stakeholders of the LLab, such as the

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bioenergy cluster representative, is involved in conversations at the EU level to change very restrictive requirements such as re-certification processes for feedstock variability as well as for the high certification costs. Further, there have also been conversations to establish a certification entity at the Irish level to navigate the aforementioned difficulties, but the establishment of such an entity is probably still a few years away.

SWOT analysis

Strengths

Bio-materiality and local ecological embeddedness: The LLab is trying for this value chain to be crafted around the feedstocks that can be made available and the sources where it is made available, instead of crafting a value chain independent of feedstock considerations and then having to procure feedstocks in an unsustainable and inefficient way. This is evident in the discussion the LLab and its stakeholders had about thinking of a technology and process model that can be located close to the sources of the feedstock to minimise logistical efforts as well as the degradation of the bio-based feedstock. This discussion is expected to also determine the technological configuration the LLab provides to the end-user during and after the piloting process. LLab stakeholders also discussed how their work is based on a story of sourcing and generating value locally, from Irish suppliers for Irish people (emphasising that they want to cater to all possible Irish markets first before thinking beyond), and that this story of local embeddedness must be told to people in the commercialisation phase for better market acceptance.

Dynamic testing abilities and process recommendations: The LLab is in talks with their technical partner to possibly conduct a micro-pyrolysis testing process before the piloting, and this testing will include dynamic configurations of several variables. For instance, the testing can be obtained for different atmospheric conditions, such as different nitrogenic levels and temperatures, to find the optimal process configuration to be advanced to the pilot scale, and eventually, to the commercial scale.

Application-specific biochar end-product analysis: The aforementioned technical partner has also agreed to carry out analyses of the end-product (biochar), not just regarding its generic physical and chemical compositional properties, but also, analyses catered to the specific end-use case. For instance, in this case, they have offered 30 different kinds of analyses that may be useful to have for a biochar-based soil additive for agricultural uses. These include analyses on porosity, water holding capacity, electoral conductivity, germination inhibition and finally, planned growth trials. The end-user complemented this breadth of analysis options by bringing in a community-based approach, highlighting how it is important for them to have a discussion with the farmers who will be using this end-product to understand the properties they care about and wish for in the end-product, and to prioritize those in the analyses.

Weaknesses

Technological configuration challenges: The LLab's scientific team has identified that achieving a particle size of 15–20 millimetres are optimal for efficient bioreactor performance and the success of the pilot project. The technical partner currently aims to reduce particle size to approximately one centimetre, although this capability may vary depending on the specific type of forestry-based feedstock. In cases where Lurra Bio will use a blend of feedstocks, additional steps, such as separation, independent size reduction, and detailed characterisation, will be undertaken with the technical assessment partner. The approach presents a valuable opportunity for collaboration between the LLab and the technical partner to align technical specifications, optimise biomass processing workflows, and co-develop a tailored configuration that supports robust pilot testing and scale-up potential.

Expanding product potential and strengthening commercial partnerships: The current value chain aims to develop biochar as a versatile product, with ongoing R&D efforts with technical partners, refining its properties based on the source materials used in pyrolysis and the potential for post-treatment with beneficial microorganisms. Beyond this primary focus of Lurra Bio & IBF, there are promising opportunities to diversify end-products and value chains. This will be achieved by partnerships with dairy farmers could enable on-farm biochar enhancement using water-diluted residues, thereby helping to reduce input costs and mitigate risks of water contamination. By standardising the size of biochar bags and accounting for weight variation post-loading, deployment could be made user-friendly and scalable. Nevertheless, further research is needed to define the optimal placement depth, nutrient infusion methods, and performance timelines to validate its use as a fully bio-based fertiliser.

Building entrepreneurial engagement and commercial pathways: To unlock the full potential of the LLab, expanding its network of entrepreneurial partners and commercial users is essential. Strengthening ties with local communities and primary producers—particularly those open to co-developing innovative applications—will help grow demand for the facilities and accelerate the transition from pilot-stage research to market-ready bioeconomy solutions. With strategic outreach and the right resources, the LLab is well-positioned to become a vibrant hub for sustainable enterprise and rural innovation.

Opportunities

Information dissemination and context-specific efficacy trials: The bioenergy cluster representative explained that many potential consumers still do not even know what biochar is, let alone its benefits. Thus, it is still important to focus on information dissemination since a market cannot be cultivated on an underwhelming information base. Further, they explained that there are still very limited research that has been conducted on biochar application for Irish soil. Thus, there is an opportunity to have more advanced field trials, especially for repeat applications with a longitudinal scope. Collaboration with local universities, especially universities championing the global research agenda on alternative feedstocks for biogas production can be considered. The opportunity is two-fold. First, the collection of alternative feedstocks can ensure continuity of supply for the pyrolisis facility which will need to be built. Second, some of these alternative feedstocks can customize the recipes of microorganisms for loading, potentially offering the biochar some differentiation in the global market and/or for local application in partnership with organizations that have specific goals (such as the corridors for decarbonization).

Process efficiencies during commercial stage: From their deep expertise in biotechnology, the LLab scientific team provides its end-users with ideas on how to advance their process beyond the pilot stage and what to change during the commercialisation process. For instance, one discussion in the multi-stakeholder workshop focused on enhancing process efficiencies during commercial production, such as moving from passive or storage-based drying of the feedstock to a more active drying process by, for example, capturing heat from the bioreaction process (instead of letting it dissipate into the atmosphere) for the drying process.

Funding and financing opportunities: The LLab expressed the critical importance that funding holds in creating and maintaining the infrastructure that they have built and are continuing to develop. Conversations around funding are somewhat mature, with the team discussing how in the initial phases of infrastructural development, public funding will play a crucial role. This has been demonstrated by their biggest yet funding having been procured from EU's Just Transition Fund in 2024. However, the team also acknowledged that going ahead, as the facilities will have to be put to use and maintained, private financing would have to play a more critical role. This discussion and the distinction between funding sources for different phases of implementation, shows the LLab's maturity in the realm of understanding funding channels and purposes. There is a great opportunity for them to build upon this strength and create a systematic financing plan and timeline to target specific financing sources in a timely manner.

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Commercial partnerships: The LLab end-user has already started thinking of their commercialisation strategy. For instance, one representative talked about them preferring having one large commercial partner to whom they sell their entire output, who can sell their product at scale, targeting specific markets that they know from their expertise to be relevant. Another representative, however, expressed that they have certain farmer cooperatives in their network, which they could tap into for a more distributed commercialisation approach. A LLab representative agreed, explaining how cooperatives play a very critical role in the Irish ecosystem by encouraging local communities to use their products but also by providing support in many other ways, e.g. by providing various amenities, even utensils. The cooperatives also have an umbrella organisation at the national level, and this organisation has a bioeconomy specialist. Thus, this commercialisation pathway can be quite critical.

The LLab and the end-user need to develop these discussions further, conducting market research and analyses to conclude what markets would be better to target, and accordingly, whether their commercialisation strategy should be centralised or decentralized, what kind of commercial partner(s) they need and whether they should adopt the pre-existing branding (and thus, value proposition) of the partner(s) or create their own.

Threats

Underdeveloped commercialisation pathway: The forestry value chain aims to develop biochar as a versatile product, with ongoing R&D efforts in collaboration with technical partners, refining its properties based on the source materials used in pyrolysis and exploring the potential for post-treatment with beneficial microorganisms. The primary focus of Lurra Bio & IBF presents promising opportunities to diversify end-products and value chains.

The objectives will be achieved by partnerships between dairy farmers and end-users that could enable on-farm biochar enhancement using water-diluted residues, thereby helping to reduce input costs and mitigate the risks of water contamination. By standardising the size of biochar bags and accounting for weight variation post-loading, deployment could be made user-friendly and scalable. Nevertheless, further research is needed to define the optimal placement depth, nutrient infusion methods, and performance timelines to validate its use as a fully bio-based fertiliser.

Weak ties with local community and primary producers: To unlock the full potential of the LLab, expanding its network of entrepreneurial partners and commercial users is essential. Strengthening ties with local communities and primary producers—particularly those open to co-developing innovative applications—will help grow demand for the facilities and accelerate the transition from pilot-stage research to market-ready bioeconomy solutions. With strategic outreach and the right resources, the LLab is well-positioned to become a vibrant hub for sustainable enterprise and rural innovation.

Advancing successful bioeconomy enterprises and markets as a key objective: A central ambition of the LLab is to evolve into a dynamic and successful infrastructure that supports the growth of multiple thriving bioeconomy enterprises. This vision positions the LLab and its associated biorefinery as catalysts for innovation, investment, and job creation within the sector. Achieving this goal will not only ensure long-term sustainability for the LLab itself but also make a meaningful contribution to Ireland’s broader national bioeconomy strategy, reinforcing the country’s position as a leader in sustainable, circular development.

6.3.5 Living Lab 5: Cell Factory Lab (Leader: VTT)

The Cell Factory Lab consists of a cellular agriculture-based value chain focused on valorising agri-food side-streams as feedstock in plant cell culture propagation into novel ingredients for industries like the food, cosmetics and nutraceutical industries.

The end-use of these novel plant cell culture-based ingredients in the food industry is in a more mature stage of development when compared to use in cosmetic or nutraceutical industries, with at least one end-user and other

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related stakeholders being involved more actively in exploring this possibility. As a specific maturity level of the value chains is required for deep engagement with the value chain stakeholders, the Cell Factory Lab chose to focus on the end-use application in the food industry.

One online workshop was conducted with 4 stakeholder representatives on 5th March 2025. These stakeholders included:

- 2 LLab representatives
- 2 end-user representatives

Follow-up interviews were also conducted, one with a venture capital fund (focused on the food technology ecosystem) representative, another with an entrepreneur from one of VTT's spin-off companies that is working to commercialise a similar cellular agriculture technology and lastly, one with a university researcher working on cellular agriculture. These interviews were conducted during April 2025.

Key actors and activities

VTT scientific team: Developing plant cell culture technology with applied market foresight

VTT Technical Research Center of Finland, is the scientific research entity leading the Cell Factory Lab and has taken a proactive role in developing the new plant cell culture technology within the cellular agriculture domain. This technical expertise has been well complemented with the team also being comprised of a future consumer research expert, who is responsible for finding suitable market applications for the emerging technology and connecting the bridge going from the scientific laboratory to real-life applications.

End-users: Bringing scientific advancements to explore new ingredient production possibilities

The end-user of the LLab has been involved in initiating the process via the 1st Open Call. They are exploring the possibility to integrate novel plant cell culture-based ingredients produced on feedstock originating from their own side streams to their existing production process. Testing out the technology within their existing processes and product portfolio provides both an option for the novel ingredients to be explored in greater depth as well as a feedback mechanism for the LLab to learn and grow from industrial integration trials. As a first step, the novel ingredient substitutes components within existing products, but it is expected that in the future, higher technological uptake could lead to creation of completely novel products, as well.

Primary producers: Making primary production more sustainable via side-stream valorisation

The LLab anticipates that soon, their new technology, particularly in the broader context of cellular agriculture, could become an enabler in agricultural performance where primary production is complemented in terms of resilience and sustainability. The LLab has started engaging primary producers more actively to discussions related to agricultural side streams that could be valorised back to food and feed use via Cell Factories using them as feedstock to propagate not only plant cell cultures but particularly microbial biomass. In the future, this might result in generation of cell factories in rural areas thus providing new business opportunities and jobs.

Private investors: Enabling and accelerating a technological revolution

Three companies having their origins at VTT and working in the very same cellular agriculture domain that the LLab's technology is situated within, were able to spin off from VTT due to private financing channels that were able to provide them with the massive initial capital investment needed by these novel technologies to be operationalised at scale. While a similar spin-off has not yet been created for the plant cell culture technology, the LLab expects that this may be the case in the future. Private financing from, for instance, venture capitalists,

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especially those focusing specifically within the food ecosystem and being deeply familiar with the technological frontiers of the industry, will be crucial for mobilisation of requisite resources to take this technology to market for novel applications.

Feedstock availability

Since the cellular agriculture and representative plant cell culture technology are expected to be dynamic enough to be applied to a wide and diverse range of possible feedstocks, the opportunities for identifying, procuring and experimenting with different side-streams and creating novel value chains is very important. Creating, maintaining and updating a nationwide map and repository of all possible feedstock types, quantities and sources, is important for emerging players to determine the best feedstock fit, both in terms of quality and quantity, for their technological and process configurations. Efforts towards this have already been initiated by nationally strategic actors like the National Resources Institute Finland, in the form of the publicly accessible Biomassa-Atlas.

These efforts need to be extended further through collective decision-making and integrated activities around feedstock logistics. For instance, the emergent ecosystem can benefit from discussions around whether a nationally aggregated logistics network with one central managing entity is more optimal for the geographical feedstock distribution than a distributed network with independent but coordinating actors. These efforts would also need to consider timeliness of feedstock transportation and storage activities, especially in context of stability and preprocessing requirements of different biomass feedstocks.

Multi-sector industrial synergies

Synergies with primary production will be based on emerging collective vision: LLab representatives explained how the vision of emergence and large-scale transformative application of cellular agriculture and the representative plant cell culture technology has been intitated in regular longitudinal interactions with several players in the food ecosystem. This led the LLab scientific team to understand that the collective vision among the players is urgently needed to make food systems more resilient against geopolitical and ecological disruptions. For example, use of plant cell culture technology could replace raw materials like coffee, avocado, cocoa and other ingredients that are expected to face significant supply disruptions and price changes in the future.

This synergistic relationship with primary production can be broadened by advancing cellular agriculture expertise to not just rely on agri-food side-streams as carbon sources, but also for other nutrients such as nitrogen (also phosphate and sulphur).

Cascading material use across varying industries: The valorisation of several side-streams can lead to cascading use potential with various possible applications, and the LLab Principal Scientist explained how cellular agriculture could make this possible using grass (in ample supply in Finland) as an example. In addition to using grass as feed for ruminants, protein could be pressed from surplus grass (which can then be used for food or feed purposes), and the remaining residue could still be further valorised as feedstock in the plant cell culture technology or in microbial fermentation. Even after deriving carbon and nutrients for plant cell culture cultivation purposes, there might remain a fraction that can be used in biogas production. Such cascading use potential of a single feedstock, empowered by cellular agriculture, has the potential to create and deepen synergies amidst different industries, such as agri-food and energy in the above example.

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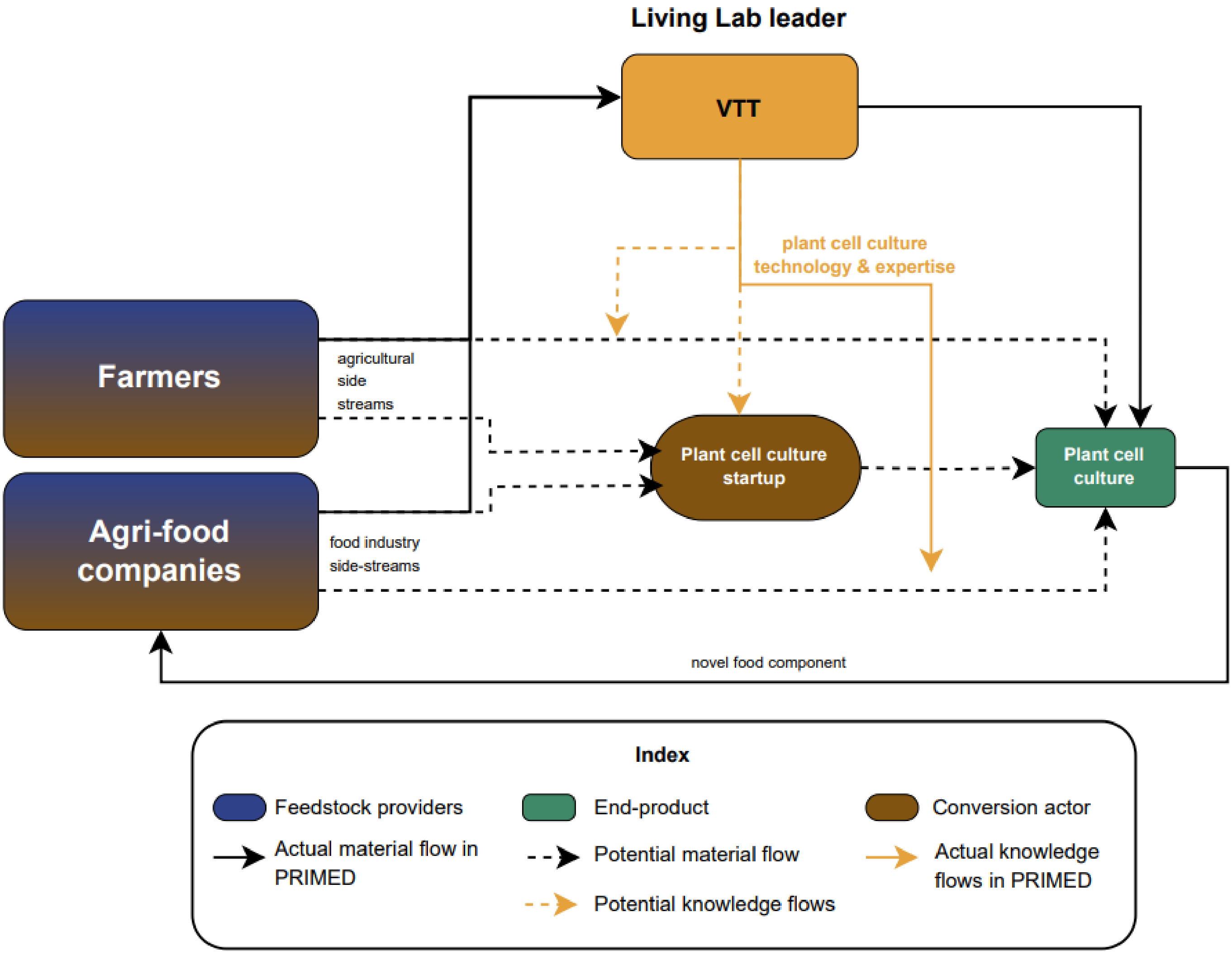

Figure 31.M ulti-stakeholder value chain map and synergies for LLab5.

Gaps in relevant schemes

EU Novel Food Regulation: The EU Novel Food Regulation was characterised by multiple stakeholder representatives as the biggest hurdle in the path of novel foods to come on to the European market. The regulatory approval itself may take up to three to five years to be granted, with approval costs that could go up to a million euros. This prohibitively expensive regulatory process, both in terms of time and money, has led some companies away from Europe to other regulatorily fertile land like Singapore and the USA, and is unfortunately likely to do the same to upcoming operators utilising plant cell culture technology.

Limited Research and Development (R&D) funding: The LLab Principal Scientist explained that for the technology to reach critical scale and for it to be prepared for commercial market applications, there needs to be an accelerated pace of research that can drive these developments and work towards making this technology to high enough TRL level. Only then uptake from a commercial perspective is possible.

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SWOT analysis

Strengths

Scientific exemplarity and legacy of successful partnerships: The LLab end-user described VTT as a "scientific leader" in Finland, explained their past relationship of collaboration for technological support and guidance and simply stylised them as being "good at solving problems". The exemplarity of VTT and its history of successful partnerships with this and countless other companies, makes its work credible and is likely to foster trust in this new technology that they are developing, which is otherwise difficult to garner for a novel technology that has not seen market success, or even application. However, VTT's well-earned repute is likely to make prospective partners become curious, engaged and eventually enthusiastic, for the novel ecosystem that the LLab is starting to create.

Advanced collaborative ecosystem for value chain development: Cellular agriculture initiatives have led to a network to emerge in Finland that focuses on research and development of technologies, processes and value chains for the creation of an ecosystem that facilitates the introduction of novel food ingredients in food production processes. This network, which includes businesses, research institutions (VTT, amongst others), non-profits and financiers, gives the LLab an ecosystem asset where information dissemination, coordination and energisation can be achieved at once with all the key players.

Data capabilities for regulatory compliance: The novelty of the plant cell culture technology as well as that of the feedstock would require compliance to possibly several regulatory frameworks like the European Food Safety Authority's (EFSA) Novel Food Regulation. To make this compliance process smooth, the end-user has operationalised strict standards of traceability regarding their feedstock, a process that originates at the point of procurement of a batch of feedstock and goes up until the packaging of the end-product. This will ensure prompt and comprehensive data transparency for the regulatory approval process to proceed as quickly as possible.

Weaknesses

Side-stream quality and safety challenges: Currently, most industries producing side-streams consider it as waste, and thus, minimal attention has been paid to stabilisation and preservation of these materials allowing acceptable and safe use for food purposes. This makes stabilisation and pre-treatment of these side-streams necessary by any actor that may wish to work with them, a process needing side stream specific development bearing in mind cost-effectiveness. This concern is likely to get alleviated in the future: as side-stream valorisation-based value chains emerge and slowly become profitable, it will pay to increase quality and safety of side-streams to enhance valorisation potential, which could become a metric that will be measured and assessed for side-stream valuation, just how product quality is measured and assessed in consumer markets.

Primary producers feeling threatened: LLab representatives explained how some primary producers have had preliminary reactions of defensiveness and disapproval against this new technology when sawn it as a competitor for primary production and thus threatening their livelihood. If this change is merely communicated to them as a technology that will transform the world and their livelihoods, such a reaction is only to be expected. Communication with primary producers needs to be open and it should emphasise opportunities that can rise from side stream valorisation and sustainability improvements of the overall value chain. The communication should elaborate primary producers' role as vehicles of the change that this new technology is bringing and how the technology is not rivalling their livelihoods but merely enabling a more certain and predictable configuration of their livelihoods.

Opportunities

Competitive advantage and global leadership opportunity for Finland: The LLab end-user explained how Finland has conventionally not been an agricultural leader due to its natural climate not supporting the growth of crops like wheat and maize. However, Finland does have a lot of straw, grass and various agri-food processing

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industries' side streams, that can serve as active sources of carbohydrates, nitrogen and other nutrients that are critical components of cellular agriculture including plant cell culture propagation. Thus, if the Finnish food ecosystem, including the primary producers, grab onto the opportunity afforded by the cellular agriculture in a timely fashion, they have enough resources to transform these feedstocks into valorised outputs for the food industry.

Solution to food industry supply chain vulnerabilities: LLab stakeholders discussed how several raw materials from the primary sector, over the past years, have been in shortage at some point, leading to some product prices having skyrocketed. These worrying trends have introduced severe concerns regarding uncertainties of food industry value chains' futures, which discourage financier confidence, eventually dampening market growth. Thus, the new cellular agriculture approaches including plant cell culture technology come with an opportunity to alleviate supply chain disruptions for companies related to raw material availability issues and provide food chains with higher certainty and predictability for them to remain stable and to continue catering food markets.

Expected shift in food consumers' culture: The LLab representative for consumer market research expressed confidence in expected food consumer behaviour changes in the future. While more and more consumers would want to consume food that is sourced and manufactured sustainably, even more consumers may be discouraged from consuming some items from conventional cultivation because of how prohibitively expensive some raw material prices may become in the future. The cellular agriculture has potential of presenting the consumers with affordable alternatives and encouraging food markets to maintain their stability.

Exploring new side-streams: LLab representatives explained how this new technology is dynamic and can work with a diverse range of feedstocks. This presents an opportunity for the LLab and several end-users across sectors to experiment with several unexplored side-streams, starting with their own, to uncover different process potentials and end-use cases for the technology which can further be used to develop new value chains for the future.

Threats

Market competition within food industry: In the food industry, there already are several different players with vastly different commercial strategies and price points (even for relatively similar products). Thus, it may be difficult for an entrant to determine where they can step in and what strategy they should adopt, especially for pricing which is a critical consideration during market entry. The early stage of the technology means that technological scaling and efficiency peaks will only be attained with time and thus, the first products to enter the market can be relatively expensive. This could threaten a problematic feedback loop wherein product prices cannot be reduced due to lack of technological scaling and technological scaling cannot be attained due to high product prices and discouraging market outlook. Thus, the commercialisation pathway has to be carefully considered, strategized on and coordinated amidst all relevant partners for a successful go-to-market transition.

Customer awareness about cell agriculture and novel food: For novel food products to reach their full market potential, it is important for consumer awareness and preferences to be able to adapt to this new emerging reality. From the beginning of this ecosystem emergence, consumers need to be enthusiastic about trying out these new products despite the possibility of marginally higher market prices, for the products to be produced at scale in response to a high market demand. Lack of customer awareness and customer hesitation regarding food products made from unconventional feedstocks, may dampen the market potential and development.

Competition from international markets: LLab members have highlighted the limitations of EU's regulatory regime with respect to the prohibitively discouraging Novel Food regulation process. This stands in stark contrast to regulatory regimes in other countries, such as the USA and Singapore, where the approval processes for companies applying such technologies are much faster, efficiently handled and possibly cheaper. This contrast in regulatory regimes underscores the threat regarding companies from other parts of the world getting a headstart on the commercialisation of their cellular agriculture technology. With heightening maturity of these global players, uptake and commercialisation of the LLab's cell ingredients may become more difficult due to advanced competition.

Different cultural approach to novel food in other potential markets: The LLab highlighted how other potential markets for their end-product, such as those in Southern Europe, may not be able to garner cultural acceptance for "lab-produced" food, thus limiting the market potential for this ecosystem. This could be an enhanced risk in regions where the food culture is very strong and is assigned a status of legacy and heritage. Cellular agriculture uptake in such markets would require a deviation from traditionally conceived notions of "originality" and "authenticity" in terms of material sourcing and processing, which threatens to be a slow process.

5.4 Discussion and recommendations

As PRIMED is progressing through several multi-dimensional Work Packages, it has helped its five LLabs co-evolve and grow their respective value chains. Comprehensive value chain mapping exercises in both WP2 and WP3 have made it possible to see the substantial growth in these LLabs that is fuelled by the work being undertaken by PRIMED, even within a short span of time: while some LLabs focusing on specific value chains are taking increasingly larger strides towards expanding and deepening their commercialisation, other LLabs with a broader scope have started streamlining their efforts towards development of specific value chains that are currently aligned with the ecosystems these LLabs are embedded in. For all the LLabs, this ecosystemic embeddedness is what has led synergies to emerge within and across value chains, which have given rise to several emerging strengths but also exposed the LLabs to emergent and multi-faceted challenges. A summary of the key aggregated results from the SWOT analysis conducted alongside the value chain synergies' analysis, is presented in the figure below.

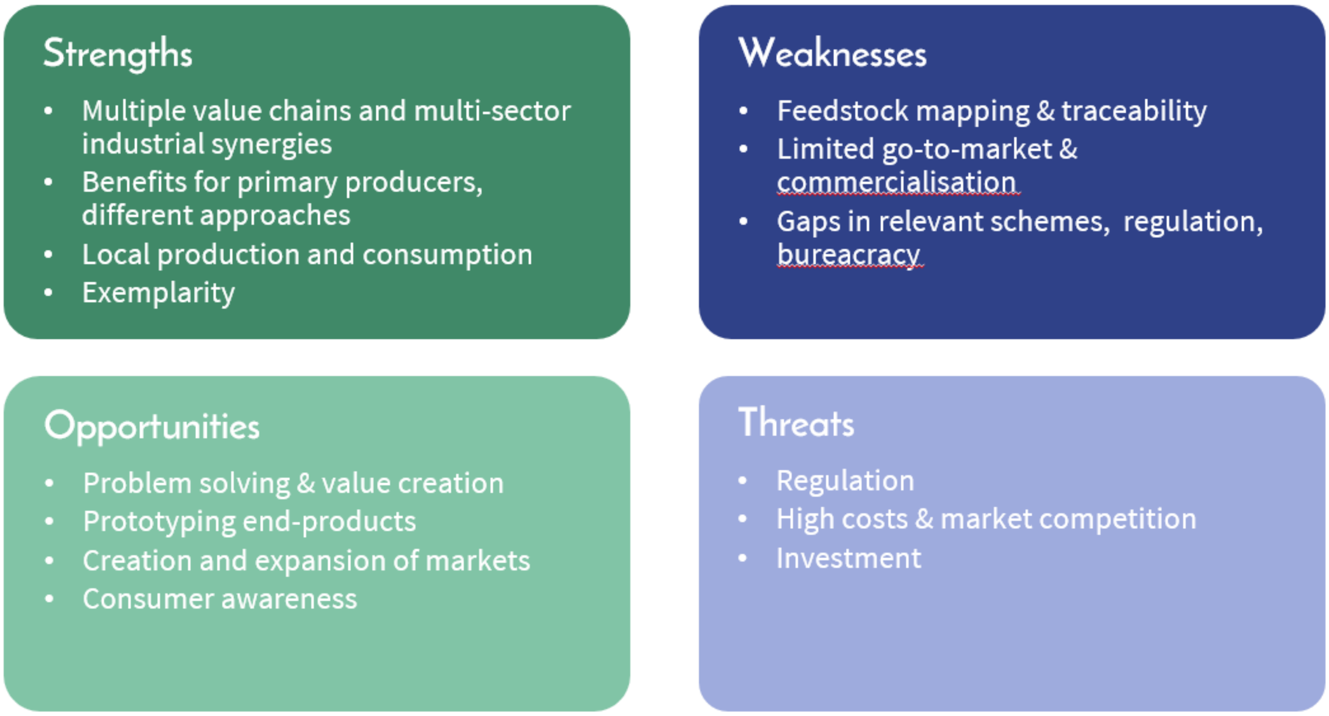

Figure 32. Key aggregated results from SWOT analyses across all Living Labs.

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A key strength of all LLabs is their ability to create multiple value chains and foster multi-sector industrial synergies. Most have succeeded in delivering tangible benefits to primary producers—one of the main targets of the PRIMED project—while adopting diverse approaches to do so. Local production and consumption serve as core drivers across all LLabs, and each has become a leading example in its region and a reference point within Europe. However, they are all facing challenges, such as feedstock mapping and traceability, limited go-to-market and commercialisation, and gaps in relevant schemes such as regulation and bureaucracy. The main threats to future development have been assessed as regulation, high costs, market competition and lack of investments.

While it is clear that the LLabs are increasingly aligning themselves with the present and future needs of the ecosystem, efforts need to be undertaken to systematise and concretise the future of the value chains partnerships and developments they are building. At the heart of a bioeconomy ecosystem, lies the potential of bio-based feedstocks that can be valorised. The LLabs, along with their relevant partners, will benefit from an exercise of not just ensuring present adequacy of feedstocks (crucial for commercialisation of these value chains), but also of forecasting their future supply. What is also crucial for the sustenance of these value chains is tackling constraints of regulatory regimes, which is likely to be a massive effort that might require cross-sectoral collaboration. Finally, the consumer markets need to be “warmed up” for the new products that these LLabs are bringing to the table - especially in an early stage when these products are not yet price-competitive against traditional fossil-based substitutes – starting from an approach of dispelling misconceptions and reservations about these novel products, eventually progressing towards an approach of fuelling enthusiasm about the value that these products can add, be it in terms of their novel properties or in terms of securing future ecosystems against mega-disruptions.

Despite the several differences in terms of their technological trajectories and stages of development, what unites all the five PRIMED LLabs is their exemplarity within and beyond their ecosystems, as well as their deep integration with local actors, which has been further developed under several PRIMED activities. It is this exemplarity and local integration that can pave a way for them to resolve the several challenges that are starting to emerge in their ecosystems, in the form of deepening established value chain synergies as well as co-creating novel ones. The approach of discovering and building synergies needs to be broadened beyond securing immediate “next step” needs of the value chains, towards proactively anticipating and tackling future challenges, visions and aspirations.

7. Policy and regulatory screening

7.1 Approach

The policy and regulatory screening aim is to work as a regulatory check of the value-chains created to validate them and avoid barriers during the demonstration and implementation stages.

This policy and regulatory screening builds upon the state of art – policy mapping and policy analysis – delivered in WP2 to establish the framework conditions. Whereas that first landscape exercise was developed based on desk research and a top-down approach that favoured a view from European legislation towards the LLabs, this second screening relies on a bottom-up approach and therefore, inputs provided by the LLabs and other relevant local stakeholders during the workshops.

As so, the outcomes may vary in terms of granularity and indicate broader landscape barriers or specific hindering regulations depending on the LLabs experience previously and throughout the project implementation. In any case, this bottom-up approach is essential to identify practical and ongoing challenges that are critical to be addressed to enable the project short-term results and support the creation of immediate value for stakeholders. Lastly, it complements the policy mapping and analysis developed in WP2 by validating, adding or challenging it, and provides insights on the LLabs policy and regulatory priorities.

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7.2 Methodology

The overall methodology assumes a bottom-up approach, with the core part of the data being collected directly from the LLabs and local stakeholders. It emphasizes the importance of considering and measuring the impact of policies on businesses and value-chains to confirm their results or identify any unforeseen or overlooked impact.

Data collection

The workshops conducted in this WP are the main source of data, as they engage directly with the value-chains and address a broad scope of challenges experienced by the LLabs including the policy and regulatory ones. This approach promotes the contact with the LLab and adjacent stakeholders and results on a comprehensive consultation.

Data categorisation and analysis

The data is then linked to the related **governance level**, depending on the jurisdictional authority (e.g., economy is regional or national, foreign trade policy is EU) and when possible, connected to the specific policy or regulation. Secondly, an analysis is conducted to categorise the barrier in terms of **nature**, if the barrier is hindering or slowing down an action or blocking it, which provides information on its importance and urgency to act. Additionally, an analysis is also done to distinguish the barriers per **scope**, if they result from a local LL context or if have or potentially have a broader impact at national or European level, which also amplifies the need for action.

Recommendations

Lastly, based on the barriers identified and their analysis, draft recommendations are produced to mitigate, avoid or overcome the challenges experienced by the LLabs and promote the future demonstration and implementation phases of the value chain.

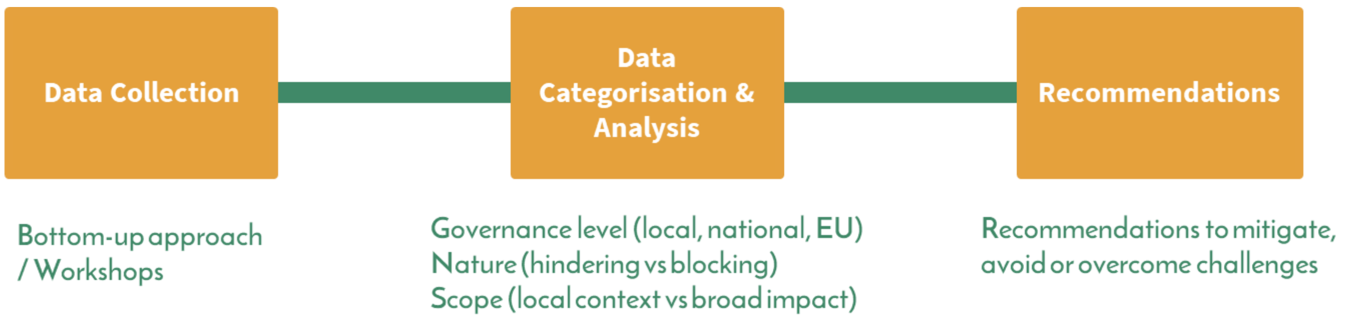

Figure 33. Methodology flow, comprising the three different stages followed (in yellow) and additional details (in green).

7.3 Results

In this section, for each LL, the identified barriers are listed, linked with the different governance levels (regional, national or European) and potentially specific policies or regulations, and analysed considering its nature and scope.

7.3.1 Living Lab 1: ALC Bio-Lab (Leader: Alcarras Bioproductors)

The LL has a well-established position within the local landscape, being the initiator or contributor to several efforts to further expand the network and business opportunities in the bioeconomy space. It presents a significant scale and maturity to deploy to market their different products: bio-compost or bio-methane.

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As the LL already has different value-chains in place, it is able to provide a clear view on the critical barriers that hinder their further development, as well as the creation of new business models and value-chains. Stakeholders identified two main challenges hindering the value-chains development: one regarding the regulation on organic waste management and another concerning market competitiveness and uptake.

Waste management regulation

- **Local** regulation at the municipality level, discourages the processing of organic waste within an industrial area and it is major barrier for the consolidation of the LL and the creation of an industrial hub around it. Nonetheless, this negative regulatory aspect is an exception within an overall supportive policy ecosystem steered by local and national bioeconomy specific strategies. Furthermore, the LL is already engaging with the municipality to unlock the current situation by updating current legislation, and therefore, it is considered a **hindering** barrier. Lastly, as novel value-chains emerge in the interface of agriculture and industry, it is expected that regulation in other municipalities and regions of Spain and Europe is not prepared to integrate these new opportunities and lead to slowing down innovation. It does so as they were created in view of a linear economy and not considering the potential value of organic waste, which validates the **broad** impact of this barrier beyond the LL context.

Market level-playing-field

- The products' price competitiveness is mostly a result of business economic performance and is noted by stakeholders as a threat. The technology novelty, limited production scale and lack of awareness compared to the mainstream products pose barriers to market entry and expansion. In new market segments, this problem may be directly or indirectly influenced by policies and regulations. Regulations need to ensure that new products can enter the market and are valued by the benefits they bring, for instance for the environment, so transparent labelling should be promoted and market demand stimulated (e.g., public procurement). This barrier is applicable throughout bioeconomy value-chains in **Europe** and is regulated at **national and/or EU levels**. It **slows down** the innovation cycle as the market level-playing-field, economic sustainability and a steady demand are key factors for business implementation.

7.3.2 Living Lab 2: Bio-Silica Lab (Leader: CeNTI)

The LL has extensive experience innovating in the field of nanomaterials and advanced materials through partnerships with the private sector or within National and European projects. Therefore, it has a strong technical and scientific knowledge, which is consequently extended to the regulatory space due to the need to integrate the novel materials into existing businesses.

At PRIMED, the LL focuses on the development of bio-silica – a material developed from rice husk waste with the potential to replace the mainstream silica, a component which takes part in many products from packaging to automotive. Nonetheless, from the workshop, the LL anticipates challenges at the beginning of the value-chain due to regulatory limitations regarding waste processing authorisation.

Waste management regulation

- The current **national** legislation in Portugal limits the waste management and treatment to selected entities who possess rights to do so, which restricts the access and hinders competition. This market structure may **slow down** the value-chain establishment and development due to a demanding regulatory application and slow approval process for new operators that creates regulatory uncertainty

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and discourages stakeholders to get involved. The novelty and innovative forms of waste processing, up-cycling and recycling opportunities face barriers in legislation that does not foresee market possibilities and approaches waste management commonly as a logistics activity. This regulatory aspect is potentially a barrier in other countries of the **EU** that still need to adapt regulation to emerging technologies and markets.

7.3.3 Living Lab 3: Liguria Bio-Lab (Leader: FILSE)

The LL works as an extension to the fisheries sector and promotes innovation to further valorise side streams, by-products and waste to benefit stakeholders along the value-chain. The value-chain under focus in this screening is the use of fish production industry by-products to integrate into other sectors like cosmetics, feed or food.

There is a deep knowledge of the regulatory landscape influencing the different innovative value-chains in the LL resulting from extensive research and close contact and partnerships with its network. The LL faces issues linked to the definition of animal by-products stated under EU regulation which leads to uncertainty and limits development.

Animal by-products regulation

- The Animal By-products - Regulation (EC) No 1069/2009 is **blocking** the development of the value-chain. It provides a framework that do not fully answer to the needs of the stakeholders and lead to multiple challenges: different **national and regional** interpretation that often goes beyond **EU** regulation itself, lack of clarity on the differences between animal by-product, waste or food product, and the limitation to use animal by-products for food production and consequently human consumption. These three factors showcase how the regulation fails to provide a clear and harmonised framework among stakeholders that promotes alignment between policymakers and businesses. The limitation of the use of animal by-products to human consumption products is leading to a sub-optimal exploitation of the resources and value-chain and blocking opportunities. It is expected that this problem has an **EU scope** as it is leading the similar barriers in different contexts.

7.3.4 Living Lab 4: BioEire Lab (Leader: IBF)

The LL is active in the broad field of bioeconomy and leverages the power of the Irish primary sector including agriculture, livestock and forestry, to boost the country's rural areas namely through industrial integration and transformation.

Within the project, it aims to validate a new value-chain starting from forestry waste and conversion into biochar. Biochar is a product that recently has earned a renewed interest among stakeholders and policymakers due to its environmental and economic sustainability at scale. During the workshop, the LL identified as main hurdle a financial policy tool that could support the value-chain development if well designed and well implemented, but that remains unclear and unpredictable: carbon credits.

Financial policy framework

The establishment of this value chain requires updated policy and regulatory frameworks that consider the current environmental, economic and social objectives. It is crucial that biochar's value accounts for its environmental benefits, specifically its ability to contribute to carbon removal, as well as enhance soil health and fertility. To this end, the LL points out the lack of clear guidelines and a predictable pathway to the carbon removal policy through carbon credits at the EU level, which makes the final product too expensive. During the workshop, stakeholders noted that the same problem is also present in other countries participating in the project, such as Finland and Spain, confirming its broad impact beyond the local context.

A financial policy instrument, such as carbon credits or others, could support stakeholders in their efforts to create the value chain. Ideally, this instrument would have a low administrative burden and cost, allowing for the participation of startups. Currently, this barrier is a hindrance to business development.

7.3.5 Living Lab 5: Cell Factory Lab (Leader: VTT)

The LL is an important player at European level in the field of biotechnology covering different applications and a seasoned stakeholder on the matters of technology transfer and product innovation. Its work in different projects and sectors has provided the LL with a sound knowledge on the key issues that are impacting its research and development.

In the project, it leads a value-chain that uses potatoes side streams and applies cell cultivation technology to produce food ingredients. From the bottom-up, stakeholders identified one main hurdle: the risk assessment and regulatory approval process, which falls under the Novel Food - Regulation (EU) 2015/2283.

Product approval regulation

- The Novel Food regulation sets the guidelines and conditions under which novel processes and products developed after 1997 need to comply for being approved and authorised in the EU market. In the value-chain, it is the step after the product development and before commercial production, as the product needs to go through a risk assessment made by European Food Safety Association (EFSA) and a regulatory approval by the European Commission (EC), to be able to reach the market and be potentially economic viable. Therefore, this barrier is created at **EU governance level** and has **impact throughout Europe**. The main factors transforming this regulation into a hurdle for the value-chain are the high complexity, administrative heaviness and slow pace of the risk assessment process conducted by EFSA, which is considered key to inform the approval by the EC. It has a **hindering** impact on the value-chain, which can be considered blocking as these processes tend to last 4-6 years compared to 1-2 years in other geographies and leads companies to move abroad. This long and complex process indirectly impacts the consumer perception and awareness of the technology.

7.4 Discussion and recommendations

The policy and regulatory screening identified three main types of barriers that are hindering or will block the establishment and development of the new value-chains: **feedstock regulations, market access and competitiveness, and existing financial frameworks, by this order of priority**. The barriers are originated from regulations at all governance levels and have different impacts depending on the value-chain leading to a hindering effect or blocking a business case – no broad pattern was identified in terms of governance level and nature of the barriers. Nonetheless, a pattern was present for the scope as all barriers identified by the LLabs can be potentially found throughout the EU, which showcases the broader impact of the project and the ability to develop solutions to the bioeconomy that will deliver beyond local or national contexts.

Challenges with feedstock regulations are mentioned by three out of five (3/5) LLabs and include waste treatment regulations (CeNTI, Alcaras) and animal by-products regulation (FILSE). It demonstrates the unpreparedness and inability of the regulatory landscape to answer to innovative ways of using new streams of resources towards the production of existing or novel products.

Barriers related to the market are mentioned by two out of five (2/5) LLabs, access by VTT and competitiveness by Alcaras. The project innovative products have a slow and complex regulatory pathway to the market and must face mainstream product alternatives that have well-established value-chains and regulatory procedures. Additionally, once products have been introduced to the market, they still must contend with price disparities due to the different scales of production and the lack of accounting for environmental impacts in the final value.

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This factor is also linked to the third barrier noted by IBF (1/5), the issue of exiting financial frameworks (e.g., carbon credits) which are not effectively implemented and therefore are not closing the gap and ensuring a market level-playing field. New value-chains that can contribute to the policy objectives and to the environmental and economic sustainability compared to the existing alternatives, require a stable and positive framework to grow.

- **Regulations need to be updated to ensure an innovation-driven and future-proof approach** that allows technology to evolve and deliver positive impacts for the economy, society and environment. This shift needs to start at the EU level but be followed or replicated at all governance levels to ensure alignment and effective implementation.
- The **definitions of waste and by-products, as well as their processing options need to convene all the technological and business opportunities** in the context of the bioeconomy.
- A **clear and predictable market pathways need to be in place** for stakeholders to plan businesses and operations and ensure economic sustainability, supported by market incentive to green and sustainable products.

8. Creation of novel governance structures

8.1 Approach

For each LLab, the bio-based value chains involve networks of actors including both direct and indirect that interact with main organizations to create the biorefineries:

- *Direct stakeholders:* Primary producers (farmers, fishers, forest owners), bio-based waste managers, municipalities and county administrations, technology providers, chemical and material suppliers, logistics and transport actors, marketing and commercial partners, service and packaging providers, customers, end-users, and investors.
- *Indirect stakeholder:* Competitors, local communities, scientists, policy-makers and others.

In this section, we identify the main process multiple actors in each LLab adopt for the creation of governance structures and practices for the LLabs and their circular value chains. We identify these main structures and practices based on different investigated approaches to governance (e.g., polycentric governance, new stakeholder theory) for guiding stakeholder engagement between the focal venture(s) and the value chain stakeholders – primary producers, technological providers, chemical and material suppliers, logistics, waste managers, customers, investors.

To identify and interconnect existing and emerging governance structures, we combine insights from new stakeholder theory and public-partner partnership in response to Grand Challenges (George et al., 2024). We specify which actors join the value chain, how selection and integration decisions are accomplished, and how they influence the co-creation of novel governance structures in anticipation of collective visions of alternative futures deemed culturally appropriate for each community, ecologically regenerative for the natural ecosystem, and techno-economically viable within established and novel market categories.

8.2 Methodology

Governance in this context refers to how the main organization, focal ventures and their stakeholders in each LLab —across the entire value chain—collaborate and interact to set up the rules and norms to govern the exchange of resources and the value creation and distribution processes. Governance encompasses the system of relationships, practices, structures, rules, power dynamics, and communication within each LLab.

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In this section, we study how each LLab have adopted different logics for the governance of value chains. We have studied the LLabs main organizations, PRIMED Open Call applicants, and PRIMED evaluation. Each LLab is presented with these topics:

- *Invitation and selection of new actors into the value chain puzzle.* We analyze the PRIMED Open Call.
- *Qualification and puzzling of different pieces of the value chain.* We analyze the evaluation of PRIMED Open Call applicants
- *Articulation of the value chain governance logic.*
- *Architectural blueprint for value chain governance.* We analyze the emergence of structures and practices for value chain governance.

According to Gereffi et al. (2005), value chain governance depends on the complexity of transactions, the ability to codify those transactions, and the capabilities present in the supply base. Value chain governance model that can take different structural forms, depending on levels of coordination and power asymmetry (Gereffi et al., 2005; Kano, 2018), **hierarchical, relational, modular, market or captive**.

These models can be connected to firm–stakeholder models of governance (Bridoux & Stoelhorst, 2002), including:

- **Hierarchical and centralized models**: where the focal organization manages stakeholders through hierarchical and dyadic relationships (hub-and-spoke governance).
- **Relational models**: involving lead-role governance, where the focal organization manages a network of stakeholders and fosters multilateral interactions, while retaining decision-making authority.
- **Shared governance or polycentric models**: characterized by multiple governance units with equal distribution of resources, decision-making power, and value among all stakeholders.

Patala et al. (2022) studied the shared and polycentric model in the context of emerging circular economy systems for waste and by-product exchange. They showed how firms and stakeholders co-created practices for **collective agency**, enabling the sharing of information on waste and residual resources, as well as structures for sharing knowledge, transactions, and governance mechanisms.

In all the Living Labs (LLabs), the main organizations and stakeholders co-develop a **logic of governance**—the principles, structures, and practices used to manage their value chains (Patala et al., 2022). These models can vary: some are more centralized and hierarchical; others are technologically driven, market-oriented, regionally focused, or aimed at system-level change. These orientation and practices gives each LLab a different governance logic.

To understand these governance logics, it is crucial to examine structures and practices related to stakeholder inclusion and selection; information sharing; resource and feedstock exchange; knowledge creation and dissemination; transaction costs; decision-making; joint strategizing; value creation and distribution; standards for products and processes; and capacity building and training. This analysis also explores how relational capital and trust are built within these value chains in each LLab.

Based on our analysis, we build our model of value chain governance in emerging bioeconomy in the next figure.

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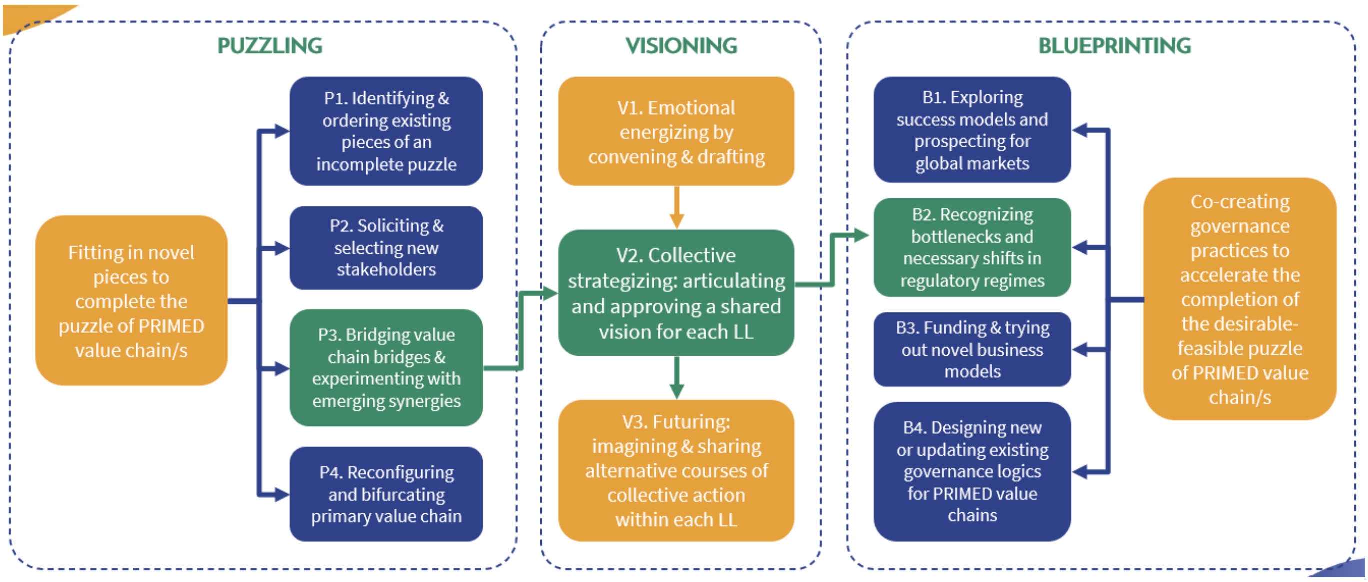

Figure 34. Process model of value chain governance in emerging bioeconomy

The model is centered on Visioning of value chains for bioeconomies. **Visioning** refers to the creative imaginaries of bioeconomy value chains within each LLab. We approach future creation in three stages:

> *V1. Emotional Energizing* – convening stakeholders and drafting possible future visions;
> *V2. Collective Strategizing* – actors articulate and approve a shared vision for the LLab;
> *V3. Future Imagining* – exploring and sharing alternative courses of collective action within the LLabs and their respective value chains.

Collective strategizing and vision articulation are rooted in connecting value chain components, experimenting with emerging synergies, and identifying both bottlenecks and necessary regulatory shifts.

To build these visions, actors engage in two key processes: **puzzling** and **blueprinting**.

Puzzling involves fitting novel pieces into the value chain puzzle—connecting stakeholders and processes. This includes:

> P1. Identifying and organizing existing elements of an incomplete value chain;
> P2. Engaging and selecting new stakeholders;
> P3. Bridging gaps and experimenting with emerging synergies;
> P4. Reconfiguring and bifurcating the primary value chain.

Blueprinting focuses on co-creating governance practices to accelerate the development of a desirable and feasible value chain structure. This involves:

> B1. Exploring successful models and assessing global market opportunities;
> B2. Identifying bottlenecks and necessary regulatory shifts;
> B3. Funding and testing novel business models;
> B4. Designing new—or updating existing—governance frameworks for bioeconomy value chains.

For each LLab, we begin by presenting the **main governance components, actors and processes**. First, we focus on how each LLab has engaged new actors to build or expand value chains during the PRIMED project. In 2024, PRIMED launched an open call to select and fund new stakeholder-led value chain projects. This call helped clarify the main components of the value chain puzzle. Multiple actors submitted proposals highlighting value creation

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opportunities and outlining their specific contributions or alternatives to the existing value chain. The analysis of these submissions enabled each LLab, together with PRIMED members, to qualify and assemble the key pieces of the full value chain.

Second, we introduce the **architectural blueprints** for value chain governance, which outline the structures and practices needed to ensure effective coordination and support the development of robust, sustainable value chains.

8.3 Results

8.3.1 Living Lab 1: ALC Bio-Lab (Leader: Alcarras Bioproductors)

As explained earlier in this deliverable (refer to sub-section 6.3.1), Alcarràs Bioproductors SAT is owned by a farmers' association composed of 150 farming families. These families collectively purchased the land and sought a collective solution to a shared challenge: managing animal waste from their farms. They decided to invest in a bio-compost plant and have now expanded their business to set up a biogas plant as well. The farmers serve both as shareholders and as feedstock providers to these plants. With the land, they also negotiate the creation of a bioeconomy circular industrial park, the Bio-Polygon.

Alcarras Bioproductors SAT is governed by the general assembly of the 150 farmer families. This assembly holds final decision-making power through voting rights and meets annually to make key decisions—such as approving major investments, validating the business strategy, and selecting members of the board of directors. The board, composed of 10 farmers, meets weekly to oversee day-to-day operations. It is responsible for defining the company's main strategies, evaluating and acquiring technologies, designing business models, and appointing the executive team. ALC Bio-Lab members have explored and extended their governance processes while inviting new actors into their value chains.

Invitation of new actors into the value chain puzzle: PRIMED Open Call

In this sub-section, we explain the criteria possible partners used to nominate themselves to participate in the value chains of the LLab. They also used these criteria, focusing on very intentional language in PRIMED's Open Call applications, to position themselves as being good fits for the LLab's value chains. The ALC Bio-Lab received applications from two companies for end-use validation, and we analysed both the applications in detail.

In the case of this LLab, these stakeholders already had been engaged with by the board of directors and the executive team of Alcarras Bioproductors SAT, even before they applied for the Open Call. In fact, they were invited to participate in the Open Call by the LLab itself. During the Open Call, PRIMED evaluators facilitated the assessment of stakeholders.

Establishing synergies with the LLab ecosystem: In the first open call conducted within the scope of the PRIMED project for end-product validation, Alcarras Bioproductors received applications from two companies, one each for each of the two end-products (bio-compost and biogas). The former applicant highlighted their work with bio-fertilisers, alluding to principles of "improving crop yields", "optimal bioavailability", "soil biodiversity" and "minimising dependence on imported fertilisers" to highlight how their work contributes towards a "paradigm shift in agriculture", that underscores ecosystemic linkages with the heart of the LLab's work. We later found out that this applicant is already in talks with the LLab, and had been invited to participate in the open call by the LLab itself, for the acceleration of the value chain relationship that they were trying to consolidate.

While this first applicant aimed to add the LLab's bio-compost to their product and validate the effectiveness of the resulting bio-fertiliser, the second applicant aimed to test the modification of a vehicular internal combustion engine for biofuel usage using the LLab's biogas. Even though the second applicant's area of work is not directly

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linked to agricultural systems, they highlighted expected synergies with agriculture by underscoring the role of good air quality in benefiting the feed, health and well-being of farm animals.

Demonstrating viability of validation process: Both the applicants understood and tackled viability concerns in different ways. The first applicant approached viability of their bio-fertiliser as something that will be established during further testing processes using “optimisation”, “validation” and “market exploration”, that will enable them to progress from a current TRL 3 to a potential TRL 6. The second applicant explained how the viability of biofuel-driven engines has already been established in the markets, both in terms of fuel and maintenance costs.

Proposing commercialisation activities: One of the applicants explained specific market segments where the demand for their bio-fertiliser is expected to be concentrated and to grow in the future, highlighting these as the target markets they would aim to go after. They also mentioned ambitions to leverage “customer relationships and certifications” that would make their market strategy more robust.

Qualifying and puzzling together pieces of the value chain: Evaluation of PRIMED Open Call applicants

With insights from ALC Bio-Lab representatives, the evaluation committee for the Open Call, consisting of PRIMED consortium members, assessed the suitability of each applicant as a “fitting piece” for the value chain puzzle of ALC Bio-Lab. This process indicates how governance decisions can often be influenced by, sometimes outsourced to, actors who are not directly a part of the value chain but have external expertise that may bring forth broader insights and thus, steer the value chain’s governance in a certain direction. The key criteria that were used to qualify applicants for inclusion/exclusion into ALC Bio-Lab’s value chains, are explained below.

Ecosystemic synergies: The board of directors, the executive team and Open Call evaluators assessed the applicants based on their synergies with the ecosystems. For example, one of the applicants was considered to not be a good fit due to its limited synergies with the ecosystem that the LLab is a part of, especially with regard to the topic of primary producers remaining untouched. The other applicant was favourably assessed for its association with the LLab’s “territorial problems”, especially since it paid attention to primary producers’ integration in this value chain.

Viability and commercial strategy: Missing discussions on implementation timeline, scale-up potential, commercial strategy and risk management by one of the applicants was assessed negatively by the evaluators. Even for the other applicant that had some insights on a prospective commercial strategy, these insights were deemed inadequate and more detailing was expected by the evaluators, with some being critical about the market demand in the specific target markets that the applicant had highlighted as well as about certain budget estimates that were tagged as “unrealistic”.

Regulatory outlook: Underspecified discussions on the topic of regulation were judged negatively by the evaluation committee. Further, evaluators felt that having awareness of the regulatory landscape was itself inadequate for developing a robust value chain partnership, with an evaluator criticising an applicant for merely stating a potentially restrictive regulation and not detailing an action plan to navigate such regulatory restrictions and uncertainties.

Evaluative mechanisms: Evaluators assessed both applicants negatively due to inadequate planning and underspecified criteria and mechanisms to measure and evaluate the implementation and impact of the value chain partnerships.

Ambition level: Multiple evaluators assessed an applicant negatively due to its partnership not bringing much innovativeness or novelty to the LLab’s value chain, with some evaluators being sceptical of whether the partnership will even advance the TRL of the applicant. On the other hand, the other applicant was judged

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favourably for its potential “multi-level impact”, indicative of high ambition, even though it was also negatively judged for being “not super innovative”.

Articulation of the value chain governance logic in value chain partnerships

The articulation of the ALC Bio-Lab governance logic is mainly based on the construction of a collective action project that serves the community of farmers in solving the waste management problems of their farmlands as well as supporting the long-term resilience of their farms. Bioeconomy helped in finding a solution to sustain their farms, their village and their region.

At the same time, the growing of their cooperative project become a main illustrative initiative on bioeconomy in Catalonia. They have demonstrated how a network of farmers is able to join forces, invest in and lead the bioeconomy, without depending on external investment to initiate the process.

Collective action but also community control on the business seems to drive the work being undertaken by the ALC Bio-Lab. Value creation for the community and self-determination for their future is also involved in fostering new connections that are consequently critical in governing the emerging value chain. The LLab has a long history of ecological pollution that the primary producers had to go through, to solve which they had to work collectively. A spirit of self-determination and controlling one’s own future has emerged through this process, which is evident in the farmers seeking to retain financial as well as operational control over the Alcarras Bioproductors business as well as the Bio-Polygon hub to the extent possible, emphasising that never should the focus of solving farmers’ problem be lost from this business.

The communities surrounding the LLab also strive towards creating new opportunities for the young and adapting their livelihoods toward the future. The amalgamation of a long historical rootedness in farmers’ struggles and successes, coupled with technological innovation and searching for business opportunities, drives much of the LLab’s current work as well as its expanding partnerships, such as that with one of the aforementioned open call applicants that is working on making biochar-based bio-fertilisers for farmers using advanced technologies like pyrolysis.

Architectural blueprints for value chain governance

ALC Bio-Lab members have created certain structures and practices that guide the governance of their value chains, as described below.

Structures for value chain governance

Joint venture of farmer association: The land on which the Alcarras Bioproductors facilities are located, is owned by the two farmers associations. The general assembly, that is composed of the 150 farmer families from these associations, makes major financial decisions for the business as well as elects the board of directors who make decisions about the value chain operationalisation and governance, including whom to initiate, negotiate and consolidate relationships with. For each business, Alcarras Bioproductors has a separate board of directors, one each for the bio-compost and biogas businesses, and is further looking into the process of separating legal ownerships of the businesses to keep governance matters independent amidst the two businesses.

Practices for value chain governance

Regional bioeconomy network development: The LLab builds and maintains active collaborations with the Alcarras municipality, the Lleida regional authority and Catalonian Bioeconomy Hub, to seek support on several research and development activities that can further advance their value chains.

Community engagement and commensal work: The LLab organises and facilitates several events in the local community aimed at enhancing the understanding of sustainable farming practices and environmental responsibility, which is not just crucial for community acceptance of the expanding business facilities of the LLab

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by the local community, but also for the LLab to foster behavioural change amidst the local farmers using their end-product. The community feeling is also strong and comes to the fore in resolving conflict scenarios, where a lot of informal resolution mechanisms are used, such as spending time with one another and having meals together.

Knowledge prerequisites: The LLab built its existing value chains based on thought leadership co-created with a range of actors embedded in the ecosystem that it is a part of: local leaders, university researchers and technology consultants. The executive team and the board of directors are also in talks to hire a dedicated officer who can take on the role of building and fostering commercial relationships by studying and understanding the interdependencies between other actors and the LLab. Hiring a legal counsellor is also being considered to navigate the structure of the Agricultural Transformation Society and whether to retain this structure or to transition to a for-profit structure, that will both give more operational flexibility but also minimise certain governmental support.

8.3.2 Living Lab 2: Bio-Silica Lab (Leader: CeNTI)

As explained earlier in this deliverable (refer to sub-section 6.3.2), the Bio-Silica Lab is promoted by CeNTI, an R&D center committed to exploring and creating innovative solutions. CeNTI leverages its extensive know-how in waste stream valorisation and has been actively working on the extraction (and further modification) of bio-silica extracted from rice-husk, designed for integration into value-added end products.

Invitation of new actors into the value chain puzzle: PRIMED Open Call

In this sub-section, we explain the criteria possible partners used to nominate themselves to participate in the value chains of the LLab. They also used these criteria, focusing on very intentional language in PRIMED's Open Call applications, to position themselves as being good fits for the LLab's value chains. In the first Open Call, the Bio-Silica Lab received applications from three companies for end-use validation, and we analysed all three applications in detail.

Establishing synergies with the LLab ecosystem: The first applicant, an automotive equipment supplier, emphasised its commitment to "innovation and sustainability". The second applicant, a multi-sectoral three-dimensional device manufacturer, described itself as a "cutting-edge" "innovative R&D company" working at the "forefront of emerging technologies". The third applicant, a textile manufacturer, mentioned its "state-of-the-art machines".

These framings helped the companies position themselves as being aligned to the cornerstone of sustainable innovation guiding Bio-Silica Lab's work driven heavily by scientific knowledge. The applicants took this positioning a step further, with the second applicant highlighting their previous involvement in a project for valorising by-products. Both the second and third applicants mentioned integration of the exact three properties of modified bio-silica that the LLab is developing ("flame retardant, water repellence, antimicrobial"). This shows that instead of expressing their end-use needs as they exist, the applicants framed their needs depending on what the LLab is offering, to position themselves as perfectly fitting pieces of the value chain puzzle.

Demonstrating exemplarity: The first applicant positioned itself as a market exemplar ("second largest supplier in the European market") by citing its certifications and leadership initiatives. The second applicant emphasised its "proven track record" of "experience and knowledge" by citing its leadership role in several EU projects and "partnerships with important academic and industrial partners across Europe, providing further credibility". The third applicant framed close to a century of its company's legacy as an "iconic standing" and "an esteemed international position" in its market.

Demonstrating viability of validation process: The first applicant sees merit in its involvement in the value chain because its bio-silica validation will enable the identification of "suitable functionalisation routes for bio-silica nanoparticles to become compatible with the chemical formulations". It further substantiates this viability by presenting seven quantifiable key performance indicators (KPIs) over the course of two phases of implementation. It also shed light on five critical risks it identified as possibly impeding the implementation of the validation, and also presented mitigation measures focused on "small-scale compatibility tests", "iterative approaches with continuous refinements" and "regularly reviewing and adjusting".

The second applicant discusses the viability of its process by explaining how their validation will rely on using "a proven method for producing nanofibers with exact control over fiber diameter, composition and structure", while also referring to "preliminary studies that have demonstrated its (bio-silica integration) potential for applications". They highlight their end goal to be "consistent and reliable production" of their bio-silica integrated end-product.

Complementing value chain commercialisation: The first applicant explains why testing their proposed prototype is a crucial signpost towards bio-silica commercialisation in their industry, because "material technical performance and safety are key factors for market acceptance". They also boost the outlook for bio-silica in their industry by mentioning "the industry, increasingly focused on innovation, is open to the adoption of new materials that can offer these advantages, which creates an excellent market opportunity for the coming years". They also highlight that access to "markets where environmental regulations are stringent" is easier. They offer an insight into strategic commercial rethinking that may eventually be fuelled by bio-silica integration in their end-product, including more "strategic partnerships", "expansion to other market segments" and "revenue model based on premium products".

The second applicant also mentioned a positive market outlook in their industry, stating that the "global market is projected to see significant growth", signalling that this is a good space to expand the bio-silica value chain into, with a scope to both "scale out" and "scale up", a distinction that they explained and substantiated with industry-specific examples. Their work plan culminated in the final phase of "market analysis", wherein they promised to "analyse market trends, identify target customer segments and evaluate competitive products", insights from which will "guide strategic decisions regarding marketing, pricing and distribution strategies". They also expressed their ambition of applying for a prestigious global-level certification for their end-product to "further enhance market acceptance" and "build trust among end-users".

Qualifying and puzzling together pieces of the value chain: Evaluation of PRIMED Open Call applicants

With insights from Bio-Silica Lab representatives, the evaluation committee for the Open Call, consisting of PRIMED consortium members, assessed the suitability of each applicant as a "fitting piece" for the value chain puzzle of the Bio-Silica Lab. This process indicates how governance decisions can often be influenced by, sometimes outsourced to, actors who are not directly a part of the value chain but have external expertise that may bring forth broader insights and thus, steer the value chain's governance in a certain direction. The key criteria that were used to qualify applicants for inclusion/exclusion into Bio-Silica Lab's value chains, are explained below.

Viability: Evaluators judged applicants negatively for not discussing the viability of their implementation sufficiently, including not clarifying the specifics of the technology that they were planning on using. It was also emphasised that the capabilities of the team should be shed light on, to make the case for the applicant's expertise and skills more convincing.

Commercialisation opportunities: Evaluators appreciated a product-focused description of how the market could benefit from the product and the integration of bio-silica into it, but were critical when specific market segments and target customers were missing, with one evaluator commenting on an applicant's "products and technology being too far from market". Commercialisation was considered so critical that at least two evaluators assessed the third applicant very favourably because of their market reach, which they assessed as one of the applicant's critical strengths. The evaluators discussed how this applicant could provide the LLab with a strategic starting point for the commercialisation journey of bio-silica due to the applicant's "good environment for potential scaling-up and -out activities" since "they already have production capacity, distributors, market", thus making the "time to market short".

Regulatory outlook: A lack of understanding of relevant regulations that will affect the future end-product, once scaled, was assessed negatively, as was a missing discussion on how the relevant regulations will be tackled.

Ambition level: Evaluators highlighted applicants' engagement with the "state-of-the-art", "innovation in processes" and "innovative end-use" extremely positively, also highlighting the applicants' proposed "impact at different levels" and "strong sustainability focus" as being key.

Risk assessment and mitigation: A detailed risk assessment and proposition of risk mitigation measures by two of the applicants was enthusiastically commended by the evaluators, with one evaluator commenting on how new and important information was brought to light in the risk management section.

Articulation of the value chain governance logic in value chain partnerships

The Bio-Silica Lab seems to be governed by the dualistic logic of tapping into professional competence and scientific expertise to systematically advance science as well as to utilise these advancements to enhance industrial processes and outputs, by systematically substituting out the old for the new, the better and the more advanced. Both sides of this logic can be seen in the evolution arc of the Bio-Silica Lab, with the LLab's researchers' history with silica (researching it and providing consulting services to industrial partners) long predating the implementation of the LLab. It was in the spirit of scientific advancement that the researchers were led towards bio-based silica extraction in the literature produced by the scientific community, which they decided to explore because they felt that this could replace synthetic silica in several industries and make their manufacturing processes more sustainable. The living lab logic is then embedded in applying scientific knowledge to the creation of a novel value chain and ecosystem.

The selection of the open call applicant, the invitation of the value chain stakeholder to the workshop and the LLab consolidating its relationship with this new value chain partner, was both an expression of this logic as well as served to re-emphasise it. Like the LLab with its bio-silica, the second applicant (now the winning value chain partner) also does not see itself as tied to any specific industry: it too engages itself in advancing the frontier of the scientific community and does so by innovating on multiple technologies for multiple industries. This provides the LLab with a fruitful partnership with a company that is like itself in spirit, but directly engages with several markets at once, giving them an opportunity to keep co-exploring bio-silica in several different capacities even outside the scope of the open call and to sustain this partnership.

Architectural blueprints for value chain governance

Bio-Silica Lab representatives and stakeholders, who participated in the multi-stakeholder workshop, co-explored and recommended new structures and practices for value chain governance. This was a prospective exercise as most of them do not yet exist.

Structures for value chain governance

Since the LLab's value chain is just emerging, there are no existing official structures in place to govern the value chain, but the participants in the multi-stakeholder workshop co-facilitated by us expressed both a need and a desire for such a structure. An end-user cluster representative suggested a cooperative to be co-constituted for bio-silica related information dissemination, adoption and regulatory influencing, starting from the stakeholders who were a part of this workshop itself. Further workshops under the scope of this cooperative were also suggested to address concerns on a regular basis and align on next steps.

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More detailed structuring of the suggested cooperative was also discussed, with a steering committee deemed as critical in carrying forth the larger agenda of bio-silica's industrial integration and in ensuring that regular progress updates are collated and conveyed to members. This would comprise of individuals who have an extensive, in-depth and yet an overarching higher-level understanding of the industry they are working in. The steering committee could be further supported by smaller working groups that would be responsible for working on specific agendas.

Practices for value chain governance

Consolidating knowledge prerequisites: The scientific knowledge base, its co-creation and advancement is very crucial for the Bio-Silica Lab, since it is situated within a technological research centre. To do this, collating pre-existing knowledge and building further on it, was a systematic practice that was adopted at the inception of the LLab. The LLab researchers explained how they started working on creating bio-silica after drawing inspiration from scientific community literature on the potential and feasibility for making silica from bio-based sources, as well as from the laboratory trials they conducted with multiple feedstocks before narrowing down their focus on rice husk.

The LLab members understand the importance of standardisation and quality control and management for its potential end-users, especially since some of the end-use cases for bio-silica may involve relatively conservative industries. To ensure such quality standardisation, the LLab has already put into place traceability practices that provides it with the requisite knowledge on its feedstock batches, sources and quality, to be able to curate and control the process and end-product depending on the needs of an end-user.

The LLab also requested its potential end-users to cooperate in the preparation of product characterisations and analyses from data post end-product applications in their respective processes. The objective is to perpetuate a positive feedback loop that takes end-user data to further improve bio-silica development by the LLab, as well as co-ideate on new characteristics of the bio-silica that could be developed for specific use cases. An end-user cluster expressed enthusiasm towards this request by proposing workshops with the LLab and its members, to enable the cross-fertilisation of knowledge and concerns regarding bio-silica, including economic feasibility and regulatory aspects. They also mentioned that this could be a cross-sectoral workshop with the other end-user clusters also participating for common themes to emerge and for common solutions to be co-ideated.

Creating and safeguarding rights to created knowledge: CeNTI has patented the process of creating the modified bio-silica with the anti-microbial, hydrophobicity and flame retardancy properties. This practice of consolidating rights to newly created intellectual property gives the LLab a mechanism to legally channelise the flow of knowledge resources through the value chain, while also ensuring that those outside this value chain can be excluded from unduly exploiting these resources. This feeling of intellectual property safeguarding is crucial for value chain partners to feel that they are being governed respectfully.

Practising of end-product and regulatory modification: As the LLab and its potential end-users expressed enthusiasm to collaborate for understanding and developing bio-silica to cater to the specific needs of each industry, this discussion was followed by a potential end-user's appeal for everyone in the room to collectivise and work for pushing against regulation that currently restricts waste handling by non-waste management bodies as well as against industry-specific rules that are either ambiguous or discouraging on using novel materials like bio-silica. They expressed that unlike scientific testing and validations, this process cannot be achieved without the power and scale of a collective appeal by several organisations.

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8.3.3 Living Lab 3: Liguria Bio-Lab (Leader: FILSE)

As explained earlier in this deliverable (refer to sub-section 6.3.3), Liguria Bio-Lab is promoted by FILSE, the technical in-house company that provides support to Liguria region, working in active collaboration with other regional entities in defining, planning and implementing the policies that back Liguria's socio-economic development. FILSE, with other actors, explored and created a new bio-based ecosystem in the region. Via its value chains exploring valorisation of fish by-products and side-streams into various end-products, FILSE contacted and invited several potential value chain stakeholders to participate in building these value chains further.

Invitation of new actors into the value chain puzzle: PRIMED Open Call

In this sub-section, we explain the criteria possible partners adopted to nominate themselves to participate in the value chains of the LLab. They also used these criteria, focusing on very intentional language in PRIMED's Open Call applications, to position themselves as being good fits for the LLab's value chains. The Liguria Bio-Lab received applications from six companies for end-use validation, and we analysed all the applications in detail.

Establishing embeddedness and synergies with the LLab ecosystem: The fifth applicant was a fishers' cooperative, and it highlighted its marine ecosystem-related activities, positioning itself as the centre of the ecosystem that the LLab is trying to work around by explaining how their ambition includes "creating a new source of income" for the fishers. The sixth applicant mentioned "Liguria" as the title of the project they were proposing for the Open Call, hinting at their understanding of the LLab's and FILSE's deep embeddedness in and focus on the Liguria region, while explaining the advantage of their proposal being as follows: "suppliers from Liguria will reduce waste disposal costs and profit from their waste or by-products".

Even though the first applicant was not related directly to the fish industry in any way (since it is a textile-related research laboratory), they tried establishing synergies with the LLab's ecosystem by not just mentioning the "fish-derived gelatine" that can potentially replace an expensive pigment compound, but also expressed enthusiasm to try out "fermentation process using alternative feedstock from the fish industry" since "incorporating the fish industry side streams in microbial pigment production would promote the concept of novel biorefinery with zero waste".

Demonstrating viability: The first applicant took viability quite seriously, already touching upon it in the company introduction itself with their mention of "proof-of-concept projects and preindustrial runs". They immediately backed this up with details of "public and research grants" that they have procured in millions, emphasising financiers' trust on the viability of this process, which is already at a "TRL 6" and is "successfully upscaled into pilot-scale reactor" from "10 to 150 litres volumes". The second applicant emphasised a similar process development phase, being at the same TRL, and highlighting how the validation has already been conducted with a "20 litres batch". The second applicant explained how their process is further viable because of the amalgamation of scientific principles and techniques that are already "widely used" and "well-documented" in other applications. The sixth applicant emphasised undertaking "compatibilization" and "quality control assessment" of their process, "to reach target processing performance" and "to ensure the replicability of the process".

The fourth applicant had a broader take on viability, positioning their proposal as something that will enhance viability for all bioeconomy-related initiatives. They mention how each bio-based "by-product stream is different" and "scaling up processes will complicate once they try to valorise different types of side-streams". Thus, they "want to create a solution to homogenise the ingredients by separating different compounds using biotechnology".

Highlighting ecosystem-relevant collaborations: Three applicants, in their company introductions itself, highlighted their origin from, collaborations with and even recognitions received from important ecosystemic

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partners, like the University of Genoa and the Italian Institute of Technology (IIT), who have been key partners for the LLab that is managed by FILSE. This provides signalling for the LLab and the evaluators to understand the existing embeddedness of the company within the ecosystem the LLab operates in, thus contributing to a better understanding of the company's fit based on a better picture of its existing role. The sixth applicant further explained how they will "leverage on the network of IIT and FILSE to identify and select the most interested" partners for further collaboration in this value chain.

Proposing commercialisation pathways: The first applicant explained how the LLab's "fish-derived gelatine" can, if successful in replacing peptone in their violet pigment production process, will significantly reduce the cost of the entire process because of how expensive peptone is. This characterisation of the LLab's end-product being a cheaper replacement of a critical compound in the large-scale textile industry, presented a potentially important commercialisation opportunity for the end-product. They, alongwith two other applicants, also alluded to global market analysis reports and their estimates of the current as well as forecasted market sizes for their end-product to provide further credence to the claim that it is a suitable time for the LLab to partner with them to commercialise their end-product via this applicant's end-use pathway.

The second applicant discussed specific target customer groups that can be focused on for efficient commercialisation as well as a multi-faceted "go-to-market strategy", that included details on "partnerships and collaborations, B2B sales, scientific conferences and publications and regulatory alignment". They also discussed "obtaining relevant ISO certifications" for standardisation purposes that will help in "ensuring global compatibility and market acceptance".

The sixth applicant explained the specific process advantages they have on "optimization, performance, costs, exploration" fronts they have as compared to "competitors", they will be able to "reach, through their future industrialisation, a competitive advantage and product diversification in the market". They also mentioned that they participate in industry "fairs and exhibitions" and will continue these efforts to promote this initiative. Finally, they explained how they will initiate "joint applications to fundings" with potential partners who may be interested in participating in the commercialisation process but may not have the finances to do so.

Qualifying and puzzling together pieces of the value chain: Evaluation of PRIMED Open Call applicants

With insights from Liguria Bio-Lab representatives, the evaluation committee for the Open Call, consisting of PRIMED consortium members, assessed the suitability of each applicant as a "fitting piece" for the value chain puzzle of the Liguria Bio-Lab. This process indicates how governance decisions can often be influenced by, sometimes outsourced to, actors who are not directly a part of the value chain but have external expertise that may bring forth broader insights and thus, steer the value chain's governance in a certain direction. The key criteria that were used to qualify applicants for inclusion/exclusion into Liguria Bio-Lab's value chains, are explained below.

Ecosystemic synergies: Despite assessing some applications as excellent, evaluators still hesitated from vouching for them if they deemed the applicant to not be fitting well into the LLab's ecosystem, especially for some applicants that were from relatively unrelated industries and even from geographically distant locations. On the other hand, "relation to FILSE and fish side-streams", "territorial focus" and "involvement of primary producers" were assessed as some of the most important aspects of some applications.

Viability: Merely a generic description of the technological process was deemed insufficient to substantiate the viability of an applicant's proposal, evaluators mentioned expecting more detailing, for instance, periodic monitoring and validation steps with every step in the process, as well as benchmarking the process principles to related applications that already exist and have been successful.

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Further, a high TRL was assessed as a good indicator of a proposal's viability, with applicants with an already high TRL being vouched for by some evaluators. Some expressed that an especially high TRL, where the applicant's end-product (or a related one) is already in the market, signals less difficulties in and a shorter pathway to commercialisation.

Commercialisation considerations: Applicants backing their commercialisation plan in as much detail as possible, was assessed positively. For instance, evaluators expressed appreciation for applicants discussing what competitive advantage this proposal will bring to them and found a significant gap in applicants missing a market/competitors' analysis (especially when the relevant markets were seen as "mature" and/or "crowded"). Detailing was so important that an evaluator expressed that a broad category of end-products (such as one applicant's "high-value ingredients") cannot be looked at with the lens of the same commercialisation plan. They expected the applicant to further define at least one specific end-product within the broader category, and describe the specifications of its commercialisation strategy.

Further, an evaluator expressed that especially for early TRL applicants, it was not just important to have a commercialisation plan, but to also have a financial plan for scaling after the Open Call ends. They explained how, for early TRL applicants, almost all of the Open Call funding will go in building and operationalising the prototype itself (with one evaluator with a technological background expressing that the Open Call funding may not even be sufficient for the complete construction of a prototype), and thus, to take the proposal beyond just the prototyping, into even a pilot scale, would require much larger financing from other sources. If such discussions have not been touched upon in the applicants' scaling or commercialisation plans, then these may not work well.

Risk assessment and mitigation: Insufficient discussion of risks and how to mitigate them by some applicants, were assessed negatively by evaluators.

Regulatory outlook: A lack of understanding of relevant regulations that will affect the future end-product once scaled, was assessed negatively, as was a missing discussion on how the relevant regulations will be tackled.

Articulation of the value chain governance logic in value chain partnerships

Liguria Bio-Lab's work seems to be governed by the logic of developing and advancing the competitiveness and distinctiveness of the Liguria region, their land and natural resources, their communities and wellbeing that they are deeply embedded in. There is a lot of place-based drive, a lot of emotions, like pride and joy, for the beauty of the place, that these foster a sense of geographical belonginess. This belongingness drives work that can sustain the region and its bioeconomies, even make it prosper further, as well as nurtures a collaborative attitude towards other like-minded actors, associations and communities a who feel similar place-based emotions and belonginess.

The selection of the Open Call applicant and the LLab consolidating its relationship with this new value chain partner, was both an expression of this logic as well as served to re-emphasise it. The Open Call winner, a fishers' cooperative, is situated at the centre of the LLab's governance logic, with their lives revolving around and even physically situated with the natural landscape of Liguria's coast. Further, they also fit well with the LLab's focus on fishing-related actors. This focus emphasises another layer of the LLab's governance logic: promoting Liguria's development by using underutilised resources that exist within Liguria. It is this emphasis that led the LLab to focus on fishing-related activites, which happen in abundance within the predominantly coastal Liguria.

This collective action logic was also explored during the workshop and the field visit and interviews. Many different associations and actors, fishers, farmers, scientists and universities, entrepreneurs, innovators, SMEs, waste managers, regional developers act as core contributors to this governance logic.

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Architectural blueprints for value chain governance

Liguria Bio-Lab representatives and stakeholders, who participated in the multi-stakeholder workshop, co-explored and recommended new structures and practices for value chain governance. They are already co-creating together.

Structures for value chain governance

Since the LLab's value chain is emerging, there are not yet formal or official structures in place to govern the value chain, but the participants in the multi-stakeholder workshop co-facilitated by us expressed both a need and a desire for such a structure. For instance, motivated by the acknowledgement that this value chain should not be led by conventional "growth" considerations that leads to further overfishing, a stakeholder suggested the establishment of a consortium between the feedstock providers (fishermen) and the end-users (farmers, gardeners and agricultural researchers) to align on the quantity of the biostimulant that is actually required by the end-users and for the fishers to decide the portion of the by-catches to valorise accordingly towards this end (and perhaps find another suitable application for the rest) to avoid a demand-supply misalignment for the product in the market.

Regional development associations, such as FILSE, already exist and collaborate with other organizations focused on industry clusters and innovation. These associations are becoming key players in driving, supporting the creation of novel bioeconomy value chains by supporting existing bioeconomy companies, SMEs, and funding novel entrepreneurs—including primary producers, who play a central role as feedstock providers.

Practices for value chain governance

Consolidating and promoting knowledge prerequisites: The fishers' cooperative and the main scientific lead of the value chain have already engaged farmers and regenerative farming innovators as they see their complementary practices in the value chain. A farmer emphasised that for the biostimulant to reach critical scale in the agricultural market, the knowledge about its benefits needs to be propagated in a palatable manner. Thus, farmer engagement with simplified demonstration of the biostimulant results (vis-à-vis the non-application of the biostimulant in a comparable setting), coupled with some approval or certification of the scientific validity and verification of the claims, was suggested. Farmers themselves can be a critical channel for the transfer of this awareness, with one farmer highlighting how farmers exchange knowledge about best practices as well as resources (like seeds) to preserve local crop varieties and adapt to climate change. Thus, this pre-existing culture of knowledge transfer amidst farmers can be used for the biostimulant as well.

The non-profit partner of the LLab that promotes sustainable food consumption expressed its desire to organise events to promote awareness about the biostimulant, its benefits for agriculture, for the larger terrestrial ecosystem and for how it can promote human health. They proposed inviting other partner organisations alongside individual consumers, which could help in finding potential partner organisations for the biostimulant value chain, who share similar concerns and principles relating to sustainable food consumption.

Community-based commensal practices: The LLab has representatives and stakeholders showed strong community-rootedness, with the value chain being developed and extended based on who existing representatives know as doing relevant work from within the community. The Santa Margherita fishers' cooperative has also had a long history of community engagement in terms of having conducted several environmental campaigns and educational efforts in their community: thus, it becomes easy for them to garner local support when they bring forth a new initiative like the currently proposed value chain. The work on this value chain is so rooted in the local community that bringing resources or expertise from outside has not even been considered up until now, with even the technology being developed and assembled locally.

A farmer explained how increasingly, synergies between farmers and fishers of the Liguria region are coming to be recognised and realised, and this upcoming value chain is another effort that is helping with that. They

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explained that this will provide more opportunities for farmers and fishers to have a common conversation on something that brings both of them benefits. This could also lead to realisation of initiatives that have been in talks, such as locating fish and vegetable and fruit markets together.

Further, the LLab is planning to promote these value chains in a cultural summertime festival near the Santa Margherita fishing harbour. One of the LLab's partners collaborates with social non-profits to provide rehabilitatory work for prisoners, explaining that "we need to have a heart for people".

Several different stakeholders also expressed the negative realities of the interpersonal life of the community, in terms of how there is often "jealousy" between individuals, and thus, bringing people together serves to be difficult. LLab actors emphasise the need for them to take this into account in their own work and address certain matter sensitively when having certain kinds of conversations.

Practices for eliciting institutional support: The LLab representatives have, time and again, highlighted how important it is for the policy and regulatory landscape to change in their region as well as at the EU level, for their value chains to be able to scale to their potential. They are also lobbying for this with some relevant partners, at both the local (regional authorities) and the EU levels. However, they acknowledge that this is not a short or easy process and thus, slow advances and developing allies along the way, can help them bit by bit. In this spirit, LLab representatives have practices of bringing to local administrators' notice the work they are doing on these value chains and how it is benefiting local communities as well as the regional economy. Sometimes, they do this one-on-one (for instance, while meeting a mayor), while at other points, they bring these discussions to working tables that discuss policy matters related to the region. These practices are likely aimed at developing local administrators' and decision-makers' familiarity with this new ecosystem that the LLab is trying to foster, so that eventually, they can facilitating the changes and support that this ecosystem needs.

8.3.4 Living Lab 4: BioEire Lab (Leader: IBF)

As explained earlier in this deliverable (refer to sub-section 6.3.4), BioEire Lab is promoted by IBF, the national-level entity that provides support for all bioeconomy-related organisations in Ireland, working in active collaboration with other entities, including at the governmental level, in planning and implementing initiatives for bioeconomy development in Ireland. Via its value chains exploring valorisation of forestry- and dairy-based side-streams into various end-products, IBF contacted and invited several potential value chain stakeholders to participate in building these value chains further.

Invitation of new actors into the value chain puzzle: PRIMED Open Call

In this sub-section, we explain the criteria possible partners used to nominate themselves to participate in the value chains of the LLab. They also used these criteria, focusing on very intentional language in PRIMED's Open Call applications, to position themselves as being good fits for the LLab's value chains. The BioEire Lab received applications from five companies for end-use validation, and we analysed all the applications in detail.

Establishing embeddedness and synergies with the LLab ecosystem: The first applicant expressed their relationality to the same ecosystem that the LLab operates in by referring to collaborations with strategically important partners of the LLab, like Trinity College Dublin and Biorbic, the Irish national bioeconomy research centre. Further, they emphasised how they were adding value to the ecosystem by valorising "undervalorised Irish wood, available roundwood supply to improve the quality of life of our rural citizens and primary producers" with the "potential to see future high value rural jobs". The second applicant, who was from another country, showed its willingness to valorise any available Irish "dairy by-products" to test its replacement potential for a more expensive component in their production process, thus "supporting rural economies by creation of green jobs". They also emphasised their ecosystemic proximity to the LLab by mentioning their involvement in "several

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EU funded projects", which signals understanding of how the LLab works and its expectations given that IBF is also actively involved in many EU projects. The third applicant positioned itself as being nationally significant and thus strategically important for the LLab, by describing itself as "Ireland's oldest private family food business", alongside mentioning their valorisation of "readily available biomass material". The fourth applicant emphasised its relevance to the LLab's ecosystem via the route of benefiting primary producers and local community by offering "contracts to the farming community" for growing the required feedstock. They also highlighted "reducing globalisation" as a strength of their proposal due to their feedstock being "grown and manufactured locally". Lastly, the fifth applicant referenced Irish national-level strategic targets (for 2030) for bio-based production in the specific sector that they are planning on targeting with their end-product, thus positioning their work as very timely and critical in the Irish context.

Viability: The first applicant mentioned developing their process optimising it with help from IBF, which proxies well to establish their process viability since the PRIMED consortium trusts the scientific expertise of the IBF team in developing scientific processes. They also mention how their proposal builds on "international benchmarking of wood research and innovation", referring to their technology as mature at a global level. The second applicant mentioned "feasibility testing and demonstration" as key to establishing their process' viability. The third applicant explained how their process included an "accepted and well-known" technology and could thus be considered viable. The fourth applicant explained how their proposed end-product has been shown to have "greater performance" as compared to its conventional alternative along three metrics. The fifth applicant referenced "published research" to cite "increase in the production" and cost reduction "by reducing feedstock throughput" of the value chain they are hoping to enhance using their end-product.

Commercialisation potential and pathways: The first applicant showcased the potential market demand for their product by referring to the "European market size" (similar to the second applicant's referencing of the "Total Available Market" and "projected increase") and the size of Irish imports for their targeted market. They emphasised the credibility of their commercialisation approach by alluding to how they have "successfully brought our first biobased product to market", implying that this success can be replicated for their next product as well using their "existing distribution channels", while still being open to explore "different markets" and "different distribution models". They also mentioned the possibility of getting "certified in an accredited biomass analysis laboratory".

The second applicant mentioned their "strong traction with industrial partners" and "existing customer portfolio", naming specific sub-categories of actors within their industry whom they will tap into for commercial success using "personal contacts and key partners' contacts, agents in some countries, trade shows, and contact with brands". They also alluded to something very unique that we did not come across in other applications: product "versatility", as a proxy for "commercial potential". This is something they touched upon as an ambition they have for their end-product, but it was not clarified how exactly this will be attained.

The fifth applicant positioned themselves as "market makers", since they are "connecting the dots between waste producers and end-users (of the waste)". They did not just express the specific market segment that they aim to target with their end product but also mentioned a Letter of Intent (similar to the fourth applicant's "several Expressions of Intent) that they have worth several millions to supply their end-product to several proposed plants across Ireland via an intermediary. They also mentioned "continuing to conduct (market) research" about market demand "to further develop our product".

Qualifying and puzzling together pieces of the value chain: Evaluation of PRIMED Open Call applicants

With insights from BioEire Lab representatives, the evaluation committee for the Open Call, consisting of PRIMED consortium members, assessed the suitability of each applicant as a "fitting piece" for the value chain puzzle of the BioEire Lab. This process indicates how governance decisions can often be influenced by, sometimes outsourced to, actors who are not directly a part of the value chain but have external expertise that may bring forth broader insights and thus, steer the value chain's governance in a certain direction. The key criteria that were used to qualify applicants for inclusion/exclusion into BioEire Lab's value chains, are explained below.

Ecosystemic proximity and embeddedness: Being closely situated within the LLab's ecosystem (preferably even geographically) was deemed to be so important that an evaluator specifically noted an applicant's implementation plan as comprising of companies from Finland and Norway, and deemed this as a disadvantage due to the distance of these countries from the LLab's ecosystem. Applicants who were embedded within the local ecosystem but were still missing a discussion on the involvement of primary producers, were also negatively assessed.

Viability: Proposal viability was assessed in close interconnectedness with proposed team and competences. The viability for one of the applications was questioned since the team only comprised of graduates in "law and business" disciplines, backgrounds that were deemed insufficient for deep engagement with valorisation-related technologies. Missing analysis on risk assessment and mitigation were also deemed as a potential threat to viability.

Commercialisation considerations: The lack of specification of target markets, underdefined competitive advantage aspects, lack of discussion of scale-up potential and missing competitors' analysis, were assessed as gaps in applicants' commercialisation plans. Further, commercialisation that was described as viable based on previously successful go-to-market strategies, were deemed insufficient without further detailing of the previous projects, end-products and why those markets are comparable to the now relevant markets.

Regulatory outlook: A lack of understanding of relevant regulations that will affect the future end-product once scaled, was assessed negatively, as was a missing discussion on how the relevant regulations will be tackled.

Ambition level: For applicants that proposed to use existing technologies, evaluators wished to clarify their ambition in terms of what innovativeness they are bringing to the table and how what they are doing can be deemed as novel from a technological perspective.

Articulation of the value chain governance logic in value chain partnerships

BioEire Lab's work seems to be governed by the logic of socio-ecological remediation, wherein what drives the focus on bioeconomy is both remedying the natural environment that has suffered from industrial activity in the past and also deep community-rootedness, that is expressed in the sentiment of using the community's resources (notably the land that previously had a mine on it that employed a lot of people) and thus, the desire to give back to the community that is evident in the National Bioeconomy Campus' ambition in creating 400 jobs for the local community. This dualism is also expressed in the LLab's frequent referencing of "just transition" in addition to bioeconomy, since they acknowledge that the new bio-based ecosystem that they are creating must also be inclusive and take along and uplift all affected actors. Another layer of the governance logic includes credence to the Irish national interest, with the LLab choosing to focus on sectors and resources that are nationally relevant and widespread.

The selection of the Open Call applicant and the LLab consolidating its relationship with this new value chain partner was fit in well with this governance logic. The Open Call winner's proposal was arguably the one with the most community-centredness, benefiting the local farming community directly in terms of the biochar-based soil amendment they aimed to prepare. Their rootedness in the community is so pervasive that not only do they wish to advance their process and specify their end-product characteristics based on direct farmer feedback, but further, local consultations have made them aware of newer issues such as surface water runoff from farms, which they are thinking of tackling with biochar as well. Beyond social aspects, their drive for local ecological

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remediation has been evident in them being open to adapt to the rhythmicity of nature. For instance, due to the Eowyn Storm in 2024, the sitka spruce forests were the hardest hit, and thus, they are choosing to prioritise this feedstock for valorisation into biochar.

Architectural blueprints for value chain governance

BioEire Lab representatives and stakeholders, who participated in the multi-stakeholder workshop, co-explored and recommended structures and practices for value chain governance.

Structures for value chain governance

Roles and responsibilities within local administration: The Tipperary County Council, the local administrative body responsible for the Lisheen region where the National Bioeconomy Campus is situated, has defined certain roles, coupled with specific implementation guidelines, to align with the work being undertaken by initiatives like the National Bioeconomy Campus as well as to streamline the efforts in a direction that are both in line with the community interest as well as the national-level sustainability targets. The specific roles include the Decarbonising Zone Officer (who has the responsibility to ensure that sufficient progress is being made on county-level decarbonisation plans, which includes advancement of the National Bioeconomy Campus) and the Circular Bioeconomy Outreach Officer (who must ensure that the community is involved in all major decision-making aspects within the County's bioeconomy ecosystem). These officers and their staff work on organising frequent public consultations where the work and progress of the National Bioeconomy Campus is shared with the community and the Campus representatives have to engage with the community, alleviate their expressed concerns and convince them of the relevance of the developments that they are trying to foster. For any new initiative that requires support from the County Council, a full disclosure plan of the project has to be publicly published, which the community members are given rights to provide comments on. The initiative is not allowed to be approved until the full plan, with modifications, is re-approved by community members. Approval iterations are allowed to go on through multiple rounds until all public concerns are fully addressed.

Policy implementation working groups: The Irish bioeconomy ecosystem has constituted some working groups for policy implementation which meet on a periodic basis to discuss developments in the biochar space and how to advance this further. These groups, through their collaborative efforts, managed to get recognition for biochar in Ireland's Carbon Action Plan in 2024, and will also be leading the development of a national biochar standard in the future. The LLab and some its stakeholders engage with these entities on a regular basis to discuss the progress that they are making on the scientific development front and to express the support they require from the policy sphere to advance specific value chains in the ecosystem.

Practices for value chain governance

Consolidating knowledge prerequisites: The LLab pays close attention to knowledge prerequsites for the value chain to emerge and to be governed, so much so that the invitation and integration of new partners is valued the most because of the different knowledge bases, expertise and capabilities they bring to the table. These partners include the LLab scientific team, the end-users, other bioeconomy clusters from different regions of Ireland, university researchers, research centres and policy implementation groups.

The first step for consolidating knowledge prerequisites is for value chain actors to characterise the feedstock that they will be working with, and in this value chain, they typically expect the end-user to have already done that in the laboratory testing before they come for the pilot testing. In this value chain, a technical partner is also helping with this process, with their expertise on different kinds of analyses, including analysis of fixed carbon chains and testing for heavy metal contamination. Such characterisation lays fertile groundwork for further processes. For instance, in this value chain, the LLab partners have been working on reducing particle sizes and for ensuring moisture control for efficiency to be aligned with the pilot bioreactor's specifications. It is only when

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these characterisations and modifications have been conducted, that the value chain is then progressed to the pilot run.

An interesting facet unique to this LLab was the approach to community involvement in prioritising and developing certain knowledge prerequisites. This came to light when, complementing the technical partner's explanation of the various soil amendment-related analyses they can conduct on the end-product, the end-user commented that they would also like to have some conversations with the farmers, the prospective consumers of the end-product, and hear from them about the properties they would value, and prioritise and possibly develop specific analyses accordingly.

Discussing creation and safeguarding of rights to created knowledge: The LLab end-user is developing new knowledge in developing the current value chain of biochar-based soil amendment. Thus, it has been having recent discussions regarding intellectual property, how and when to apply for it and whether (and how) to share it amidst collaborating partners like researchers from other universities, when such knowledge is co-created. This practice of determining rights to the newly created intellectual property, would give the company a mechanism to legally channelise the flow of knowledge resources through the existing as well as extended value chains, while also ensuring that those outside this value chain can be excluded from unduly exploiting these resources. This feeling of intellectual property safeguarding is crucial for value chain partners to feel that they are being governed respectfully in future commercial processes, by fair transaction of only what is rightfully owned.

Liaising with the community: Aligned with its drive for social remediation, the LLab actively participates in efforts to engage with the community in several consultation meetings, where the community raises its concerns about the work at the National Bioeconomy Campus and IBF alleviates their concerns, which often involves them closing certain information gaps. Efforts have been made for these conversations to go beyond merely the verbal channel into the realm of visualisation with, for instance, IBF having created a three-dimensional model of a biomethane plant that they are planning to develop, so that through this model, IBF scientific experts can show the layout to the community members in real time and explain the purpose of each part of the layout, including the safety measures that will be taken to prevent any risks to the community.

Co-cultivating and maintaining bioeconomy network: Being a major driver of the Irish bioeconomy, IBF deems it important to know, have deep relationality with and consult other important bioeconomy players in Ireland to align on and advance important systemic developments and strategic considerations. These efforts involve openness in information about where resources like funding flows and knowledge resources are being channelised and thus, yields important connections and resources for specific value chains to develop (e.g. if a potential end-user does not know where to get the massive volume of feedstock for its pilot testing, IBF can tap into its extensive network to find suitable sources for this) since everyone gets extensive knowledge of the network they are embedded in, including who is responsible for what role and where certain expertise can be sourced from.

8.3.5 Living Lab 5: Cell Factory Lab (Leader: VTT)

As explained earlier in this deliverable (refer to sub-section 6.3.5), Cell Factory Lab is promoted by VTT, a scientific entity located in Finland, working towards the advancement of applied scientific research. Via its cellular agriculture-based value chain exploring valorisation of agri-food side-streams into various novel components for industries like novel food, cosmetics and nutraceuticals, the LLab contacted and invited several potential value chain stakeholders to participate in building this value chain further.

Invitation of new actors into the value chain puzzle: PRIMED Open Call

In this sub-section, we explain the criteria a partner used to nominate themselves to participate in the value chain of the LLab.

They also used these criteria, focusing on very intentional language in PRIMED's Open Call applications, to position themselves as being a good fit for the LLab's value chain. The Cell Factory Lab received one application from a beverage company producing plant-based juices and purees, and we analysed this application in detail.

Establishing embeddedness within the LLab ecosystem: The applicant contextualised the struggles it was facing as a beverage company with the heightening uncertainties and unpredictabilities of raw materials in their supply chain. This positioned the applicant as being affected by the core problem the LLab is trying to address, thus becoming a fitting recipient in need of the LLab's solution.

Viability: The applicant mentioned that process viability will be determined by undertaking a preliminary "feasibility study", "analysis of side-streams" and by assessing the "suitability of existing process equipment to cell farming ingredients".

Commercialisation potential: The applicant expressed how the adoption of the plant cell culture technology to their value chain (creating purees and juices) will give the technology a good opportunity to scale and get commercialised due to it providing them feedstock supply certainty by replacing the (qualitative and quantitative) feedstock variability of traditional raw material sources that have been so affected by climate change-related supply chain disruptions that some shortages have become "usual". This certainty and supply chain stability could prove to be a strategically worthwhile investment for the applicant to make into larger-scale commercial use of this technology (if the Open Call validation turns out to be successful) since this could deliver cost savings in the long run.

Further, the commercialisation potential of the applicant's proposal was described in the broader market context by referring to estimates of the Finnish and Asian (the applicant's main export destination) "market potential" of the applicant's end-product, as well as of the applicant's projected market share. In addition to this, a "market survey" of the proposed end-product was also promised and allocated budget for.

Qualifying and puzzling together pieces of the value chain: Evaluation of PRIMED Open Call applicants

With insights from Cell Factory Lab representatives, the evaluation committee for the Open Call, consisting of PRIMED consortium members, assessed the suitability of the applicant as a "fitting piece" for the value chain puzzle of the Cell Factory Lab. This process indicates how governance decisions can often be influenced by, sometimes outsourced to, actors who are not directly a part of the value chain but have external expertise that may bring forth broader insights and thus, steer the value chain's governance in a certain direction. The key criteria that were used to qualify the applicant for inclusion/exclusion into the Cell Factory Lab's value chain, are explained below.

Ecosystemic considerations: Evaluators took the applicant's claim of the process being "more sustainable than agriculture" cautiously, acknowledging the missing discussion on social sustainability issues, especially the primary producers from whom the raw materials have been sourced up until now.

Viability: "No mention of TRL" was negatively assessed for inhibiting the lens through which viability claims can be understood and evaluated comprehensively.

Commercialisation considerations: The applicant hoping for immediate market success with the proposed end-product in distant export markets, especially when coupled with an underspecified commercial strategy, was assessed to be far-fetched by evaluators, implying that the domestic market should be focused on first since there is likely to be better acceptability of the end-product therein. Further, a lack of characterisation of the proposed end-product's competitive advantage was assessed negatively.

Risk mitigation: An insufficient discussion on how to mitigate the identified risks were assessed negatively by evaluators.

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Articulation of the value chain governance logic in value chain partnerships

The Cell Factory Lab's work seems to be governed by several logics converging together to drive technological radicalisation towards global-scale stability while transforming the food industry. A core driving logic within this convergence is the exploration of scientific novelty, driven by the Principal Scientists and the VTT team who had been working within cellular agriculture for several years and kept seeking newer modifications of the several variables involved in the scientific process. Further, the application of this scientific novelty to a systemic, possibly global, transformational scope, was fuelled by the governance logic of engaging in long-term radical futuring by placing big bets on the synergies between science and markets. The governance logic also involves a set of entrepreneurial companies and stakeholder that aim to explore food security in Finland.

The selection of the Open Call applicant and the LLab consolidating its relationship with this new value chain partner, was an expression of this logic. The Open Call winner is a company within the food industry that characterised the uncertainties it had started facing regarding its raw material quality and quantity considerations in its supply chain. This gives meaning to the LLab's long-term radical futuring governance logic by bringing to the fore problems so intricate that they cannot be solved by short-term marginal solutions anymore. Given that the company belonged to the food ecosystem - the very ecosystem that the LLab sees as the hotspot of the pervasive supply chain disruptions that will only worsen in the future, the very ecosystem where the need of security and self-determination is very crucial due to the ecosystem's ubiquity - the LLab possibly saw the applicant's validation process as the beginning of their technology starting to effect change at a sizable scale, within a sector that matters.

Architectural blueprints for value chain governance

Structures for value chain governance

Novel food ecosystem: The LLab leader, VTT, is part of a food ecosystem that has been created in Finland, with 170+ members (spanning the breadth of businesses, researchers, financiers and other partners) interested in research, development and innovation work related to emergence of novel food in the food industry. A systematic effort has been made under this initiative to have regular events to discuss development of business capabilities via a better understanding of considerations like funding sources and targeted market strategies. Steps are actively being taken to further enhance networking and knowledge sharing amidst partners. This ecosystemic structure is likely to be at the centre of the LLab's efforts to share its innovation in cellular agriculture with its novel plant cell culture technology and propose collaborations with relevant partners that will help to expand and scale the LLab's value chain. It is, thus, clear that the opportunities provided by this broader ecosystem will determine who gets involved in the future governance of the LLab's value chain and how this governance is carried out.

Utilising market foresight capabilities: The LLab scientific team has a market foresight and consumer research expert working closely with this emergent technology to not just develop a value chain around it, but to give it the most suitable direction possible. This process involves forecasting for different ecosystemic scenarios, from which market-specific scenarios are derived and further analysed. A dynamic systems perspective is taken, where the fit of the technology is assessed in several different versions of the future world, and it is based on this assessment that specific value chains are chosen to be developed and specific actors involved for these developments. Further, as this value chain gets extended with newer and more diverse actors, it is this very structure of foresight that will steer the governance of the value chain more or less urgently, towards broader or more specific priorities. For instance, current scenario predictions have estimated the threshold for the market maturity of this emergent technology to be around 2040.

New role for aggregating available feedstock: Since cellular agriculture including the plant cell culture technology is dynamic enough to be applied to a wide and diverse range of possible feedstocks, the opportunities for experimenting with different side-streams and creating novel value chains is huge. To tap into this potential

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comprehensively, the LLab deems it important for a centralised body to take up the responsibility for aggregating and providing feedstocks from multiple sources, especially for larger scale valorisation efforts for which the requisite logistics may be driven by complex considerations like feedstock variability, time until decomposition and intra- and inter-regional interconnectedness of transport networks. This role could be taken up by an existing body, or a new organisation could eventually be established to fulfil this role as the ecosystem scales and new value chains and actors keep emerging on the scene with increasing informational and coordination needs.

New financing network: Given the scale of the transformation of the food system (systemic reconfiguration) , it is anticipated that the existing quantum of funding to finance food-related innovations (marginal change) won't be enough. Several more financiers and financial resources will be required for this change to be set in motion, and LLab stakeholders are confident that deeper understanding of the reach of this transformation will encourage more finance to pour in. However, to coordinate, align with, get insight from and share knowledge on food companies' developments along this front, LLab stakeholders proposed establishing a financiers' network focused on the food ecosystem's transformation. This network could further help to clarify the financial sector's priorities and communicate them to businesses in an effective manner to chart an alignment between capital flows and business interests.

Practices for value chain governance

Consolidating knowledge prerequisites: LLab and end-user representatives emphasised the need for collation of knowledge prerequisites for the development of a successful value chain built around the plant cell culture technology. This is because the novelty of the technology as well as the feedstock would require compliance to possibly several regulatory frameworks as the first step, at the very least the European Food Safety Authority's (EFSA) Novel Food Regulation. To make this compliance process smooth, the end-user adheres to strict standards of traceability regarding their feedstock, a process that originates at the point of procurement of a batch of feedstock and goes up until the packaging of the end-product.

Creating and safeguarding rights to created knowledge: VTT owns proprietary plant cell lines as well as IP related to plant cell culture technology. This practice of ownership and consolidating rights to newly created intellectual property gives the LLab a mechanism to legally channelise the flow of knowledge resources through the value chain. Particularly the plant cell culture ownership of VTT and related expertise and know-how is crucial for value chain partners to be able to rely on that they are being governed respectfully in transactions of this created knowledge during future partnerships.

Updating knowledge assessments: As a LLab representative explained, the early-stage novelty of the plant cell culture technology leads to its key indicators changing very fast, whether it be the process performance, efficiencies, scope, scalability or financial viability. The estimates that are collated from feasibility studies and techno-economic assessments could become dated very fast, since the early development phases of a technology are marked by quick and significant changes. Thus, the LLab members mentioned engaging in practices of periodic updating of their knowledge prerequisites regarding the technology via revised assessments of key indicators and market opportunities.

Simplifying and disseminating knowledge: The transformation that the LLab is wishing to elicit via its technology requires cooperation from a diverse range of actors. Thus, translating the benefits of this novel technology (not just in terms of its functioning but also in terms of its scope of transformation) in the language of the specific stakeholders is very crucial to convince them that this transformation will not threaten them and how the massive resource allocation will be worth the benefits that will eventually follow. The LLab representatives explained how they have to use different language, arguments and communication strategies to engage primary producers vis-à-vis policymakers and make the story accessible to them.

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8.4 Discussion and recommendations

We have studied how each LLab has built its own governance logic by emphasizing different targets and mechanisms, such as scientific advancement, systems change, market-orientedness, regional development and local environmental problem-solving.

The inclusion of new actors in the **puzzling process** involved establishing synergies within the LLab ecosystem, demonstrating the viability of processes and proposing activities that complemented existing value chains. A key consideration has been how new actors propose **commercialisation pathways**, especially those that highlight ecosystem-relevant collaborations and address regulatory challenges.

Regarding the **architectural blueprints for value chain governance**, we have observed that all five LLabs have begun developing governance practices. However, only a few are more advanced in creating formal governance structures. These include clearly defined roles and responsibilities, particularly within joint ventures like associations.

Emerging governance practices across LLabs included:

- Consolidating knowledge prerequisites;
- Creating and safeguarding rights to generated knowledge;
- Facilitating network development;
- Promoting community engagement;
- Simplifying and disseminating knowledge;
- Demonstrating end-product viability; and
- Advocating for regulatory adaptation.

All these practices might transform into structure for governance in the next years, but important work needs to be done. Actors within the LLabs have shown enthusiasm to support such developments. We propose the following recommendations to further strengthen and consolidate a systematic and phased approach to governance:

1. Regulatory hurdles have been identified as discouraging feasibility, scaling, and in some cases even sustenance, of emergent value chains across the five LLabs. Thus, we recommend the preliminary focus of each LLab as aligning expectations, roles and responsibilities amidst several stakeholders regarding a two-pronged approach to tackle regulation, emphasising both regulatory compliance as well as pushing for regulatory adjustments.
2. Once the value chains can be sustained, the governance activities' focus can shift towards scaling. This would involve allocating stakeholder roles and responsibilities focused on transcending the ecosystem perspective towards larger, possibly global, exploration. Quite likely, this may involve completely new actors within the governance lens with governance logics that are not rooted in a specific localised ecosystem.
3. Lastly, the LLabs might broaden their governance perspective beyond the "scaling up" perspective to the "scaling out" perspective, by considering inter-value chain governance. This would remain a dynamically evolving process involving seeking out synergies with existing as well as emergent value chains and governing the resulting interconnectedness for mutual co-development.

This multi-phased approach to governance can ensure that each LLab can orient their focus on the needs of their specific stage of development and channelise governance discussions and mobilise efforts around the most relevant aspects and stakeholders from within the expansive horizon of value chain governance.

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9. Conclusion

The five Living Labs in the PRIMED project have initiated several novel bioeconomy value chains in their respective ecosystems, that utilise side-streams from several bio-based industries to generate sustainable sources of value creation in the modern economy. This deliverable has provided several insights on complementing the development of these value chains and nurturing them towards creation of novel circular business models in the bioeconomy (CBMBs). These insights have been drawn from a broad range of different perspectives – technological, regulatory, multi-stakeholder and ecosystemic.

A preliminary techno-economic assessment has contributed to define the key processes and technologies as well as to estimate product yields, costs and minimum product selling prices for the selected value chains. Production of compost using the solid manure shows to be feasible, achieving minimum selling prices of 30-45 €/t with feedstock capacities of 10-100 kt/t. These values are even lower that market prices for non-certified bulk compost for agricultural use, varying in the range of 50 to 150 €/t. The alternative use of pig slurries and cow manure in anaerobic digestion for production of electricity and heat has a poor economic performance with MSP of electricity in the range of 0.3-0.9 €/kWh, significantly lower than current market prices. However, considering further upgrading of the biogas to biomethane can be a feasible option due to the high market demand. The production of raw bio-silica from rice husk shows a good economic performance when the excess heat from calcination can be sold and depending on availability and transport distance of the rice husk, achieving MSP of 0.4-0.6 €/t with rice husk supply cost of about 0.1 €/kg. The alternative of extracting silica from ash residues exhibits a lower economic performance than using rice husk due to the impact of high operating cost without revenues from heat export. The economic viability of producing biofertilizers from fish waste depends much on reducing maintenance and labour costs by either using robust and automated Equipment or increasing plant capacity above 5 kt/y. Under these conditions, the MSP can reach values below 3 €/kg, which are within current market prices for liquid fertilizers. The economics of producing biochar from saw dust or forest residues via pyrolysis is very dependent on the plant capacity and the cost of feedstock supply. Considering market prices of biochar of about 300 €/t, using saw dust as feedstock can be economically feasible when the cost of saw dust is between 5-30 €/t. Using forest residues increases the overall cost of biochar production relative to using saw dust, due to additional investment and energy required by the feedstock pretreatment, but can be economically feasible if the supply cost of the forest residue is below 70-90 €/t. Cell cultivation using liquid effluents from juice Production exhibits high production costs mainly due to Direct operating costs of nutrients and Utilities consumption. The value chain considered can reach MSP values for dried cell products in the range 200-350 €/kg for plant capacities of 100 kt/y (feedstock) which lay within foreseen market values. Reduction of the cost of the carbon source and other nutrients is a key factor in improving the economy of cell cultivation and needs to be addressed further. This preliminary assessment lays a firm groundwork for further and more in-depth analysis of the technologies and the critical aspects affecting the overall value-chain economy.

The techno-economic risk analysis of LLabs and their regional ecosystems followed next. For each Living Lab, the annual feedstock availability and current processing capacities were quantified, and scalability risks and opportunities were explored. The outputs were segmented by local market categories. Each scenario was evaluated against technical, regulatory, financial, and social risk dimensions. Risks were mapped against potential impacts to visualize phased expansion pathways. Assumptions were grounded in regional policy frameworks, local project ecosystems (with a list of success cases included at the end), and potential strategic partnerships identified to de-risk each development phase.

This was followed by a multi-stakeholder value chain mapping exercise and value chain synergies analysis, wherein the perspective was broadened beyond the LLab to exploring how other local actors positioned the relevance of the LLab within their ecosystem. Several emerging synergies with other established as well as upcoming value chains and partners were uncovered. These provided a more contextual landscape to undertake an ecosystemically grounded SWOT analysis. Community integration, local leadership and exemplarity were

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identified as cross-cutting strengths, and we proposed tapping into them further to develop partnerships, especially focused on commercialisation. Regulation was identified as the strongest barrier across all LLabs. We proposed multi-stakeholder collaborative efforts, in line with existing value chain synergies, to build on the strengths and tackle emergent challenges towards a favourable positioning for the value chains within their ecosystems.

A policy and regulatory screening for each LLab was presented, which identified three main types of barriers that are hindering or will block the establishment and development of the new value-chains: feedstock regulations, market access and competitiveness, and existing financial frameworks, by this order of priority. It was proposed that efforts need to be taken for regulations to be updated to ensure an innovation-driven and future-proof approach that allows technology to evolve and deliver positive impacts for the economy, society and environment. The definitions of waste and by-products, as well as their processing options need to convene all the technological and business opportunities in the context of the bioeconomy.

Finally, the analysis on governance initiation, logics, practices and structures provided an overarching framework to understand how the LLabs and their collaborators invite actors to get involved in the value chain and eventually co-develop multi-faceted governance logics. The former "puzzling" process involves considerations of ecosystemic embeddedness, process viability and commercialisation potential and pathways. Governance logics get consolidated around socio-ecological remediation, community belongingness, scientific advancement and long-term radical futuring. The "puzzling" process, fuelled by these governance logics, is followed by multi-stakeholder co-evolution of governance practices and structures. We conclude the discussion on governance approaches by proposing a three-phased approach where governance "puzzling" as well as governance practices and structures can be formulated around evolving strategic foci, originating at overcoming regulatory hurdles for value chain sustenance, advancing towards value chain scaling beyond the local ecosystem and finally, seeking and advancing cross-value chain synergies.

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