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PRIMED

D2.3. FRAMEWORK CONDITIONS FOR CIRCULAR VALUE CREATION: GOVERNANCE MODELS POLICIES, INVESTMENTS OPTIONS AND IMPACT MONITORING

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ACRONYM GLOSSARY

ADS	*Association of defense of porcine*
ALC	*Alcarras Bioproductors*
ARD	*Association of farmers of bovine*
CBMB	*Circular Business Model in Bioeconomy*
CHP	*Combined Heat and Power*
EU	*European Union*
MICAMO	*Microbiologia Ambientale Molecolare*
SAT	*Agricultural Transformation Society*
TRL	*Technological Readiness Level*
VC	*Value chain*

DISCLAMER

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EXECUTIVE SUMMARY

The objective of this deliverable is to consolidate the expertise within the consortium on circular value chains and sustainable value creation in the bioeconomy, addressing both the micro-level (local rural development) and macro-level (national and regional scales). The principles of circular economy and bioeconomy are inherently synergistic, sharing a common goal of sustainability and resource efficiency. To achieve this, we will conduct a comprehensive review of the literature on bio-based value chain creation, circular business models, policy frameworks, investment strategies, and impact monitoring. This review will allow us to analyse the current state of the art, identify best practices, and address existing challenges and barriers. The goal is to establish the framework conditions necessary for circular value creation across all bio-based value chains in the Living Labs.

The deliverable is structured to provide a comprehensive analysis of circular bioeconomy practices and is divided into five major parts, each addressing a distinct aspect of bio-based value chain development and sustainability.

The first section, led by Ruhr University Bochum (RUB), provides an in-depth analysis of the business models utilized within the five Living Labs. Drawing on the framework from Bröring & Vanacker (2022), this section classifies the Living Labs' models based on three core bioeconomic business model types: new bio-based products, processes, and integrated services. The analysis then delves into the internal and external value generation and the specific challenges that living labs face.

The second section, coordinated by LUT University, focuses on understanding and distinguishing the bio-based value chain types within the Living Labs. This analysis maps key stakeholders, technologies, and innovative synergies that support bio-based value chain development. Additionally, it highlights the challenges associated with the value chains.

Led by EUBIO, the third section identifies the main regulatory bottlenecks impacting bio-based value chains. The analysis explores economic, market, and legislative frameworks at both national and EU levels, addressing specific regulatory contradictions and issues that may hinder the development and scale-up of sustainable value chains.

The next section, contributed by Inveniam, evaluates investment opportunities within the bioeconomy, including potential risks and barriers. Finally, an analysis by Inveniam reviews existing impact monitoring indicators and methodologies used in the bioeconomy sector.

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1. CIRCULAR BUSINESS MODELS IN BIOECONOMY ANALYSIS

1.1. INTRODUCTION

Circularity and bioeconomy represent critical pillars in the shift towards sustainable development, aiming to create regenerative economic systems that minimize waste and make efficient use of natural resources (Yadav et al., 2021). Within this context, business model innovation plays a vital role, as it enables organizations to adopt more sustainable practices while creating value for stakeholders (Schalgetter et al., 2012). This report focuses on analyzing the business models of five European living labs, which explore and implement circular and bioeconomic solutions.

Drawing on the frameworks of Bröring and Vanacker (2022), the report examines the specific business models of these living labs, along with the unique challenges they face. Two of these labs are further explored through a detailed lifecycle analysis and a study of the ecosystem of actors involved. The following sections present the methodology used for this analysis, followed by an in-depth examination of each living lab and its corresponding business model. Finally, the challenges are outlined, and the conclusion synthetized.

1.2. METHODOLOGY

To conduct a comprehensive analysis of the business models of five living labs, a systematic literature review was performed using two major academic databases: Scopus and Web of Science. These databases were chosen for their extensive coverage of peer-reviewed literature in the fields of bioeconomy, circular economy, and business models.

Search strings were developed to identify relevant studies, focusing on keywords related to circularity, bioeconomy, and business models. The following search strings were applied:

- Scopus: TITLE-ABS-KEY ((bio-econom* OR bioeconomy*) AND (circular*) AND ("business models" OR "business model")) which resulted in 82 articles.
- Web of Science: TS= ((bio-econom* OR bioeconomy*) AND (circular*) AND ("business models" OR "business model")) which resulted in 64 articles.

Additionally, four articles were included through the snowballing technique, where references from relevant studies were explored further.

After comparing the results from both databases and removing duplicates, a filtering process was applied based on relevance, quality, and contribution to the topic. This resulted in a total of 31 articles selected for deeper analysis. These articles provided the foundation for understanding the challenges and business models applied in living labs, as well as valuable insights into lifecycle and ecosystem analyses.

From this analysis, four frameworks were identified as particularly relevant for living labs and their associated business models within the context of circular and bioeconomy practices.

1.3. RESULTS

Based on the methodology outlined, the analysis of the five living labs' business models draws on a range of key academic sources that provide crucial frameworks for understanding both circularity and bioeconomy in practice. Based on the methodology outlined, the analysis of the business models within five European living labs draws on a combination of well-established academic frameworks that collectively provide comprehensive

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insights into both circularity and bioeconomy in practice. These frameworks were chosen for their ability to map the complex dimensions of business models, sustainability, resource optimization, and stakeholder integration.

The foundational framework for this analysis is derived from Bröring and Vanacker (2022), who identify three distinct business models within the bioeconomy: new products, substitute products, and services. Each of these business models is analyzed through three key categories—value proposition, value creation, and value capture. This structure allows for a comprehensive understanding of how each living lab operates within the bioeconomy.

Beyond the work of Bröring and Vanacker (2022), two of the living labs will be further analyzed using additional frameworks to deepen the evaluation. The cascade use of biomass (Berg et al., 2020) framework is applied to map the material and energy flows across the labs what provides a detailed understanding of how resources are optimized and reused at different stages. . This framework was chosen to map how biomass flows are managed across the living labs' operations, particularly focusing on how biomass is utilized in multiple stages to maximize resource efficiency. This framework offers a clear view of the living labs' processes, showing how they move from the initial use of raw biomass to secondary and tertiary applications, ensuring that each material is fully utilized before waste is generated.

Additionally, the framework on circular business models developed by Nußholz (2018) provides an essential insight for this analysis. This article provides a valuable tool for assessing how living labs aim to close resource loops, extend product lifecycles and reduce waste by adapting the business model canvas to incorporate circular economy principles.

Nußholz's circular business model canvas is another critical framework selected for this study. This framework adapts the conventional business model canvas to explicitly account for circular economy principles. Nußholz (2018) extends the traditional business model canvas by integrating the concept of circularity, which is essential for analyzing living labs. The key addition to this framework is its ability to assess how living labs aim to close resource loops, ensuring that resources are reused, recycled, or repurposed at various stages of the value chain.

Moreover, the analysis is enriched by a framework that identifies seven archetypes of bioeconomy business models (Salvador et al., 2023). These archetypes provide a broader classification of how businesses can operate within the bioeconomy, covering a spectrum of approaches:

- Optimizing resource efficiency
- Value recovery from waste
- Innovation towards bio and renewable resources
- Establishing biorefineries
- Resource exchange
- Valuing the local economy
- Service- and result- oriented offers

These archetypes are integrated with the circular business model canvas developed by Nußholz (2018), thus combining the principles of circularity and the bioeconomy. By mapping the living labs to these archetypes, the analysis is able to determine which strategies are most prevalent and successful within each lab. For instance, some living labs may focus heavily on resource exchange and local economy valuation, while others may emphasize waste recovery or the creation of bio-based products. The merged framework may be found in Appendix 1 as well as the condensed forms of the complex tables (Appendix 2, 3 & 4).

Finally, an ecosystem analysis is conducted using a stakeholder "pie chart" (Talmar et al., 2020) to map the various actors involved and their contributions to the joint value proposition. This method highlights the

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interconnections and collaborative dynamics between stakeholders, such as producers, consumers, regulators, and other entities, which are crucial for understanding how value is co-created within the living labs. This framework was selected for its ability to highlight the interconnectedness of stakeholders within the bioeconomy and circular economy ecosystems. It helps to show how value is co-created by these stakeholders, particularly in living labs that require active participation from a range of actors.

The specific models were chosen because they capture the multifaceted nature of living labs, enabling a comprehensive analysis from both bioeconomy and circular economy perspectives. Compared to other frameworks, the combined approach of Nußholz's circular business model and Salvador et al.'s archetypes is particularly novel, as it interconnects circular bioeconomy archetypes with the circular business model canvas. This integration provides a unique and nuanced lens for assessing how living labs (LLabs) create value through resource efficiency and local economic impact. Additionally, the Bröring and Vanacker framework provides a foundational understanding of core bioeconomic business models, essential for examining LLabs' focus. Finally, the cascade use model and ecosystem pie chart contribute critical insights into biomass flow and multi-stakeholder collaboration within LLabs. Together, these frameworks were selected because they provide an in-depth exploration of both bioeconomy and circular economy dimensions, an approach that other frameworks in the literature do not fully address, making them less suitable for the complex analysis of LLabs.

In the following section, there are five living labs analyzed. Starting with Alcarràs Bioproductors, which is a company originally founded in 2022 by 150 local farmer's families and whose mission is to deal with the management of animal waste for a high-density farming region in Catalonia, Spain. By using organic waste as input, the company produces biogas, organic fertilizer, and electricity as main outputs.

The second living lab is FILSE which is a company in the Liguria region in Italy with the main goal of supporting the regional economic development. It targets the fishing industry's side-streams to enhance the resulted waste through recycling and extraction of bioactive components.

The third living lab is the Irish Bioeconomy Foundation (IBF) is a not-for-profit organization in Ireland. Its mission is to support the transition of Ireland's resources to high-value products. the IBF aims to use dairy by-products as feedstock, which undergo fermentation to produce biobased chemicals, which are then used to create bioplastics.

The fourth living lab is the Bio-Silica Lab at CeNTI that is dedicated to the innovative extraction and modification of bio-silica sourced from agro-industrial byproducts, with a particular emphasis on rice husks. Currently, the lab has advanced its capabilities by successfully implementing the alkaline sol-gel method at a pilot scale, enabling the production of both unmodified and functionalized bio-silica for various applications.

The last living lab is the CellFactory at VTT which focuses on developing innovative plant cell cultures by utilizing agricultural and food side-streams as feedstock. Currently, the lab is conducting small-scale experiments with residues from potato processing to explore the potential of these byproducts in producing valuable plant cell culture -based ingredients and materials.

1.3.1. Living Lab 1: ALC Bio-Lab (Leader: Alcarràs Bioproductors)

Bioeconomy Business Models

The first model focuses on substitute products, offering environmentally friendly alternatives to fossil-based resources such as biogas, organic fertilizers, electricity, and water. This approach not only replaces traditional fossil-based products but also upgrades by-products from local farming partners into valuable resources. The second model is centered on services, specifically providing picking up service of the organic waste from farmers.

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First, we will explore the substitute products model in detail, followed by an examination of the service-based model.

Business Model for Alcarràs: Substitute Products

Alcarràs Bioproductors exemplifies a business model focused on substitute products, which involves offering bio-based alternatives to traditional fossil-based products. Below, in Figure 1, the value proposition, value generation, and value capture associated with this business model are summarized and subsequently explained in detail.

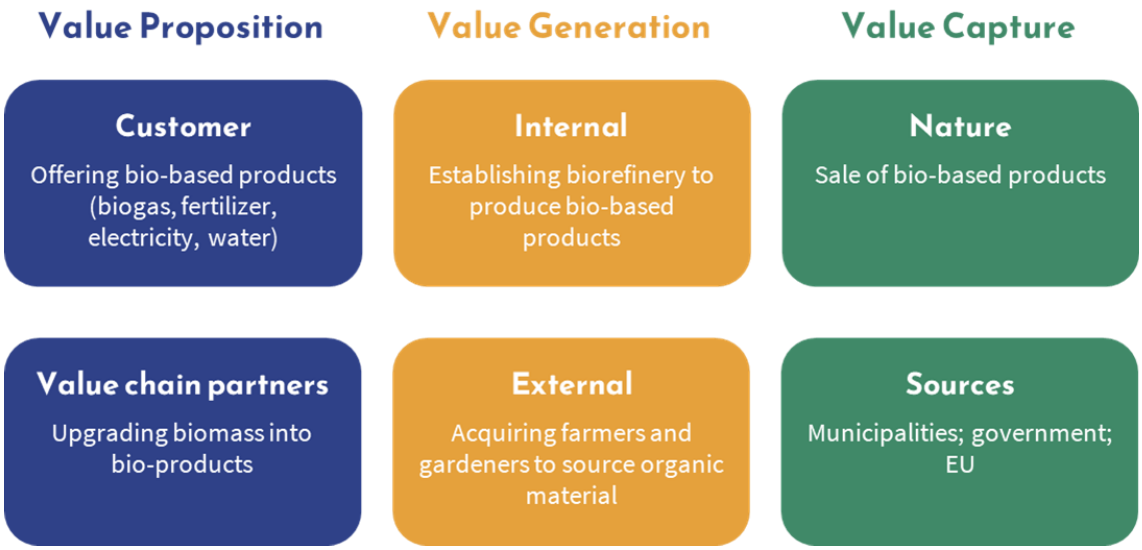

Figure 1. Substitute products – Alcarràs (Based on Bröring and Vanacker, 2022)

Value Proposition:

Customer*:* Alcarràs Bioproductors delivers a range of bio-based substitutes for fossil-based products, including biogas, organic fertilizers, electricity, and water. These offerings provide environmentally friendly alternatives that fulfill the same functions as their fossil-based counterparts, catering to the needs of various stakeholders such as local farmers, gardeners, and broader agricultural and energy sectors.

Value Chain Partners: The company enhances its value proposition by upgrading biomass, in this case an organic by-product from local farming, into these bio-based substitutes. This supports the waste management efforts of value-chain partners and transforms their by-products into valuable resources.

Value Generation:

Internal: Alcarràs Bioproductors focuses on the establishment and operation of a biorefinery that efficiently converts organic waste into bio-based substitutes. This infrastructure is pivotal for producing biogas, organic fertilizers, electricity, and water, thereby establishing a robust internal system for generating substitute products that serve as alternatives to fossil-based ones.

External: Externally, the company collaborates with local farmers and gardeners to source organic materials. This partnership ensures a steady supply of raw materials and creates a network that supports the entire region's sustainable development.

Value Capture:

Nature: The primary revenue stream for Alcarràs Bioproductors is derived from the sale of its bio-based substitute products.

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Sources: Financially, the company benefits from various forms of support, including partnerships with municipalities, government funding, and European Union (EU) contributions. These financial resources are crucial for sustaining the company's growth and the ongoing implementation of its circular economy model.

Business Model for Alcarràs: Services

The service-based business model of Alcarràs Bioproductors is focused on offering services tied to the disposal and management of biomass. This model fits within the broader category of Product-Service Systems (PSS), where the company not only provides products but also delivers essential services related to their use and management.

In this model, Alcarràs Bioproductors offers services such as the collection, storage, and processing of organic waste from local farms. This approach benefits customers by providing a comprehensive waste management solution, while also enabling the company to enhance the value chain by improving the utility of organic waste (Figure 2).

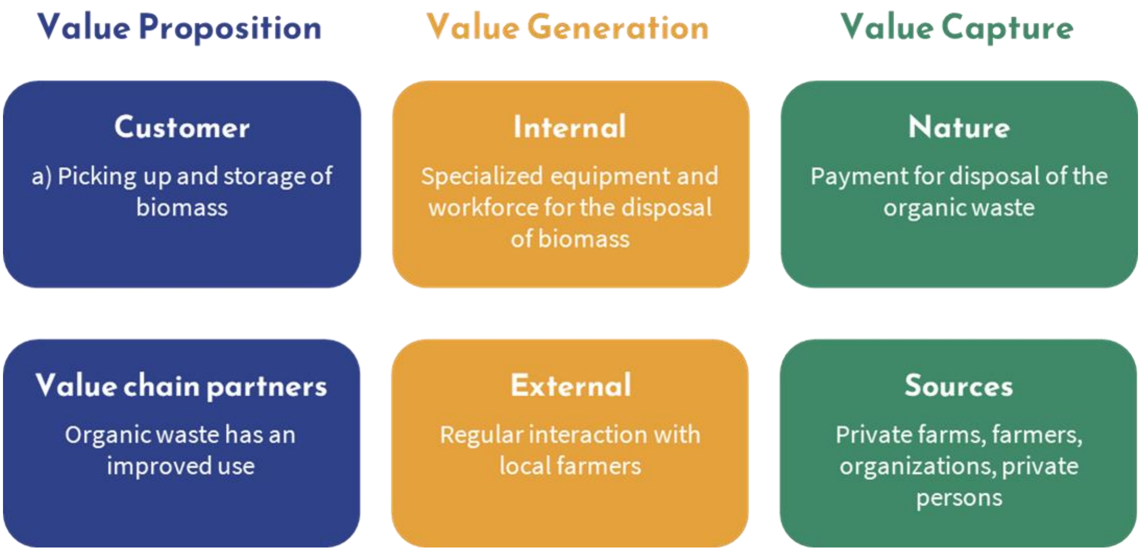

Figure 2 Service-based business model – Alcarràs (Based on Bröring and Vanacker, 2022)

Value Proposition

Customer: Alcarràs Bioproductors provides services centered around the picking up and storage of biomass. By managing the collection and disposal of organic waste, the company integrates waste processing into its operations and focuses on the efficient use of resources.

Value Chain Partners: For value chain partners, the service-based model ensures that organic waste has an improved use. Through the efficient processing of biomass, Alcarràs Bioproductors transforms waste into valuable resources.

Value Generation

Internal: Internally, the company relies on specialized equipment and a skilled workforce dedicated to the efficient disposal and management of biomass. This infrastructure is essential to delivering high-quality services and ensuring the effective transformation of waste into bio-based products.

External: Externally, the company maintains regular interaction with local farmers, ensuring a steady supply of biomass for processing. This ongoing collaboration strengthens relationships within the community and supports the continuous flow of organic material needed for operations.

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Value Capture

Nature: The primary revenue in this service-based model comes from the payment for the disposal of organic waste. By charging for these services, Alcarràs Bioproductors captures value while providing a vital service to the agricultural community.

Sources: The company's income sources include private farms, farmers, organizations, and private individuals who utilize Alcarràs Bioproductors' waste management services. These stakeholders are integral to the financial sustainability of the service-based business model.

Cascade Use of Biomass

In this section, it is depicted how the biomass is utilized and how many use cases there are for the case of Alcarràs. Therefore, the framework based on Based on Berg et al. (2022) (Figure 3). Alcarràs utilizes the biomass in four steps.

First Use: Collection and Direct Sale of Organic Material:

Organic material, including slurry, manure, and other agricultural waste, is initially collected. A portion of this material is sold directly to farmers as non-optimal fertilizer. This allows for immediate use in agriculture, providing a basic level of nutrient content for soil improvement.

Second Use: Anaerobic Digestion for Energy Production:

The remaining collected organic material is subjected to anaerobic digestion. This process generates biogas and electricity. The biogas, although unrefined, can be utilized or further processed, and the electricity produced is sold to the energy market, contributing to renewable energy supply.

Third Use: Processing of Digestate:

The digestate, a by-product of anaerobic digestion, is processed further. It is separated into:

Liquid Fraction: Treated to reduce nitrogen content, creating a liquid fertilizer that is safe for application in agriculture, preventing nitrogen overloading in the soil.

Solid Fraction: The solid digestate is composted, producing a high-quality solid fertilizer rich in organic matter.

Fourth Use: Final Distribution:

The final products, including biogas, electricity, liquid fertilizer, and solid fertilizer, are distributed to various markets. Biogas and electricity are supplied to businesses, municipalities, and potentially even consumers. The liquid and solid fertilizers are sold to farmers and other agricultural stakeholders, ensuring the sustainable enrichment of soils.

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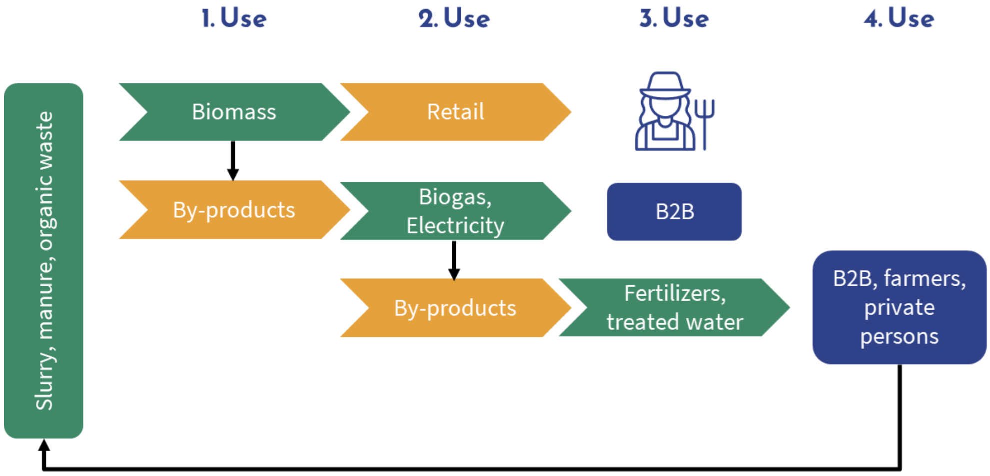

Figure 3. Cascade Use – Alcarràs (Based on Berg et al., 2022)

Circular Business Model Canvas and Bioeconomy Archetypes

The following chapter presents an analysis of Alcarràs' business model, which is divided into five phases over a time horizon. Each phase is examined individually. The initial phase, (*Collect & Integrate*) entails the procurement of requisite biomass and its incorporation into the system. The resulting products are sold during the *First Sale Phase*. The remaining by-products with potential are reintroduced into the system (*Reintegrate Phase*) for sale to the customer in the *Additional Sale Phase*. Subsequently, the waste is employed in the generation of electricity and heat (*Material Recovery Phase*).

In each of these phases, the value proposition, how the value is generated and how it is captured differ. The respective findings on the individual phases are first summarized and then described in detail below.

Collect & Integrate

The Collect & Integrate phase of the Alcarràs Living Lab (Figure 4) focuses on transforming agricultural waste, specifically slurry and organic farm residues, into valuable resources through biorefineries. This system revolves around the recovery of biomass, resource exchange, and the localization of biorefineries, which contribute to creating a circular bioeconomy that benefits the local agricultural community and the environment.

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Collect & Integrate			
Value Proposition	Offer	*Resource exchange; Valuing the local economy*	Collection service, storage of waste
		Establishing biorefineries	Local plants for production of waste
		Value recovery from waste	Bio-based products
	Value proposition	*Resource exchange; Valuing the local economy*	Exchange of waste, partner with local community
		Establishing biorefineries	Local disposal and utilization of waste
		Value recovery from waste	Bioproduction, value from organic waste
	Customer segments	*Resource exchange; Valuing the local economy*	Farmers, companies, private persons
		Establishing biorefineries	-
		Value recovery from waste	Farmers, companies, private persons
	Relationships customers/partners	*Resource exchange; Valuing the local economy*	Farmers and other groups of interest for organic waste management, government, commune, partner companies
		Establishing biorefineries	Suppliers, engineers, universities
		Value recovery from waste	Farmers and other groups of interest for organic waste products, commune, organizations like universities
Value creation and delivery	Key activities	*Resource exchange; Valuing the local economy*	Logistics, picking up material, acquisition of local farmers resources
		Establishing biorefineries	Extracting value, production
		Value recovery from waste	Managing resources, extracting value trough production processes
	Key resources	*Resource exchange; Valuing the local economy*	Technology, means of transportation, network
		Establishing biorefineries	Plants, inputs, locality, knowledge
		Value recovery from waste	Strong position in market, technology, knowledge
	Key partners	*Resource exchange; Valuing the local economy*	Community, government, farmers, suppliers of technology
		Establishing biorefineries	
		Value recovery from waste	
	Channels	*Resource exchange; Valuing the local economy*	Transportation means, website, social media, spoken word
		Establishing biorefineries	
		Value recovery from waste	
Value Capture	Costs	*Resource exchange; Valuing the local economy*	Logistics, picking up material, acquisition of local farmers resources, networking
		Establishing biorefineries	Build and maintain refineries and the related knowledge needed
		Value recovery from waste	Production, maintanance, logistics
	Revenue flows	*Resource exchange; Valuing the local economy*	Disposal of waste, local sales
		Establishing biorefineries	-
		Value recovery from waste	-

Figure 4. Collect & Integrate - Alcarràs (Based on Nußholz, 2018 and Salvador et al., 2023)

Value Proposition

In this phase, the value proposition is rooted in resource exchange, the establishment of biorefineries, and value recovery from waste. The primary resource being collected is slurry (liquid manure) from local farms, as well as other organic residues from agricultural activities. This waste is collected and processed to create bio-based products like biogas, fertilizers, or biofuels. The Alcarràs Living Lab is specifically focused on utilizing local agricultural waste, minimizing transport and creating a closed-loop system that benefits both farmers and the local economy.

By establishing local biorefineries, the lab can efficiently process the waste on-site, reducing costs associated with transporting waste to distant processing plants. The resource exchange aspect ensures that waste from farms becomes the input for energy and material production, fostering collaboration and economic sustainability at a local level.

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The customer segments include farmers, agricultural companies, and private persons who generate the waste and benefit from its responsible disposal and conversion into usable products. These customers are also able to utilize the bio-based products (e.g., fertilizer) generated from the slurry.

The relationships with customers and partners in the Alcarràs Living Lab are built on the foundation of waste management partnerships. The living lab collaborates with local farmers, agricultural cooperatives, government bodies, and private enterprises that have an interest in sustainable waste management and energy production. Additionally, universities and technology suppliers contribute to developing innovative techniques for turning slurry and organic waste into bioproducts and energy. This close cooperation ensures an ongoing flow of resources and technological improvements.

Value Creation and Delivery

The key activities in the Collect & Integrate phase involve the collection of slurry from local farms, the preprocessing of this biomass, and its conversion into energy and fertilizers through the biorefinery process. A major component of this phase is the coordination of logistics, ensuring that organic waste from farms is efficiently collected and brought to the biorefinery. The preprocessing stage involves separating the solid and liquid components of the slurry, both of which are then further processed into biogas or fertilizers.

In terms of key resources, the living lab relies on advanced slurry-processing technologies and anaerobic digesters that break down the organic material to produce biogas. The lab also depends on an extensive network of local transportation, specialized equipment for collecting and transporting slurry, and local expertise in both farming and bioeconomy practices.

The key partners include farmers, waste management companies, local governments, and biorefinery technology providers. Farmers are crucial as they provide the raw material (slurry), while local government agencies support the waste management and conversion process through regulatory frameworks and incentives for renewable energy production. Universities and research institutions also play a vital role by contributing knowledge on optimizing slurry processing technologies. Biorefinery equipment suppliers ensure that the technology for converting waste into valuable products is up-to-date and efficient.

The delivery of value is done through local logistics systems, which transport the collected slurry to biorefineries, where it is processed.

Value Capture

The costs associated with this phase are primarily linked to logistics, preprocessing, biorefinery operations, and technological maintenance. The collection of slurry from various farms, transportation to the biorefinery, and the processing all incur significant costs. Additionally, investments in biorefinery infrastructure and research & development are necessary to ensure that the technologies used remain efficient. Maintaining strong relationships with farmers and local governments is also key to reducing operational risks and costs.

On the revenue side, the living lab does not generate income from collecting the biomass in the moment, however, in the future they could generate income by collecting residuals. Farmers also benefit economically by lowering their waste disposal costs and having access to locally produced high-quality fertilizers.

First Sale Phase

The First Sale phase of the Alcarràs Living Lab (Figure 5) is focused on optimizing resource efficiency and delivering service- and result-oriented value offers. This phase emphasizes making the initial transactions of products and services that are designed to be resource-efficient and meet specific customer needs. The aim is to

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optimize the outputs, ensuring that the products generated from agricultural waste—such as biofuels, biogas, and other bio-based materials—are successfully sold to relevant customers.

First sale			
Value Proposition	Offer	*Optimizing Resource efficiency and use*	Maximum output or minimal input
		Service-and result oriented value offers	Demanded product offerings
	Value proposition	*Optimizing Resource efficiency and use*	Maximize output from a given input to improve conditions for customers
		Service-and result oriented value offers	Products to meet demand
	Customer segments	*Optimizing Resource efficiency and use*	-
		Service-and result oriented value offers	Companies in need of (bio)fuel
	Relationships customers/partners	*Optimizing Resource efficiency and use*	Universities, researchers
		Service-and result oriented value offers	Biogas customers
Value creation and delivery	Key activities	*Optimizing Resource efficiency and use*	R&D, increase efficiency by optimizing production
		Service-and result oriented value offers	Selling of products
	Key resources	*Optimizing Resource efficiency and use*	Know-how, technology
		Service-and result oriented value offers	Unrefined bio-gas
	Key partners	*Optimizing Resource efficiency and use*	Universities, labs, researchers
		Service-and result oriented value offers	
	Channels	*Optimizing Resource efficiency and use*	-
		Service-and result oriented value offers	Direct sales to farmers, companies (B2B)
Value Capture	Costs	*Optimizing Resource efficiency and use*	R&D costs, operational optimization costs
		Service-and result oriented value offers	Production costs, marketing, sales, opertaions
	Revenue flows	*Optimizing Resource efficiency and use*	Passively via improved product
		Service-and result oriented value offers	Sales

Figure 5. First Sale Phase - Alcarràs (Based on Nußholz, 2018 and Salvador et al., 2023)

Value Proposition

In this phase, the primary value proposition revolves around optimizing resource efficiency and use, meaning that the lab aims to achieve the maximum output with minimal input. The biorefineries and related production processes are designed to make the best possible use of agricultural waste (such as slurry) to generate valuable products like biogas, biofuels, and fertilizers. By improving the efficiency of these processes, the lab maximizes the benefits for customers, allowing them to gain higher-value products from fewer resources.

Additionally, service- and result-oriented value offers are tailored to meet specific demands. The living lab ensures that the products it offers are exactly what its customers, whether farmers or companies, require to meet their sustainability and energy needs.

The customer segments in this phase include companies in need of biofuels, specifically industries that are looking for renewable energy sources like biogas to reduce their carbon footprint. Farmers and agricultural

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companies who require organic fertilizers for their fields are also a key customer segment. These customers are looking for environmentally sustainable solutions.

The living lab fosters relationships with universities, researchers, and bio-oriented customers. Universities and researchers play a critical role in the continuous research and development (R&D) efforts, ensuring that biorefinery processes remain efficient and cutting-edge. Meanwhile, bio-oriented customers—who could range from energy companies to industrial users—are crucial stakeholders.

Value Creation and Delivery

The key activities in this phase include R&D focused on increasing efficiency and optimizing production processes. These activities ensure that the biorefineries can produce biogas and other outputs as efficiently as possible, reducing waste while maximizing value. The lab is also responsible for the sale of products, ensuring that the bio-based products created are brought to market and meet the demands of local and regional customers.

In terms of key resources, the living lab relies on its know-how and the use of advanced technology in biorefinery processes.

The key partners include universities, labs, and researchers. These partners contribute to the R&D process, helping to improve the technologies used for converting organic waste into valuable products like biofuels and fertilizers. They also support the lab in discovering innovative ways to further optimize resource efficiency, ensuring that the biorefinery processes evolve and adapt to changing market conditions and technological advances.

In terms of channels, the biorefinery primarily relies on direct sales to farmers and companies (B2B). These channels ensure that the bio-products are sold to those who will use them in agricultural or industrial applications.

Value Capture

In this phase, the costs include R&D expenses, which are essential for continually improving the efficiency of production processes. Additionally, there are operational optimization costs, such as those associated with maintaining the biorefineries, keeping production efficient, and ensuring that the products meet market demand. Marketing, sales, and logistics also incur costs, as the lab must promote and distribute its bio-products effectively.

In terms of revenue flows, income is generated primarily through the sale of bio-products. Additionally, the living lab may gain passive revenue by improving its products over time, allowing for increased customer satisfaction and demand for the lab's outputs.

Reintegrate Phase

The Reintegrate phase of the Alcarràs Living Lab (Figure 6) is dedicated to capturing value from residual materials. This step is crucial for ensuring that all potential resources are fully utilized, reducing waste and contributing to a circular bioeconomy. In this phase, the focus shifts toward the management and reintegration of digestate back into the system in the form of useful products like fertilizers and purified water.

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Reintegrate			
Value Proposition	**Offer**	*Value recovery from waste*	Additional products after anaerobic digestion
	Value proposition	*Value recovery from waste*	Deriving value from digestate ad turning it into fertilizer
	Customer segments	*Value recovery from waste*	-
	Relationships customers/partners	*Value recovery from waste*	-
Value creation and delivery	**Key activities**	*Value recovery from waste*	Rellocation of residual, composting, splitting of solid and liquid parts, refinement/purification of water and gas
	Key resources	*Value recovery from waste*	Technology, residual (digestate), know-how, biogas
	Key partners	*Value recovery from waste*	-
	Channels	*Value recovery from waste*	-
Value Capture	**Costs**	*Value recovery from waste*	Logistics and production
	Revenue flows	*Value recovery from waste*	-

Figure 6. Reintegrate Phase - Alcarràs (Based on Nußholz, 2018 and Salvador et al., 2023)

Value Proposition

In the Reintegrate phase, the offer is centered around the value recovery from waste, specifically focusing on the creation of additional products that can be derived from the digestate left over after the biogas production process. The primary offer involves converting these residual materials into valuable outputs such as fertilizers, refined water, and other by-products, ensuring that nothing from the anaerobic digestion process goes to waste.

The value proposition in this phase is particularly focused on deriving value from the digestate by turning it into useful products like fertilizers or purified water. The key objective is to close the loop in the circular bioeconomy by ensuring that the by-products of waste processing are reintroduced into the system in a beneficial way.

The customer segments in this phase primarily include agricultural businesses or farmers who can benefit from the use of organic fertilizers produced from digestate. Additionally, municipalities or other entities interested in clean water from the refinement process could be potential customers.

There are no new relationships highlighted in this phase, but maintaining close partnerships with existing customers, such as farmers is essential. Their continued interest in the by-products, like organic fertilizers, helps

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sustain demand. The Living Lab may also collaborate with researchers and agricultural institutions to optimize the reintegration process and ensure that the by-products meet agricultural standards.

Value Creation and Delivery

The key activities in this phase include several crucial processes related to residual management. The digestate undergoes processes such as relocation, composting, and the splitting of solid and liquid parts to prepare it for use as a fertilizer or for further refinement. This phase also involves refining and purifying water to ensure that these materials are clean and safe for reintegration into agricultural or industrial processes.

The key resources for this phase include the digestate itself as well as the technology needed to process it. Technological know-how is vital in ensuring the refinement and purification processes are efficient and yield high-quality products.

While no specific key partners play a role, partnerships with technology providers, and researchers are essential to improve the efficiency of refining the digestate and enhancing the value of the final products. Agricultural partners and municipalities can also play a role in testing and adopting the products generated from the digestate, such as fertilizers or water.

No new channels are highlighted for the reintegration phase, but the distribution of organic fertilizers and other by-products would likely follow similar channels used in previous phases. This includes direct sales to farmers or businesses that can use the refined by-products.

Value Capture

The costs associated with the Reintegrate phase largely revolve around logistics and production. The costs of relocating the digestate, processing it through composting or purification are significant. Furthermore, maintaining the technology and facilities for the purification and refinement processes requires ongoing investment.

In terms of revenue flows, this phase creates opportunities for generating income through the sale of organic fertilizers or purified water.

Additional Sale Phase

The Additional Sale phase in the Alcarràs Living Lab (Figure 7) framework focuses on capitalizing on the by-products created during the Reintegrate phase. In this stage, the living lab offers additional value through bio-based products derived from sustainable sources, thus extending the economic potential of the waste-to-resource system.

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Additional Sale			
Value Proposition	**Offer**	*Service-and result oriented value offers*	Bio-products
	Value proposition	*Service-and result oriented value offers*	Products from sustainable sources
	Customer segments	*Service-and result oriented value offers*	Farmers, other companies, private persons
	Relationships customers/partners	*Service-and result oriented value offers*	Logistic companies, network, farmers
Value creation and delivery	**Key activities**	*Service-and result oriented value offers*	Selling of fertilizer, water and biomethane, marketing, logistics, operations
	Key resources	*Service-and result oriented value offers*	Fertilizer, bio-methane, treated water
	Key partners	*Service-and result oriented value offers*	-
	Channels	*Service-and result oriented value offers*	Direct sales, retail, B2B
Value Capture	**Costs**	*Service-and result oriented value offers*	Production, purification, marketing, shipping, sales
	Revenue flows	*Service-and result oriented value offers*	Sales

Figure 7. Additional Sale Phase – Alcarràs (Based on Nußholz, 2018 and Salvador et al., 2023)

Value Proposition

The offer in the Additional Sale phase revolves around service- and result-oriented value offers, specifically focusing on selling bio-products. These bio-products include items such as fertilizers, biomethane, and treated water, all of which are derived from the waste processing and anaerobic digestion that occurs in previous phases. The overarching value proposition here is that these products are sourced from sustainable processes, reducing reliance on synthetic or non-renewable inputs, and contributing to a more circular bioeconomy.

The customer segments targeted in this phase include farmers, other companies, and private individuals. Farmers are the primary market for organic fertilizers, while companies, particularly those in need of sustainable energy solutions, can benefit from biomethane. Private persons or smaller enterprises might also be interested in bio-products for personal use, especially those focused on sustainability.

The flexibility in customer segments allows the living lab to cater to both B2B and B2C markets.

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In this phase, maintaining close ties with logistics companies, networks, and farmers is essential. Logistic companies ensure the smooth distribution of bio-products, while farmers and local networks help spread awareness about the benefits of these products.

The living lab's connection to these partners also supports the local economy by creating jobs in logistics and reinforcing existing relationships within the agricultural community.

Value Creation and Delivery

The key activities in the Additional Sale phase focus on providing bio-products such as fertilizers, biomethane, and treated water.

Marketing plays a critical role in this phase, as bio-products require clear communication of their benefits over traditional alternatives. The lab must also focus on operations and logistics to ensure that the products are delivered in a timely and cost-effective manner.

The key resources in this phase are the bio-products themselves. These resources are the outputs of the sustainable processes conducted in the Reintegrate phase. The value captured from these resources depends on their quality and the lab's ability to produce them.

Partners such as logistic companies, retailers, and agricultural networks are likely critical in helping the living lab scale up the distribution of its bio-products.

The distribution channels for bio-products include direct sales, retail, and B2B sales. Direct sales allow the living lab to engage directly with farmers and other customers, ensuring a close relationship and potentially higher profit margins. Retail channels expand the lab's reach, allowing products to be sold on a larger scale.

Value Capture

The costs associated with this phase primarily involve production, purification, marketing, shipping, and sales. Producing bio-products such as fertilizers or biomethane requires ongoing investment in purification and treatment processes to ensure the products meet quality standards. Marketing costs are essential to communicate the benefits of these bio-products and differentiate them from conventional alternatives. Logistics and shipping also incur significant costs as products need to be transported efficiently to reach a wide range of customers.

In terms of revenue flows, this phase relies on sales of the bio-products. These revenue streams come from direct sales to farmers, businesses, and possibly private individuals, depending on the product. This phase represents the monetization of the outputs of the circular economy, where waste is transformed into value-added products that can generate continuous revenue of additional products.

Material Recovery Phase

The Material Recovery phase in the Alcarràs Living Lab (Figure 8) framework is centered on the generation of electricity and heat from biological waste sources, particularly through anaerobic digestion processes. This phase focuses on transforming organic waste into valuable energy outputs, thus integrating renewable energy into the circular bioeconomy.

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Material Recovery			
Value Proposition	**Offer**	*Value recovery from waste*	Electricity
	Value proposition	*Value recovery from waste*	Heat and electricity from biological sources
	Customer segments	*Value recovery from waste*	Power providers
	Relationships customers/partners	*Value recovery from waste*	Suppliers, government, power companies
Value creation and delivery	**Key activities**	*Value recovery from waste*	Generation of electricity and heat
	Key resources	*Value recovery from waste*	Machines, know-how, technology, digestor
	Key partners	*Value recovery from waste*	Suppliers
	Channels	*Value recovery from waste*	Electricity power grid
Value Capture	**Costs**	*Value recovery from waste*	Acquiration and maintanence
	Revenue flows	*Value recovery from waste*	Sale of electricity

Figure 8. Material Recovery Phase – Alcarràs (Based on Nußholz, 2018 and Salvador et al., 2023)

Value Proposition

The offer in this phase is focused on value recovery from waste, specifically the production of electricity as a key output. Through the anaerobic digestion of organic material (e.g., agricultural waste or digestate), the living lab produces biogas, which is then converted into electricity and heat.

The primary value proposition is the ability to generate heat and electricity from biological sources, making this process not only energy-efficient but also environmentally friendly.

In terms of customer segments, the primary target for the electricity generated are power providers, who can either purchase the energy directly or integrate it into the national or local power grid. Additionally, industrial customers that require renewable heat or electricity for their operations could also be potential customers.

The relationships in this phase are built around collaboration with suppliers, government bodies, and power companies. Suppliers provide the machinery and technology necessary for efficient biogas production and

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electricity generation, while government entities might support the project through subsidies or regulations favoring renewable energy initiatives. Power companies are key partners for integrating the electricity generated into the existing power infrastructure.

Value Creation and Delivery

The key activities in this phase revolve around the generation of electricity and heat from waste materials. This includes managing the anaerobic digestion process to produce biogas, which is then converted into electrical energy. Efficient operation of these systems ensures the living lab maximizes the energy yield from the organic material.

The key resources required for material recovery include machinery (such as digesters and generators), technology, and the know-how to operate the systems. The digesters are central to the anaerobic digestion process, breaking down the organic waste to produce biogas.

The key partners for this phase include suppliers of the necessary technology and machinery, particularly companies that provide biogas digesters.

Additionally, collaboration with power companies and government entities could enhance the living lab's ability to scale up operations and feed the electricity produced into the grid.

The primary channel for distributing the electricity generated is through the electricity power grid. This allows the living lab to connect the renewable energy produced to a wider customer base, including households, businesses, and public utilities.

Value Capture

The primary costs in this phase are associated with the acquisition and maintenance of the necessary machinery, including digesters, generators, and purification units.

In terms of revenue flows, the living lab could generate income through the sale of electricity to the grid or directly to power companies. Additionally, depending on government regulations and incentives, there could be potential financial support for renewable energy generation through subsidies or green energy credits.

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1.3.1.1. Pie Model

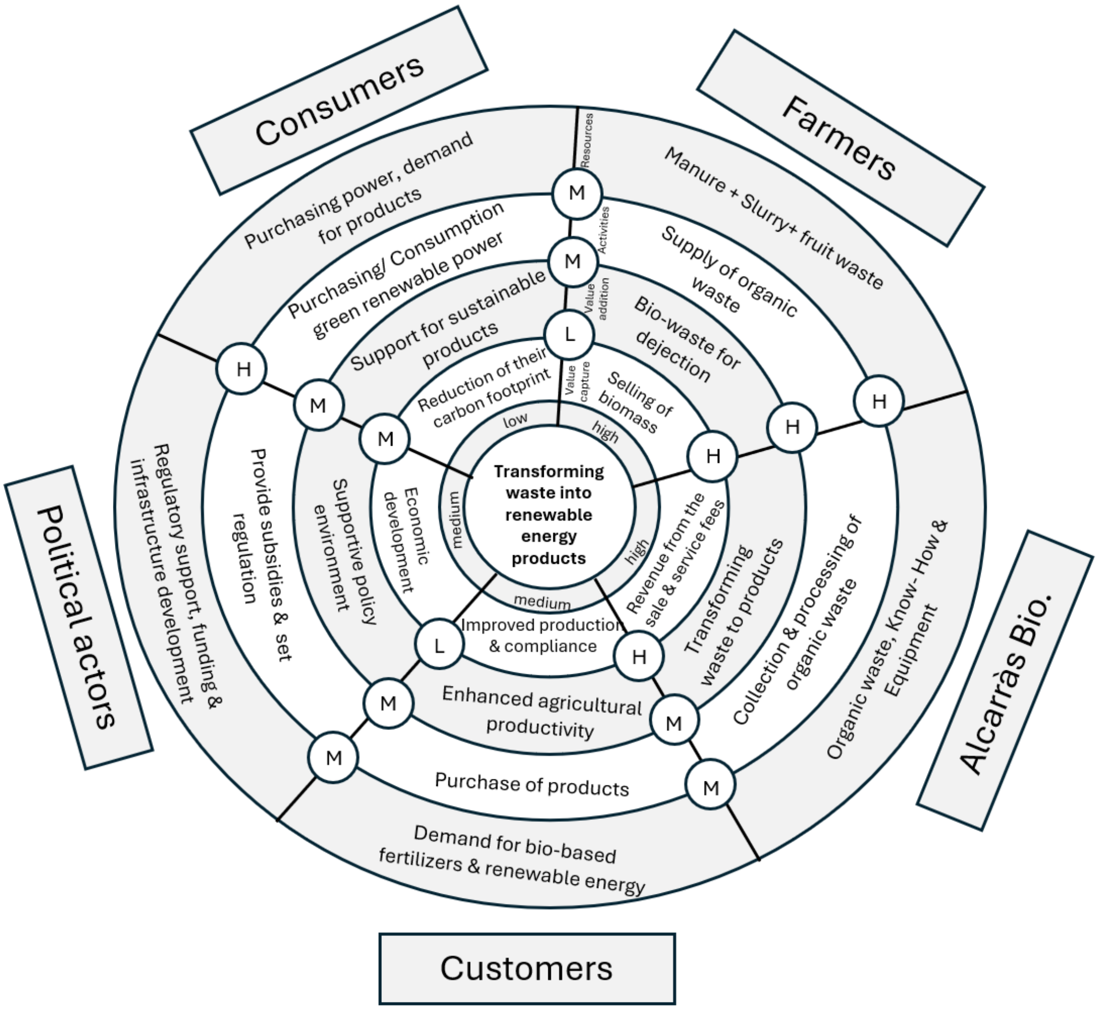

Figure 9. Ecosystem Pie Model – Alcarràs (Based on Talmar et al., 2020)

The provided graphic of the Pie Model (Figure 9) presents a comprehensive framework for understanding the transformation of biowaste within a socio-technical system. This framework is categorized into four main actors: Farmers, Customers, Political actors and Consumers, each of which interacts with the central process of converting biowaste into valuable products.

Farmers are pivotal in the initial stages of the biowaste transformation process. They supply manure, slurry, and fruit waste which are primary raw materials for biowaste conversion. The successful management of these resources is critical for sustainable farming practices and reducing environmental impact. Similar to the suppliers in the Ecosystem Pie Model who provide agricultural products and capture value through revenue generation, farmers in the biowaste framework contribute essential raw materials and benefit economically from the sale of these inputs. Value is added to the ecosystem through the provision of these necessary materials, and value is captured by the revenue the farmers generate. The dependence on the ecosystem for farmers is relatively high, as waste disposal and the use of fertilizer depend entirely on the cycle of the ecosystem pie models. In addition, the financial profitability depends on the scaling possibilities.

Technological advancements, such as motors and anaerobic digesters, are essential for efficient biowaste conversion. These technologies enable the production of heat and energy from biowaste, reducing reliance on fossil fuels. The development and installation of these technologies require substantial know-how and

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infrastructure. This is akin to the role of technology providers in the Ecosystem Pie Model, where technological know-how and infrastructure are crucial for sustaining the ecosystem. This is provided by Alcarras.

Customers, including local clients and agricultural practitioners, demand eco-friendly products and services. Their preferences drive the market for green energy production and bio products. This demand ensures a continuous supply chain from raw material collection to end-product utilization. The value addition and dependency dynamics in this segment are comparable to those in the Ecosystem Pie Model, where different actors' contributions are assessed based on their resources, key activities, and value addition.

Political actors are crucial in this framework, influencing the biowaste transformation process through policies, subsidies, and regulations that encourage sustainable practices and green technology adoption. Their support is vital for the large-scale success of biowaste management initiatives, creating an enabling environment for cooperation among all actors.

Consumers currently play a limited role in the biowaste transformation framework, as the sale of biogas and bioenergy to end-users has not yet been fully realized. At present, the primary focus is on developing and refining the technologies and systems necessary for efficient biowaste conversion. Although consumer demand for green products and renewable energy is growing, their direct influence on the market is minimal at this stage. However, as the technology matures and the sale of biogas and bioenergy becomes viable, consumers are expected to play a critical role in driving market acceptance and promoting sustainable practices. In the future, their purchasing power and early adoption of green technologies will be pivotal in shaping the market dynamics for sustainable products, aligning with the Ecosystem Pie Model's emphasis on the significant influence of consumers' purchasing decisions. The biowaste transformation framework illustrated in the graphic encapsulates a multi-faceted approach to sustainable waste management. By understanding the roles of various actors and leveraging technological advancements, this framework aims to create a circular economy that benefits both the environment and the economy.

1.3.2. Living Lab 2: Bio-Silica Lab (Leader: CeNTI)

Bioeconomy Business Models

Business Model for CeNTI's Living Lab: Substitute Products

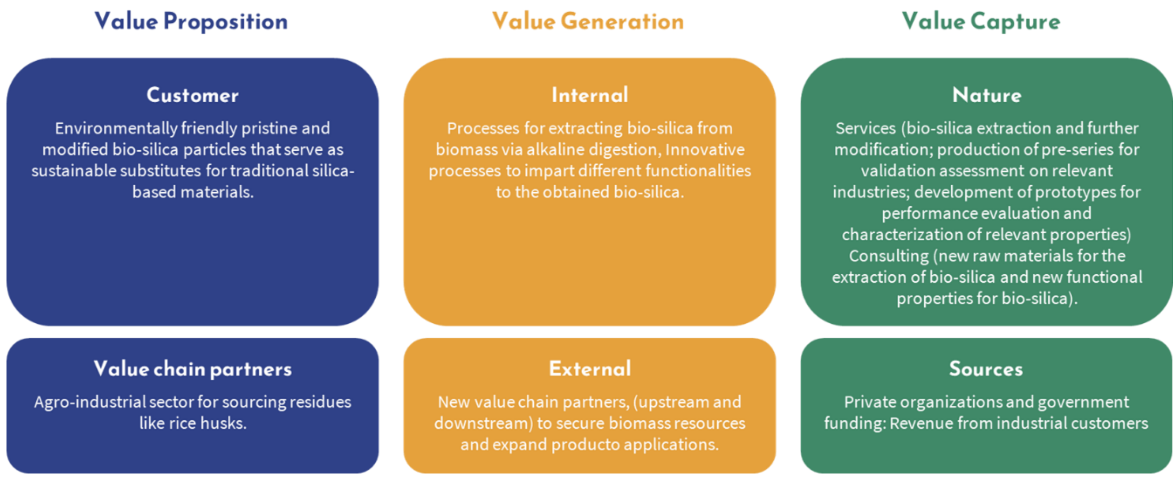

Figure 10. Substitute Products – CeNTI (Based on Bröring and Vanacker, 2022)

Value Proposition:

Customer: CeNTI provides eco-friendly alternatives to fossil-based silica materials, fulfilling functions in various industrial applications such as fillers, additives, and catalysts. The incorporation of modified bio-silica in the final products is an interesting approach to create value-added products with differentiating features. Bio-silica materials are particularly attractive for industries aiming to reduce their environmental impact and increase sustainability.

Value Chain Partners: Agro-industrial sector (farmers and producers of rice and other crops) for sourcing residues like rice husks.

Value Generation:

Internal: CeNTI uses a method based on thermal treatment and alkaline digestion to extract silica from rice husks and other agro-industrial residues. Obtained bio-silica can then undergo further modification to add different functionalities, such as hydrophobicity, flame retardancy, or antimicrobial activity. The technology used at CeNTI allows flexibility and adaptability for different types of biomass inputs and different functional properties.

External: Collaboration with new value chain partners, especially those upstream (e.g., agricultural producers) and downstream (e.g., industrial companies in the field of functional coatings, polymers and other materials or components for several applications, like automotive, construction, and textiles), is essential to secure biomass resources and expand product applications.

Value Capture:

Nature: CeNTI captures value from offering services such as bio-silica extraction and/or, modification to industries for further incorporation in the existing processes. Additional revenue streams can come from consulting on new biomass materials for silica extraction and/or new functional properties for bio-silica.

Sources: Revenue sources include organizations interested in incorporating bio-silica (whether modified or not) in their processes/products. Potential funding from government grants and private investments support research and development, process optimization, and scaling up production.

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1.3.3. Living Lab 3: Liguria Bio-Lab (Leader: FILSE)

Bioeconomy Business Models

Business Model for FILSE: Substitute Products (e.g., biodiesel)

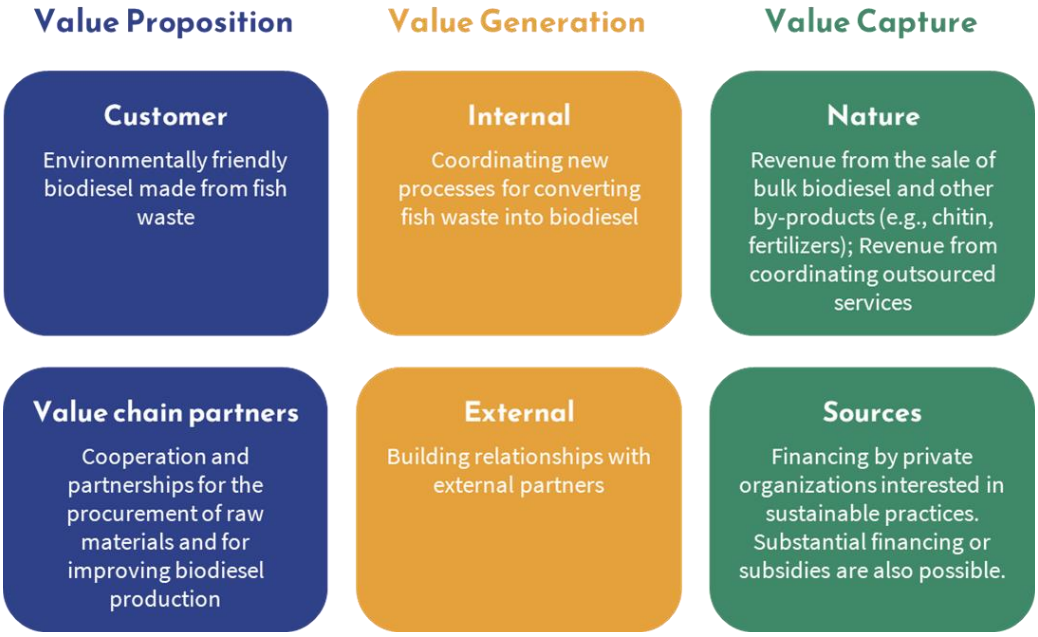

Figure 11. Substitute Products – FILSE (Based on Bröring and Vanacker, 2022)

FILSE introduces the business model of substitute products (Figure 11) with their substitutes made of fish waste.

Value Proposition:

Customer: The Liguria Living Lab focuses on focuses on providing biodiesel as a green alternative to fossil fuels, targeting sectors such as transportation, agriculture, and maritime. The biodiesel is produced using sustainable methods. Customers, such as transport companies and farmers, benefit from a sustainable, cost-effective alternative to traditional fossil fuels, which helps reduce their carbon footprint and meet regulatory requirements.

Value Chain Partners: FILSE collaborates with various partners, including local fisheries, waste management companies, and insect producers, to source and convert fish waste into valuable by-products like biodiesel. Partnerships with genetic modification companies help optimize the bioconversion process by enhancing BSFL production.

Value Generation:

Internal: FILSE coordinates new processes for efficiently converting fish waste into biodiesel using BSFL. This involves ongoing R&D to improve the bioconversion technology, ensuring the process is both effective and scalable. The company also manages partnerships with various stakeholders, ensuring a smooth supply chain and production process. By outsourcing key services like waste pre-treatment and oil extraction, FILSE focuses on core activities such as R&D and partnership management. FILSE acts as a coordinator, ensuring that all outsourced services align with the project's sustainability and quality standards.

External: FILSE builds strong relationships with external partners, including waste management companies, insect producers, and extraction companies. These partnerships are essential for obtaining biomass resources, managing waste streams, and optimizing the production process.

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Value Capture:

Nature: FILSE generates revenue primarily through the sale of biodiesel and other by-products (like chitin and fertilizers). FILSE coordinates the regional/local actors involved in the process in order to generate development and revenue for Liguria ecosystem. Additionally, revenue is captured from the service fees related to managing and coordinating outsourced services within the value chain. The sale of biodiesel, being a primary focus, offers significant growth potential, especially with the increasing demand for sustainable fuels in the transportation sector.

Sources: The LLab may receive potential funds from government subsidies or grants aimed at promoting circular economy practices and reducing carbon emissions (Regional or EU public funds). The EcoeFISHent project's alignment with regional and international sustainability goals positions well attract such funding sources in order to develop the creation of spin off, new companies and opportunity for SMEs settled in Liguria Bio Lab territory.

Business Model for FILSE: Services (e.g., recycling service, infrastructure as a service)

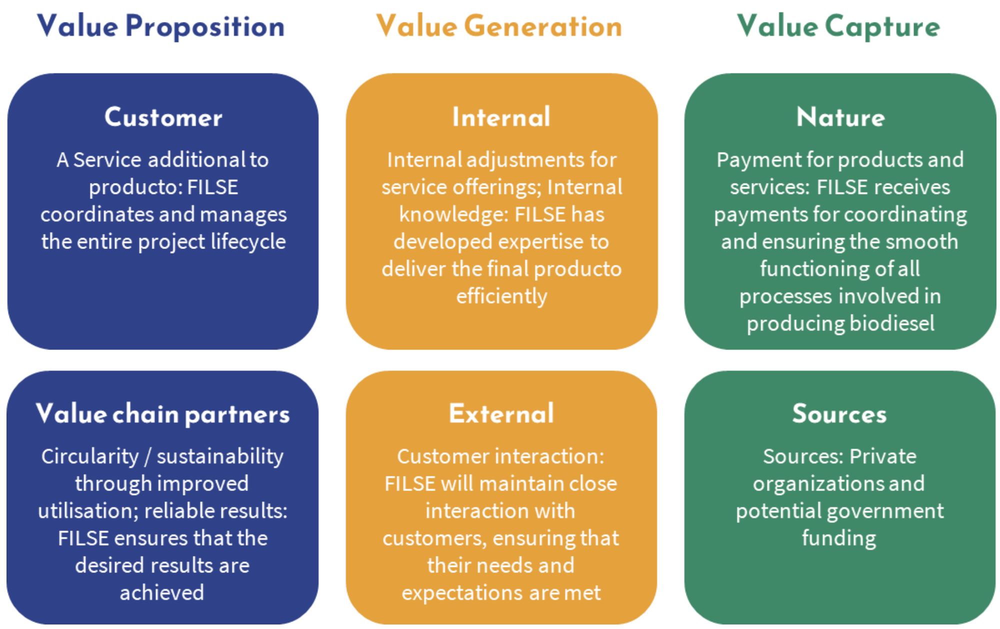

Figure 12. Services – FILSE (Based on Bröring and Vanacker, 2022)

Moreover, FILSE in their coordinator role offers also services in terms of managing the project lifecycle as depicted on the Figure 12.

Value Proposition:

Customer: Service additional to product: The Living Lab not only supports the production of biodiesel but also offers services such as managing the entire value chain, ensuring quality control, and coordinating between different stakeholders. This additional service is crucial for the successful execution of the EcoeFISHent project.

Outcome agreed upon with customer: FILSE ensures that the biodiesel produced meets specific sustainability standards, regulatory requirements, and customer expectations, such as reduced emissions.

Value Generation:

Internal: FILSE has adapted its internal processes and structures to focus on service delivery. This includes creating specialized units or teams to manage partnerships, oversee production processes, and ensure that

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customer needs are met. FILSE's expertise in project management and coordination plays a crucial role in value generation. By developing and refining these services, FILSE ensures the efficient operation of the biodiesel production chain.

Value Capture:

Nature: Payment for products and services: FILSE captures value through governmental funds for coordination of activities. This includes management fees for coordinating the project and ensuring the smooth operation of the entire value chain.

Sources: Grants, investments, or partnerships that align with the goals of the EcoeFISHent project and with environmental goals and circular economy principles, what could be catalyzed during the process through the dissemination and exploitation actions taken by the EcoeFISHent consortium and by the LLab itself.

Cascade Model

The cascade model (Figure 13) represents the cascading use of biomass, specifically fish parts, food or crop waste and how these are processed into various products within a coordinated system. The living lab in Italy acts as an orchestrator, facilitating the transformation mostly of fish parts into valuable by-products.

In the first stage of use, the process begins with the collection of fish parts (biomass). For the future there is a potential for it also being additional inputs like food or crop waste. These raw materials are the foundation of the system, entering a process that channels them into different applications. From here, the biomass is directed into two main pathways. A portion of the biomass is transformed into by-products, while another portion is prepared for retail. The retail path refers to direct commercial use, where fish parts are into sold on the consumer market. One of the possible use cases would be in the form of fertilizer.

The second stage involves the creation of by-products from the biomass. These by-products are repurposed into a variety of high-value items such as biodiesel, fertilizer, bioactives, gelatine, coatings. Each of these by-products has its own applications, finding multiple uses for materials that might otherwise go to waste. For example, biodiesel can be used as a renewable energy source, while fertilizers can benefit the agricultural sector.

Once these by-products are produced, they are further distributed for use in B2B (business-to-business) sectors. The B2B sector likely utilizes the bioactives, coatings, or gelatine in various industrial applications. As already mentioned, one possible utilization can be in the form of fertilizer. Once the frass (a biomass byproduct) has been applied as a fertilizer and degrades in the soil, the nutrients are reintegrated into the ecosystem. The crops grown with these nutrients form the new biomass, which then enters the bioeconomy cycle once again. Thus, the system supports the closed-loop nature of circular bioeconomy, where nothing goes to waste, and resources are continuously reused and recycled.

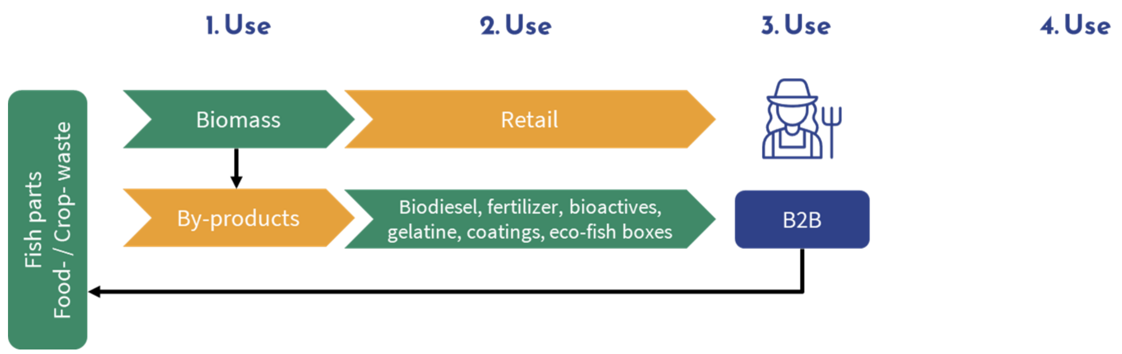

Figure 13. Cascade Use – FILSE (Based on Berg et al., 2022)

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Circular Business Model Canvas and Bioeconomy Archetypes

In the following chapter FILSE's business model is analyzed chronologically. Therefore, their circular procedure is divided into three phases. In the first phase (*Collect & Integrate Phase*) fish waste is collected and turned into valuable resources. These will be processed further and sold in the *First Sale Phase.* The loop is closed in the *Material Recovery Phase*. Residual waste and resources are integrated back into the economy for this purpose.

In each of these phases, the value proposition, how the value is generated and how it is captured differ. The respective findings on the individual phases are first summarized and then described in detail below.

Collect & Integrate Phase

The Collect & Integrate phase of the living lab (Figure 14) focuses specifically on incorporating fish waste into a circular bioeconomy system. This framework in the context of the living lab breaks down how fish waste is collected and turned into valuable resources, focusing on the value recovery from waste, innovations toward bioresources, and resource exchanges that bolster the local economy.

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Collect & Integrate			
Value Proposition	Offer	*Value recovery from waste*	Collection and processing of fish waste
		Innovation towards bio resources	Developing value-adding new products made from fish waste
		Resource exchange; local economy	Sourcing of local resources like know-how and inputs such as fish waste
	Value proposition	*Value recovery from waste*	Transforming fish into sustainable products
		Innovation towards bio resources	Sustainable and resource efficient products from fish waste
		Resource exchange; local economy	Supporting the local economy with economic activity and relieving issues like the amounting of organic waste or the lack of eco-friendly products
	Customer segments	*Value recovery from waste*	Local (municipal) government, fishers
		Innovation towards bio resources	Government, eco-aware customers
		Resource exchange; local economy	Local actors from industry and politics
	Relationships customers/partners	*Value recovery from waste*	Local actors, government, local citizens
		Innovation towards bio resources	Local actors, government, universities
		Resource exchange; local economy	Local actors, government
Value creation and delivery	Key activities	*Value recovery from waste*	Collection, incorporation, prepocessing, coordination with partners, scouting for input sources
		Innovation towards bio resources	Developing technologies to process fish waste
		Resource exchange; local economy	Building local supply chains and sourcing input factors (technology, fish waste, labor)
	Key resources	*Value recovery from waste*	Collection hubs, processing technology, skilled labor
		Innovation towards bio resources	Technologies for all operations like pre-processing, processing
		Resource exchange; local economy	Local collection system and supply chain
	Key partners	*Value recovery from waste*	Fisherman, processing companies
		Innovation towards bio resources	Technology companies innovating in bio-based sectors
		Resource exchange; local economy	Government
	Channels	*Value recovery from waste*	Direct purchases from sources, distribution via eco-companies collecting the raw product
		Innovation towards bio resources	-
		Resource exchange; local economy	Local network
Value Capture	Costs	*Value recovery from waste*	Collection, distribution, logistics, networking, preprocessing
		Innovation towards bio resources	Initial investment, R&D
		Resource exchange; local economy	Collection, networking, logistics
	Revenue flows	*Value recovery from waste*	Fees for logistics
		Innovation towards bio resources	-
		Resource exchange; local economy	-

Figure 14. Collect & Integrate Phase – FILSE (Based on Nußholz, 2018 and Salvador et al., 2023)

Value Proposition

To begin with, in the Value Proposition section of the "Collect & Integrate" stage, the primary offer is centered around the collection and processing of fish waste. This activity is geared towards value recovery from what would typically be discarded, transforming fish waste into products that can re-enter the economy. The goal here is not only to reduce waste but also to create a system where the waste from one process (fishery) becomes the input for another (such as biorefineries or other bio-product manufacturing). By innovating with bioresources, the living lab creates value by developing new technologies and processes that convert fish waste into bio-products, for example, using it to make bio-based materials. Resource exchange within the local economy is emphasized by utilizing local knowledge and materials. This means that the fish waste collection and integration are connected to the local actors and the regional economy benefits directly from the process.

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Specifically, the Value Proposition is based on three key areas: value recovery from waste, innovation towards bioresources, and resource exchange within the local economy. In this case, value recovery from waste revolves around the efficient collection of fish waste, which is processed to create useful products such as fertilizers, biofuels, or bioplastics. The innovation towards bioresources aspect involves the development of new bio-products, leveraging fish waste as an input for advanced material production. Resource exchange and the local economy come into play by encouraging local collaboration, meaning that the fish waste is collected and processed using local resources, and the benefits of this process are circulated back into the local community through job creation, resource efficiency, and economic stimulation.

Value Creation and Delivery

In the Value Creation and Delivery section, the key activities in the living lab's "Collect & Integrate" framework involve collection, incorporation, preprocessing, and coordination with partners to source fish waste. Another major activity involves scouting and identifying local resources, which is crucial for both the innovation towards bioresources and resource exchange components of the value proposition.

The key resources in the living lab include technologies for collection and preprocessing, local supply chains, and skilled labor. Local expertise is also a key resource, as individuals and institutions familiar with the local economy play a crucial role in optimizing the integration of fish waste into the circular system. The local supply chain also provides a valuable resource, ensuring that the living lab's activities relate to local markets, which strengthens regional economic resilience.

Key partners in this framework include fishermen, processing companies, and local governments. Fishermen and processing companies supply the raw material (fish waste), while local governments can facilitate the integration process by providing regulatory support and fostering collaborations. Additionally, technology companies involved in bioresource innovations act as key partners by contributing the necessary technologies to process fish waste into valuable bio-products.

Channels through which value is delivered include local collection companies and direct partnerships with eco-companies that help distribute fish waste products. The use of local networks also promotes regional economic growth.

Value Capture

Moving to the Value Capture section, the costs in the "Collect & Integrate" stage primarily involve logistics, preprocessing, and technological efforts. The costs to cover the transportation of fish waste to collection centers, the maintenance of preprocessing technologies, and the logistics needed to ensure that fish waste is integrated efficiently into the system. Additionally, investments in research and development (R&D) are required to continuously improve the technology used in processing fish waste into bio-products. The living lab's system also incurs costs related to coordination with partners and maintaining local supply chains, which are necessary to ensure the smooth operation of the fish waste collection and integration process.

Despite these costs, revenue is captured through various streams. First, fish waste can be processed into valuable products such as biofuels, bioplastics, or fertilizers, which can be sold. These sales generate income, while the reduction of waste management costs (since waste is being reused rather than discarded) adds another layer of financial savings. Fees associated with logistics or processing services might also be a potential source of income, especially when third-party companies partner with the living lab to utilize the fish waste processing infrastructure. Moreover, local economies benefit from this system through job creation and improved resource efficiency, contributing to long-term financial sustainability.

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First Sale Phase

In the First Sale phase of the circular bioeconomy framework (Figure 15) applied to the living lab, the focus shifts towards establishing systems for effectively processing and selling products derived from fish waste.

First sale			
Value Proposition	**Offer**	*Building biorefineries*	Establishing refineries, efficiently processing fish waste into bio-products
		Value recovery from waste	Creating commercially viable products from waste
		Optimizing resource efficiency and use	Maximizng the value extracted from waste inputs
	Value proposition	*Building biorefineries*	Development of an integrated system to transform waste into products
		Value recovery from waste	-
		Optimizing resource efficiency and use	Offering the latest technology when it come to yields
	Customer segments	*Building biorefineries*	Industrial clients interested in collaborations
		Value recovery from waste	Agriculture, cosmetics, bioplastics, heavy industry
		Optimizing resource efficiency and use	Businesses focused on sustainable production and resource management
	Relationships customers/partners	*Building biorefineries*	Partnerships with industrial actors
		Value recovery from waste	Collaborative partnerships with local industry actors or universities
		Optimizing resource efficiency and use	Engaging customers and partners with sustainability goals
Value creation and delivery	**Key activities**	*Building biorefineries*	Construction and maintanance
		Value recovery from waste	Production, quality control, marketing, sales, logistics
		Optimizing resource efficiency and use	Streamlining processes, R&D
	Key resources	*Building biorefineries*	Funds, partnerships, know-how
		Value recovery from waste	Know-how, technology, biorefineries, network, locality
		Optimizing resource efficiency and use	Partnerships, know-how
	Key partners	*Building biorefineries*	Engineering companies
		Value recovery from waste	Network, supply chain actors, researchers
		Optimizing resource efficiency and use	Network, supply chain actors, researchers
	Channels	*Building biorefineries*	Direct partnerships trough network, partnership programs
		Value recovery from waste	Online channels, direct sales (B2B)
		Optimizing resource efficiency and use	Marketing the efficiency of products plays into the sales
Value Capture	**Costs**	*Building biorefineries*	Innitial investment, maintenance costs, R&D
		Value recovery from waste	Production, logistics, marketing, sales, networking
		Optimizing resource efficiency and use	R&D
	Revenue flows	*Building biorefineries*	Potential fees
		Value recovery from waste	Sales
		Optimizing resource efficiency and use	Additional revenue from enhanced efficiency

Figure 15. First Sale Phase – FILSE (Based on Nußholz, 2018 and Salvador et al., 2023)

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Value Proposition

Starting with the Value Proposition during the "First Sale" stage, the offer is structured around three main categories: building biorefineries, value recovery from waste, and optimizing resource efficiency and use. Building biorefineries refers to the establishment of refineries that process fish waste into valuable bio-products. This involves setting up infrastructure and operational systems that allow fish waste to be turned into various bio-based materials and products. The goal is to create bio-products that can be marketed across different industries, including cosmetics, agriculture, and bioplastics.

Value recovery from waste is a central part of the offer, where fish waste is transformed into viable products. In this stage, the focus is on utilizing every part of the fish waste to create a range of products that can be sold in various industries. Optimizing resource efficiency and use involves utilizing advanced technologies and innovative practices to extract the maximum value from fish waste.

The Value Proposition of the "First Sale" is designed around the development of integrated systems that turn fish waste into products. Specifically, building biorefineries is an essential part of this value proposition, as these facilities enable the transformation of fish waste into various products.

The Customer Segments for this stage are diverse, as the living lab seeks to target multiple industries with different needs. For building biorefineries, the key customers are industrial clients interested in collaboration, particularly those looking to invest in or partner with bio-based industries. This might include companies in sectors like agriculture, cosmetics, or bioenergy that see potential in utilizing bio-products derived from fish waste. Value recovery from waste targets industries such as agriculture, cosmetics, bioplastics, and heavy industry. These sectors can benefit from the wide range of products derived from fish waste, such as fertilizers, biofuels, or bioplastics. Optimizing resource efficiency and use is of particular interest to businesses focused on sustainable production and resource management. These customers seek to minimize waste in their operations and are likely to value the living lab's efforts to create efficient, resource-saving products.

The Relationships with Customers and Partners in this stage are crucial for a successful market entry and maintaining long-term partnerships. For building biorefineries, partnerships with industrial actors are critical. These industrial actors could include companies looking to invest in biorefineries, either as direct collaborators or as customers. Collaborative partnerships with local industry actors or universities are key for value recovery from waste, as they enable knowledge-sharing and resource exchange that improve the efficiency and effectiveness of the waste transformation process. Additionally, partnerships with research institutions may help in advancing the technologies used for optimizing resource efficiency and use.

Value Creation and Delivery

In terms of Value Creation and Delivery, the key activities for the "First Sale" phase begin with setting up the infrastructure for processing fish waste in terms of biorefineries and manufacturing the bio-based products. For value recovery from waste, key activities include production, quality control, marketing, sales, and logistics. These processes ensure that the fish waste is efficiently turned into products and that these products reach the right customers. Optimizing resource efficiency and use involves streamlining processes, investing in (R&D), and continuously improving the systems and technologies used to extract value from fish waste.

The Key Resources needed for this phase include funds, partnerships, and know-how, particularly for building biorefineries. Investments are required to establish and maintain biorefineries, and partnerships with local and international actors provide the necessary expertise to operate them. For value recovery from waste, the essential resources include technology, biorefineries, networks, and locality. The local network plays a critical role in sourcing fish waste, while the technologies used in biorefineries ensure that the fish waste is processed efficiently.

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The Key Partners in this stage vary depending on the area of focus. For building biorefineries, engineering companies are critical partners, as they provide the expertise and technology necessary to build and operate the refineries. For value recovery from waste, the key partners include networks, supply chain actors, and researchers who contribute to the efficient collection, processing, and commercialization of fish waste products. Optimizing resource efficiency and use also relies on these partners, as well as partnerships with technology developers that can help the living lab maintain resource efficiency.

The Channels used for value delivery include direct partnerships through local networks and partnership programs, particularly for building biorefineries. These channels allow the living lab to connect directly with companies and organizations interested in bio-product development. For value recovery from waste, online channels and direct B2B (business-to-business) sales are important, ensuring that products derived from fish waste reach industrial clients quickly and efficiently. Additionally, marketing the efficiency of products derived from optimized resource use plays into the sales strategy, as it allows the living lab to differentiate itself by emphasizing the sustainability and resource efficiency of its offerings.

Value Capture

In terms of Value Capture, the costs involved in the "First Sale" phase are substantial but necessary. For building biorefineries, the primary costs include the initial investment, maintenance of the facilities, and R&D expenses. For value recovery from waste, costs include production, logistics, marketing, sales, and networking expenses, all of which are essential to ensure the smooth operation of the value recovery process. Optimizing resource efficiency and use also involves R&D costs for continuous innovation.

The Revenue Flows from the "First Sale" phase come from several sources. For building biorefineries, potential revenue streams include fees associated with partnerships or the direct sale of bio-products produced in the refineries. For value recovery from waste, sales of bio-products, such as fertilizers, biofuels, or bioplastics, provide a steady revenue stream. Additionally, optimizing resource efficiency and use can generate further revenue through enhanced efficiencies that reduce costs and create higher-value products.

Material Recovery Phase

In the Material Recovery phase of the living lab's circular bioeconomy framework (Figure 16), the focus shifts towards ensuring that materials, particularly those derived from fish waste, are collected, processed, and reintegrated into the economy. This phase is essential for closing the loop in a circular system, where waste products are not discarded but recovered and reused in a sustainable manner.

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Material Recovery			
Value Proposition	Offer	*Value recovery from waste*	Recyclable packaging designed to be easily collected and reintegrated
	Value proposition	*Value recovery from waste*	Sustainable packaging options while also providing a solution to local waste issues
	Customer segments	*Value recovery from waste*	Food manufacturers, retailers, consumers
	Relationships customers/partners	*Value recovery from waste*	Local actors from industry, retailers, customers
Value creation and delivery	Key activities	*Value recovery from waste*	Collection and processing of materials
	Key resources	*Value recovery from waste*	Technologies, network for exclusive recycling of materials
	Key partners	*Value recovery from waste*	Recycling companies, retailers
	Channels	*Value recovery from waste*	Retail partnerships, logistics systems, take-back programs
Value Capture	Costs	*Value recovery from waste*	Logistics, recycling/composting, infrastructure/plants
	Revenue flows	*Value recovery from waste*	-

Figure 16. Material Recovery Phase – FILSE (Based on Nußholz, 2018 and Salvador et al., 2023)

Value Proposition

Starting with the Value Proposition, the offer in the Material Recovery stage is centered around value recovery from waste, particularly through the recovery of food and crop waste that can be collected and reintegrated into new production cycles. This process is intrinsically linked to the utilization of living lab´s biofertilizer derived from fish waste, which enriches the soil and supports crop growth.

The Value Proposition focuses on recovering food and crop waste, creating a circular economy where these materials are reintegrated into production cycles. This process not only reduces waste but also enhances sustainability by ensuring that valuable resources are effectively utilized.

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Value Creation and Delivery

For Value Creation, the key activities revolve around the collection of food and crop waste, which is crucial for further processing into biofertilizers and other sustainable products.

Value Capture

In terms of Value Capture, the costs associated with this phase include expenses related to the acquisition and collection of waste materials. The revenue flows may arise from the collection fees for waste management services.

Pie Model

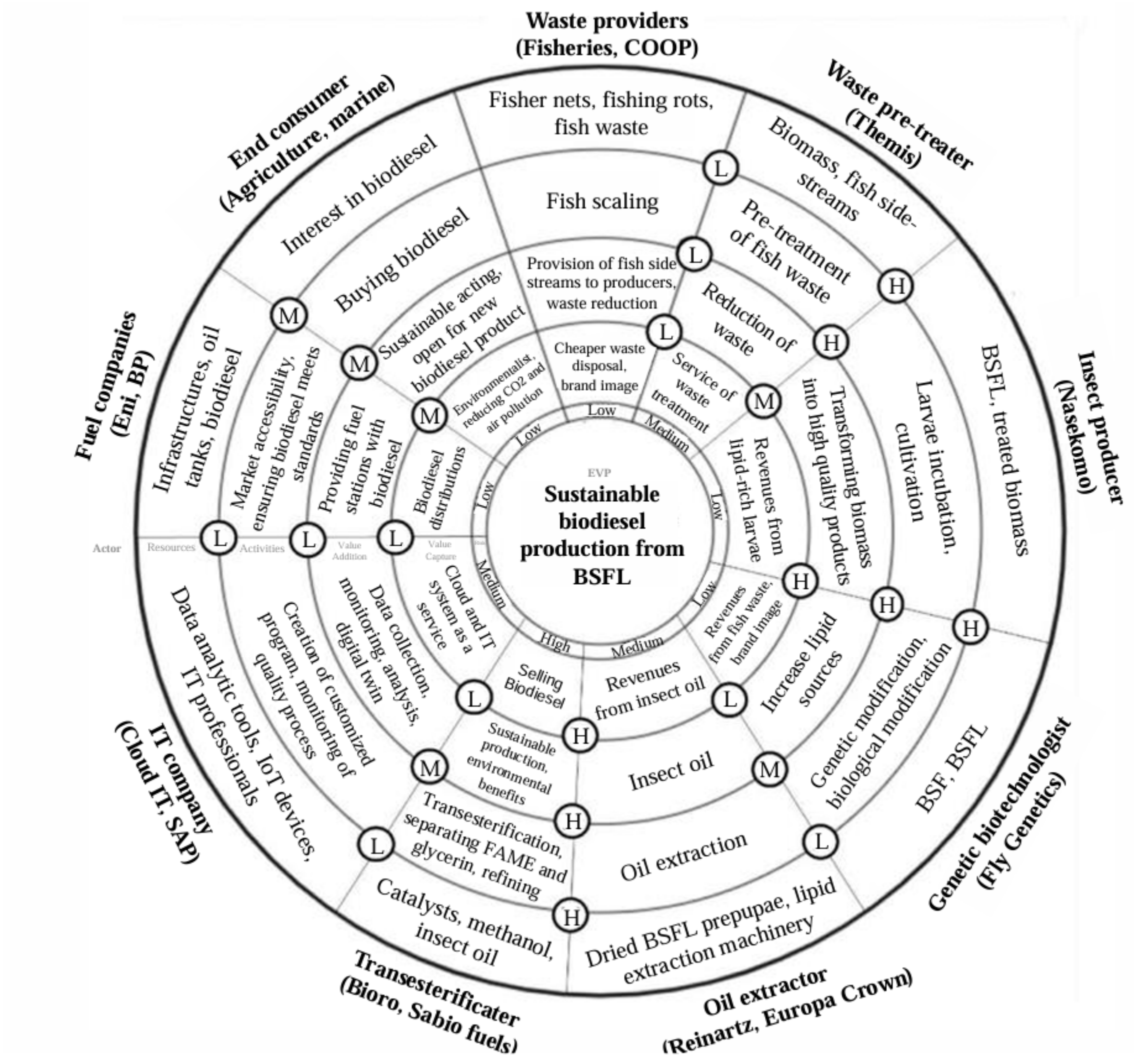

Figure 17. Ecosystem Pie Model – FILSE (Based on Talmar et al., 2020)

The Ecosystem Pie Model (Figure 17) focuses on the production of biodiesel, which presents significant potential for sustainable energy solutions. Within this model, various actors have been mapped to highlight their interactions and contributions to achieving the envisioned ecosystem value proposition (EVP) of sustainable biodiesel production utilizing Black Soldier Fly Larvae (BSFL).

A primary partner in FILSE's project is waste providers, particularly local fisheries in the Ligurian region and Ligurian COOP grocery stores. These entities are engaged in fish scaling and use fishing equipment for their

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activities. They benefit from the project by reducing waste disposal costs compared to competitors and enhancing their brand image through involvement in this sustainable initiative. Although they supply raw materials essential for biodiesel production, their dependency and associated risks are low due to the availability of multiple providers who can deliver waste.

Another important group includes waste pre-treating companies, which process fish side-streams and biomass to convert them into high-quality products. Their role is critical, as they produce the necessary resources for subsequent bioconversion processes aimed at obtaining biodiesel. Consequently, their dependency is high; they also gain revenues from providing disposal services while contributing to environmental sustainability.

Insect producers, such as Nasekomo, play a vital role in this ecosystem by incubating BSFL, which are essential for transforming biomass into valuable products. Genetic biotech companies with advanced technologies support the oil extraction process, although their contribution is secondary. As such, the dependency and risks associated with these biotech companies in realizing the final EVP are low.

A critical step in the biodiesel production process involves oil extractors and transesterification companies. Oil extractors, utilizing dried BSFL and lipid extraction machinery, focus on extracting insect oil, which is essential for subsequent production steps. Notable European companies like Europa Crown LTD and Reinartz are involved in this extraction, ensuring high-quality end products. Their value capture mainly derives from the revenues generated by oil sales. Transesterification companies, such as Sabio Fuels and Bioro, carry out the sustainable production of biodiesel by accelerating the chemical reactions necessary for efficient conversion. This step is crucial for obtaining biodiesel sustainably, and it comes with high dependency and significant risks, as the biodiesel production cannot proceed without this process.

In addition to these stakeholders, regulatory bodies also play a vital role in the ecosystem. They establish the necessary frameworks and standards that ensure compliance with environmental regulations and safety measures in biodiesel production. Their oversight can facilitate sustainable practices and encourage industry participants to adhere to best practices, ultimately enhancing the credibility and marketability of the biodiesel produced.

Additionally, information technology (IT) companies contribute to improving production efficiency through data analytics tools and the Internet of Things (IoT). They provide customized programs for monitoring the growth of larvae, enhancing product quality, and potentially generating revenue from these monitoring services. However, their involvement is marginal, and they perform secondary activities that lead to low dependency and risk in the overall production process.

Finally, fuel companies and end consumers represent the last two categories of actors involved in FILSE's project. Fuel companies primarily distribute biodiesel to market outlets, ensuring compliance with required standards. Their value capture stems from revenues associated with biodiesel distribution, indicating a low dependency and risk, as they are more focused on market provision than production. End consumers, on the other hand, are motivated to purchase biodiesel for its environmental benefits, contributing to reduced CO_2 emissions and air pollution. While they benefit from the final product, they do not actively participate in the production process, resulting in low dependency and risk regarding the creation of the final EVP.

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1.3.4. Living Lab 4: BioEire Lab (Leader: IBF)

Bioeconomy Business Models

Business Model for IBF: Substitute Products

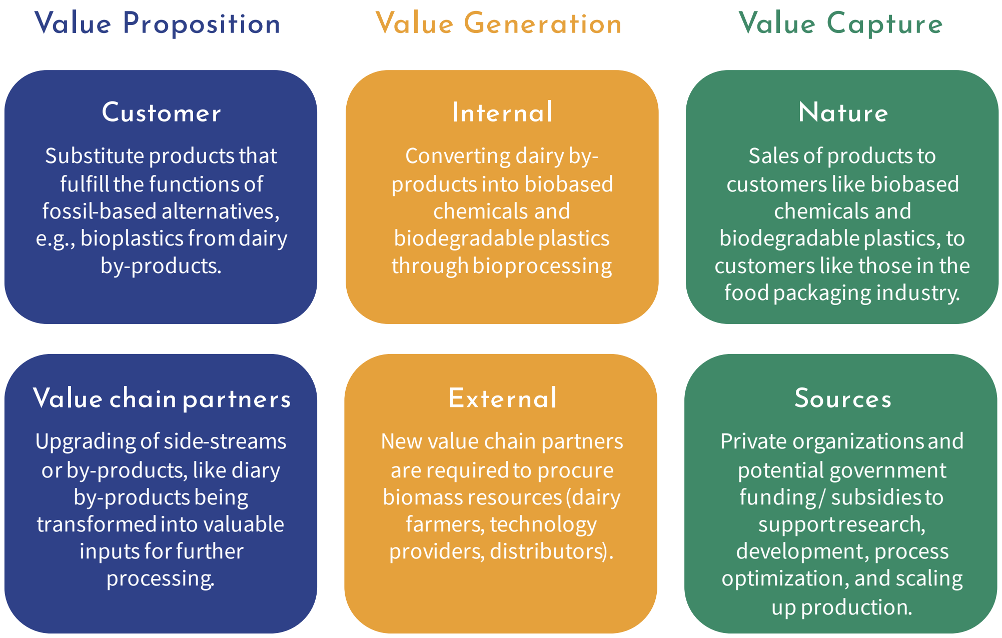

Figure 18. Substitute Products – IBF (Based on Bröring and Vanacker, 2022)

Value Proposition

Customer: Environmentally friendly substitute products (Figure 18): The IBF provides products like biodegradable plastics (e.g., Polylactic Acid or PLA) made from biological resources (e.g., dairy by-products like whey permeate). These products serve as substitutes for traditional, fossil-based plastics, fulfilling similar functions while reducing environmental impact.

Value Chain Partners

Upgrading of side-streams or by-products: Dairy processing plants convert by-products like whey permeate into valuable inputs for further processing (e.g., fermentation to produce lactic acid). This not only adds value to what would otherwise be waste but also supports the overall sustainability goals of the bioeconomy by utilizing every part of the biomass.

Value Generation

Internal: New processes to deal with bio-based resources: The IBF and its partners, such as the Pilot Plant in Lisheen, develop and scale up new bioprocessing methods to convert dairy by-products into biobased chemicals and biodegradable plastics.

External: New value chain partners: The initiative involves collaboration with various stakeholders across the value chain, including dairy farmers (biomass suppliers), technology providers, distributors, and customers in the food packaging industry. These partnerships are essential to procure biomass resources and to ensure a consistent supply of raw materials needed for bioplastic production.

Value Capture

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<u>Nature:</u> Sale of bulk products: The value capture mechanism includes selling bulk quantities of biobased chemicals and biodegradable plastics to various customers, including those in the food packaging industry, which values sustainable materials. The IBF might also monetize through partnerships and licensing agreements.

<u>Sources:</u> Private organizations and potential government funding/subsidies: Funding sources for the IBF include private investments, partnerships with private organizations, and government subsidies. These subsidies can support research and development, process optimization, and scaling up of production to meet market demand. The government also plays a role by providing regulatory frameworks and grants that promote sustainable practices.

1.3.5. Living Lab 5: CellFactory Lab (Leader: VTT)

Bioeconomy Business Models

Business Model for VTT: Substitute Products

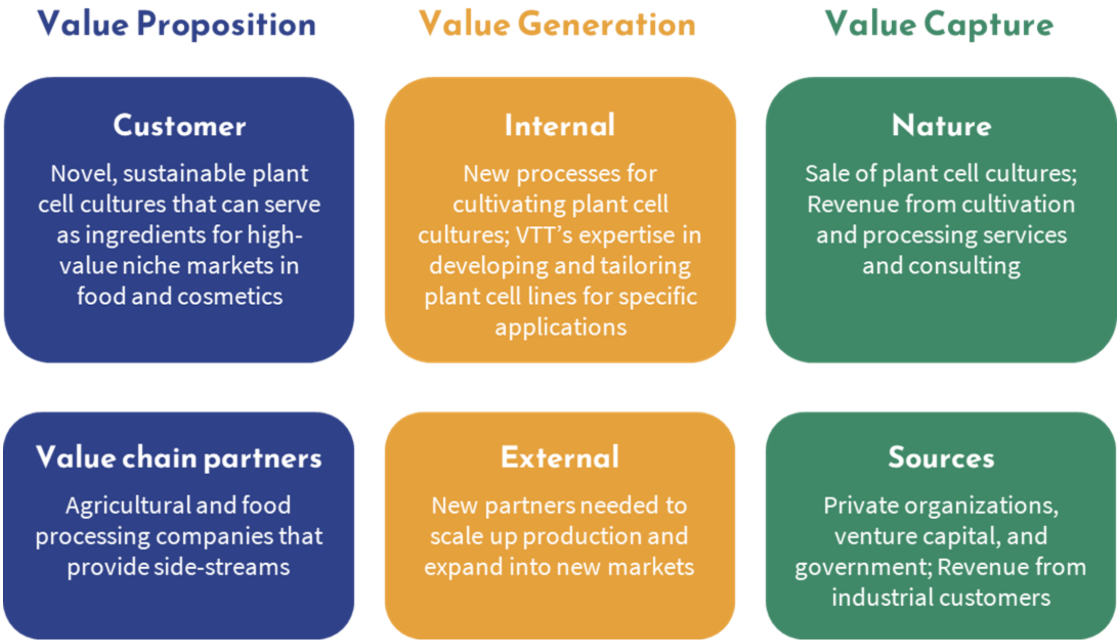

Figure 19. Substitute Products – VTT (Based on Bröring and Vanacker, 2022)

Value Proposition:

<u>Customer:</u> VTT offers a sustainable alternative (Figure 19) to traditional agricultural ingredients by developing plant cell cultures that can be used as ingredients in food and cosmetics. These cultures are propagated on agri-food side-streams, adding value to by-products and reducing waste. The novel ingredients cater to high-value niche markets seeking innovative and sustainable products.

<u>Value Chain Partners:</u> Agricultural and food processing companies (e.g., Finnamyl Ltd) that provide side-streams such as concentrated potato cell fluid.

Value Generation:

<u>Internal:</u> VTT has developed a process to cultivate plant cell cultures using agri-food side-streams (concentrated potato cell fluid), which are rich in sugars and/or other nutrients necessary for cell growth. The process involves growth medium preparation, seed cultivation, final cultivation in large vessels, and harvesting. VTT's expertise in selecting and developing specific plant cell lines from its collection is a key asset.

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External: Collaboration with agricultural and food processing companies provides a steady supply of side-stream feedstock. New value chain partners, including those involved in scaling up production and commercializing plant cell culture ingredients, are needed to expand market reach.

Value Capture:

Nature: VTT captures value by licensing plant cell cultures to companies operating in manufacturing of novel ingredients for food and cosmetic industries. Additional revenue streams come from offering cultivation and processing services, consulting on the development of new plant cell culture applications, in technology transfer and potentially spinning out a biotech start-up to commercialize the technology further.

Sources: Revenue sources include licensing of plant cell culture lines, consulting services, and partnerships with industrial customers. Potential funding from government grants and private investments supports research, development, and scaling up production.

1.4. Challenges FOR LIVING LABS

Based on a comprehensive analysis of the five living labs involved in the project, several key challenges have been identified that could impact the successful implementation of circular economy initiatives.

Regulatory Challenges

- Evolving Regulations: Living labs are confronted with rapidly changing regulations, which create significant uncertainty in their operations. This unpredictability complicates long-term planning for investments and operational strategies, forcing labs to frequently adapt to new compliance requirements.
- Permitting Delays: Obtaining the necessary permits for pilot plants and processes has proven to be a major bottleneck. The complex and time-consuming nature of the permitting process often results in certain delays.

Technological Challenges

- Technology Readiness: The varying maturity levels of the technologies being deployed poses challenges for living labs. These often lead to difficulties in scaling pilot plants or effectively implementing processes, which hinders the overall progress of their projects.

Economic Challenges

- Funding and Investment: Living labs have challenges with securing adequate funding for their innovative projects. Early-stage projects encounter difficulties attracting investment.
- Cost Competitiveness and Demand: Bioplastics and other (bio-)circular economy products face a significant challenge in competing with cheaper, fossil-based alternatives. Without appropriate subsidies or incentives, these sustainable products often lack the economic viability needed to penetrate the market effectively.

1.5. Conclusion

The analysis of the five living labs reveals that each initiative utilizes waste and side stream materials, positioning them as integral components of the bioeconomy utilizing circular principles. By transforming waste and by-products into valuable resources, these labs contribute to sustainable practices and underscore the potential for circular economy models. This report presents diverse business models through various frameworks, illustrating

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not only how biomass is utilized but also emphasizing the necessity for these labs to operate within an ecosystem. Collaboration among stakeholders—including local communities, industries, and research institutions—is crucial for maximizing resource efficiency.

However, despite that, the living labs face several challenges. Regulatory barriers can hinder progress, making it essential for them to follow complex legal frameworks that may not fully support circular economy initiatives. Additionally, increased market acceptance of bio-based products is needed with the help of subsidies for the bio-based products.

As these living labs continue to develop, effectively addressing these challenges and optimizing their ecosystems will be essential for realizing the full potential of the bioeconomy and securing long-term viability.

Theoretical implications

This research offers significant contributions to the theoretical landscape of the circular bioeconomy, emphasizing the necessity of analyzing LLabs from both bioeconomy and circular economy perspectives. By combining different theoretical frameworks, we created a multi-faceted understanding of LLabs' business models, each framework offering a unique perspective. The Bröring and Vanacker (2022) framework illustrates that LLabs predominantly focus on substitute products, rather than creating entirely new ones, though many also offer complementary services to enhance their value proposition. Integrating this with Nußholz (2018) and Salvador et al. (2023) provides a more nuanced understanding of how LLabs operate within local economies, prioritizing resource efficiency and focusing on multiple biomass use cases—as depicted in the cascade use model. This model highlights how biomass is not immediately directed to retail but undergoes several stages of transformation, ensuring that resources are used optimally and in various forms. We add a novel contribution by linking the final use of biomass back to its circular flow, reflecting the continuous regeneration and reuse of materials.

Moreover, the Ecosystem pie chart framework from Talmar et al. (2020) underlines the importance of ecosystem dynamics, revealing that LLabs rely on a network of diverse stakeholders to co-create value. Governmental influence and policy implementation—or the lack thereof—emerge as significant challenges in these ecosystems. The diversity of stakeholder roles is illustrated in LLabs like FILSE, which acts as an ecosystem orchestrator, coordinating the process, while Alcarràs takes on the role of provider, directly handling biomass and producing by-products.

Practical Implications

The practical implications of this research highlight the necessity for subsidies and governance changes to support the viability and scalability of LLabs. These labs play a crucial role in strengthening local economies through bioeconomy and circular economy initiatives, helping to build resilient and sustainable communities. Most LLabs are focused on providing substitute products and services—such as biogas, biofertilizers, and circular services—rather than entirely new products, positioning themselves as sustainable alternatives to traditional industries. Additionally, LLabs maximize resource efficiency through multiple biomass use cases, ensuring that every stage of the biomass lifecycle is leveraged to extract as much value as possible, thereby minimizing waste and promoting circularity. These findings are vital for policymakers, practitioners, and researchers aiming to understand or engage with LLabs and comprehend their business models.

Future steps

Future research should focus on understanding value capture within LLabs in greater depth, particularly how they can maintain sustainable operations amidst shifting policies, market demands, and the need for subsidies. There is also a need to investigate the stakeholder roles more thoroughly, specifically how these roles influence value

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creation, capture, and proposition. Additionally, longitudinal studies tracking business model innovation (BMI) in LLabs over time, under evolving regulatory and market conditions, would provide valuable insights into their adaptability and success.

This analysis is vital because it provides a comprehensive understanding of how living labs operate at the intersection of bioeconomy and circular economy, offering practical pathways toward more sustainable economic models. By identifying the business models and stakeholder ecosystems involved, the research helps policymakers and practitioners optimize resource efficiency, enhance value creation, and promote local economies. Additionally, it highlights critical challenges like policy gaps and the need for subsidies, offering insights that can drive future innovation and improve the scalability of these sustainable solutions.

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2. Analysis Of The State-Of-The-Art Of Bio-Based Value Chains Creation

2.1. Introduction

Circular Business Models in Bioeconomy (CBMB) present opportunities to exploit untapped value in the bioeconomy that could be capitalised on to minimise virgin resource extraction, boost resilience in bio-based value chains and combat climate change. The bioeconomy is increasingly being recognised as pivotal to addressing global sustainability concerns, especially within the European Union (EU), wherein it has officially been recognised in the EU’s Bioeconomy strategy as part of the larger European Green Deal (European Commission, 2020).

Despite this, challenges related to technological scale-up and commercialisation have continued to persist. Yet, there is insufficient research targeted at business models and value chains in the bioeconomy segment, even though the bioeconomy is unique in terms of its intricate knowledge base, vastly different innovation types and fragmented policy frameworks (Bröring and Vanacker, 2022).

This report aims to synthesise the approaches and findings on the bioeconomy (and more specifically, bioeconomy value chains and its connection to CBMB in current literature, as well as explore further insights on by mapping and analysing the value chains of the five Living Labs under the scope of the EU Horizon project PRIMED. Finally, this report concludes with some comments that compare and contrast the varied approaches used by the Living Labs to govern their respective value chains.

2.2. Bioeconomy literature review

This literature review is aimed at synthesising the different themes addressed by scholars regarding the bioeconomy and more specifically, CBMB. For this Integrative literature review, this thesis uses bibliometric analysis (occurrences in databases and journals), text similarity, and content analyses as used by Paes et al. (2019). Following the guidelines of the PRISMA statement of reporting literature searches in systematic reviews (Olah et al., 2020), the researchers identified, screened and determined eligibility before finally including 219 articles in this review. This process has been depicted in figure 20 below:

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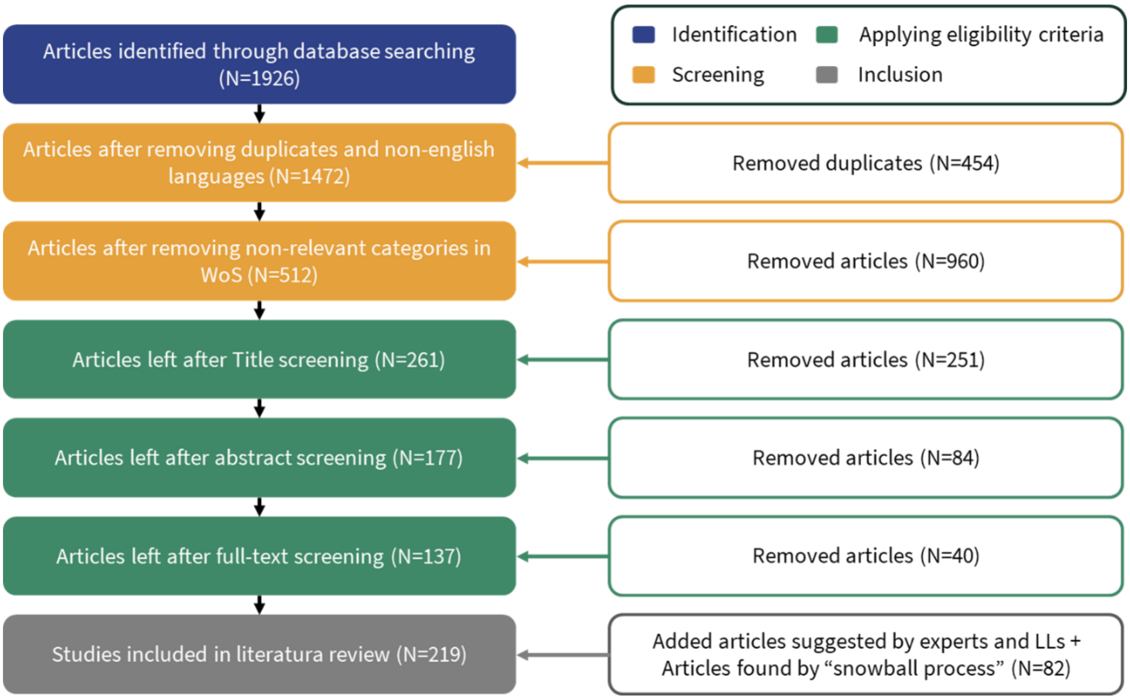

Figure 20: *PRISMA guidelines used for article selection*

2.2.1. Definitions of bioeconomy in the literature

The following table 1 demonstrates two key definitions of bioeconomy that have been proposed in the literature:

Table 1: *Definitions of bioeconomy found in the literature*

Concept	Definition	Source
Bioeconomy	An economy which *"encompasses the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy. It includes agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries"*	European Commission (2012)
	"The complete biobased value chain from biomass production, pretreatment, and conversion, through to the manufacture and marketing of biobased products and includes socioeconomic and eco-logical assessments"	Lewandowski et al (2019)

Based on these definitions, the bioeconomy aims to foster sustainability by reducing reliance on finite resources and minimizing waste. The bioeconomy focuses on the production and conversion of renewable biological resources, such as agricultural, forestry, and industrial biomass, into valuable products, energy, and materials, emphasizing sustainability and competitiveness against fossil-based alternatives. It spans across multiple sectors, including agriculture, food production, and biotechnology.

Additionally, the bioeconomy holds the promise of contributing to the circular economy, which seeks to close material and energy loops, by integrating renewable resources into circular systems, thereby ensuring a regenerative approach to resource management and economic growth.

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2.2.2. Theoretical approaches and models in the bioeconomy literature

Current literature on the bioeconomy seems to be focused on four key theoretical approaches: business models, supply chain management, social network theory and stakeholder theory. These theories provide valuable frameworks for understanding and analyzing various aspects of bioeconomy management, including social interactions, business strategies, and stakeholder engagement. This is especially salient for an evolving domain like the bioeconomy which is still, in most contexts, in its very early stages of origin and development.

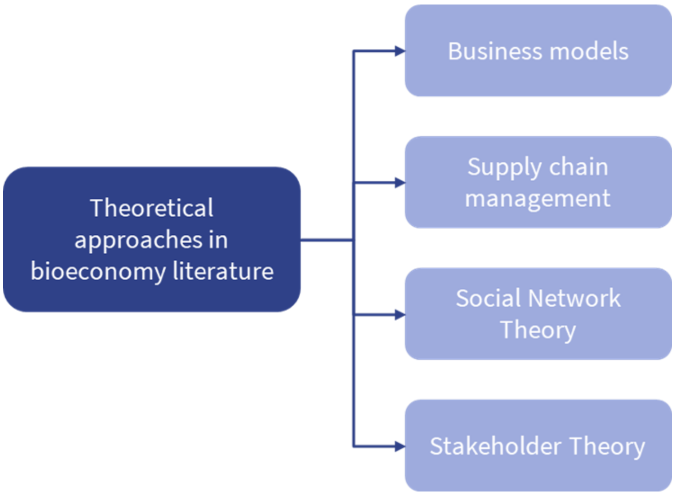

Figure 21: *Key theoretical approaches found in bioeconomy literature*

Business model research within bioeconomy literature

Business model research focuses on how organisations create, deliver and capture value. The following table 2 highlights some findings from existing literature on bioeconomy business models:

Table 2: *Business model research within the bioeconomy literature*

Key concepts within business models	Focus areas within the bioeconomy
Value creation in different stages (Bröring and Vanacker, 2022)	Offering renewable and sustainable products or services in different sectors
	Offering bioeconomy as a service (technology services, business analytics services, consulting services, logistics services)
	Circular economy approaches by utilizing residues and byproducts
	Reducing environmental footprint (CO2 emissions, waste)
	Improving social benefits, including supporting rural economies
	Green job creation
Revenue streams (Esmaeili et al., 2020)	Direct sales: Selling bio-based products and energy
	Service contracts: technology assistance, waste management and legal consulting
	Government subsidies and incentives
	Additional revenue through carbon credits and offering certified sustainable products
	Sale of feedstocks
	Sale of R&D and technology advancements
Cost streams	Procurement expenses associated with sourcing, harvesting and preprocessing

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(Belbo and Talbot, 2016), (Lautala et al., 2015)	Processing and manufacturing costs Investments in R&D and technology advancements Logistics and distribution costs Regulatory compliance and certification costs
Customer segments (Salvador et al., 2022)	Customers looking for eco-friendly and sustainable biobased products (B2C) Businesses in different sectors seeking renewable inputs (B2B) Public and Private institutions as authorities looking to promote green technologies and policies (public procurement)
Key resources (Donner et al., 2020)	Primary source for raw materials (feedstocks, waste and byproducts) Processing technologies, expertise and innovation Relationships with suppliers who can provide a consistent, sustainable supply of bio-based materials Relationships with other stakeholders (public agencies, customers) Human Resources
Key activities in the value chain (Laibach and Bröring, 2022); (Boehlje and Bröring, 2011); (Bröring and Vanacker, 2022)	Biomass sourcing Converting raw biomass into bio-based products Logistics to facilitate transportation and warehousing Quality control, sustainable certifications and property rights (regarding feedstock land ownership) Intellectual property rights, patented technologies and governance Knowledge creation and dissemination Talent attraction and retention Entrepreneurial activities Value chain design, construction and optimization

Some research gaps can be identified within the business models literature focusing on the bioeconomy. While some research has been conducted on defining fundamental aspects of emerging bioeconomy business models, lesser is known about how these nascent value chains can develop new business models to overcome some of the barriers they currently face. Additionally, the financial viability of creating innovative sustainable business models that can integrate with existing systems also remains under-explored.

Supply chain management research within bioeconomy literature

An integrative analysis of the supply chain management literature on the bioeconomy, resulted in a selection of certain main topics, which are classified in five broader topics focusing on technology, finance, regulation, markets and society. This has been elaborated upon in the following table 3:

Table 3: *Supply chain management research within bioeconomy literature*

Topics	Sub-topics	Main approach
Technology (Carraresi and Bröring, 2021); (Bröring and Thybussek,	Optimizing strategic and technological efficiency of value chain	Investigating various strategies and technologies used to enhance the profitability of biomass value chains by optimizing costs and improving operational efficiencies

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2023); (Bröring et al., 2020)			
		Designing digitalized integrated value chain optimization models	Designing models with mathematical programming, GIS, and decision-support systems to optimize the design and management of biomass value chains
		Technological barriers	Identifying technological challenges, involving when switching into biomass value chains and integrating the new technology with existing technology
Finance (Christiansen, 2021)	Financing mechanisms for scaling projects	Highlighting the importance and effectiveness of innovative financing mechanisms in bioeconomy projects	
		Application of operational cost reduction methods in value chains	Focusing on cost reductions in areas such as transportation, energy taxes, location planning, deciding the feedstock used and biomass converting processes
		Financial barriers	Identifying the financial constraints, such as high operational costs and limited access to capital, that hinder the development of sustainable biomass value chains
Regulations and policies (Pascoli et al., 2022)	Existing and missing regulation and policies and their impact	Analyzing how regulatory frameworks influence the development of bio-based value chains; Discussing the role of carbon emission policies in shaping bio-based value chains and their impact on the economic viability of a bioeconomy Project	
		Recommended policy support for main actors: industries, SMEs and farmers	Examining how policy interventions can facilitate the transition of SMEs and agricultural sectors to a bioeconomy by addressing infrastructure, labeling, and market Access
		Regulatory challenges	Discussing inconsistencies in policies and regulations across regions that pose challenges to the investment and development of biomass value chains

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Markets (Salvador et al., 2021)	Consumer markets and products	Identifying the role of consumers as active participants in bio-based value chains, influencing market dynamics through their purchasing decisions and social responsibilities
	Feedstock markets	Discussing how government policies, subsidies, and new technologies affect feedstock production and market dynamics
Society (Sjølie et al., 2016)	Social equity and inclusivity	Emphasizing the importance of social equity and inclusivity of all segments of society in the development of the bioeconomy
	Public acceptance and the role of local communities	Addressing societal challenges, such as public acceptance, consumer awareness, and stakeholder engagement that affect the implementation of biomass value chains

Some research gaps can be identified within the supply chain management literature focusing on the bioeconomy. While some research has been conducted on optimization of value chains, regulatory and policy focus and some barriers hindering the sustainable development of biomass value chains, lesser is known about how emerging bioeconomy value chains can successfully transition into commercial markets and gain social acceptance.

Social network theory research within bioeconomy literature

Social network theory literature focused on the bioeconomy has explored how networks shape interactions and innovation within the bioeconomy. Several different interactions have been identified to be under operation within the bioeconomy actors, which are summarised by the following table 4:

Table 4: *Social network relationships found in the bioeconomy literature*

Type of relationship	Purpose of relationship	Contribution to bioeconomy
Social capital (Santibanez-Aguilar et al., 2014)	The benefits (e.g., social recognition, trust, cooperation) gained from relationships in a network	Trust and cooperation within bioeconomy networks enhance collaboration and resource sharing
Knowledge diffusion (Bröring and Vanacker, 2022)	The spread of information and innovation through the network	Effective diffusion accelerates innovation and adoption of bio-based technologies
Innovation network (Carraresi et al., 2018)	A network that focuses on generating and sharing new ideas or technologies	Innovation networks are key to the bioeconomy's growth by linking diverse fields together
Cross-sectoral linkages (Christensen et al., 2022)	Connections between different sectors within the network	Cross-sectoral linkages drive bioeconomy actors' integration, fostering interdisciplinary innovation and financing
Policy networks (Panoutsou et al., 2020)	Networks of stakeholders involved in creating and implementing policies	Policy networks support the creation of frameworks that enable bioeconomy growth

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The social network analysis of the literature indicates the existence of weaker ties between intermediaries and industries. It is also possible that the current literature may have under-represented or entirely missed out some actors. These signal to possible research gaps, which can be addressed by exploring the roles of intermediary as well as other actors, in interaction with other bioeconomy actors, more deeply.

Stakeholder theory research within bioeconomy literature

The stakeholder theory literature focusing on the bioeconomy explores approaches for identification of relevant stakeholders, their needs and several opportunities for stakeholder engagement. These aspects can be further illustrated in the seven key dimensions of stakeholder research found in the existing bioeconomy literature, as shown in the table 5 below:

Table 5: *Stakeholder theory research within bioeconomy literature*

Dimension	Sub-dimension	Description
Diverse stakeholder engagement (Tortoe et al., 2021)	Identification of stakeholders	Mapping and categorizing stakeholders relevant to the bioeconomy, including farmers, researchers, policymakers, NGOs and consumers
	Stakeholder analysis	Understanding the needs, interests and influence of each stakeholder group to inform bioeconomy initiatives
	Participation mechanisms	Developing processes (e.g., workshops, surveys) that allow stakeholders to actively participate in bioeconomy projects
	Feedback loops	Establishing systems that enable stakeholders to provide input and feedback on bioeconomy policies and practices
Value creation (Santibanez-Aguilar et al., 2014)	Economic value	Assessing financial benefits generated for stakeholders through bioeconomy initiatives, including profitability, job creation in sustainable industries, and investments in green technology
	Social value	Evaluating the social impacts of bioeconomy projects, such as community development, improved livelihoods, and public health benefits
	Environmental value	Measuring the contributions of bioeconomy practices to environmental sustainability, such as waste reduction, carbon sequestration, and conservation of biodiversity
Collaboration & Partnerships (Danya et al., 2024); (Bröring and Vanacker, 2022)	Public-Private Partnerships (PPPs)	Engaging both government and private sectors in bioeconomy initiatives to leverage resources and expertise, particularly in research and development
	Interdisciplinary collaboration	Bringing together knowledge from different fields (e.g., biology, economics, policy) to foster innovation and effective solutions in the bioeconomy
	Community engagement	Actively involving local communities in bioeconomy decision-making processes to ensure their needs and insights inform project implementation

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	Knowledge exchange	Facilitating the sharing of information, best practices, and resources among stakeholders to enhance collaboration in bioeconomic development
	Coalition building	Creating networks of stakeholders (e.g., NGOs, local governments, industry) with shared goals in the bioeconomy to amplify impact and collective action
Sustainability and Resilience (Luhas et al., 2021)	Long-term planning	Incorporating long-term environmental and social impacts into bioeconomic decision-making to ensure sustainability and resilience against climate change
	Adaptive management	Developing flexible strategies that can adjust to changing environmental conditions and stakeholder needs in the bioeconomy context
	Ecosystem services	Recognizing and valuing the benefits provided by ecosystems (e.g., pollination, soil health) that support bioeconomic activities and stakeholder livelihoods
Knowledge sharing (Pubule et al., 2020)	Education and training	Offering programs and resources to enhance stakeholders' knowledge and skills related to bioeconomy practices, such as sustainable agriculture and biotechnologies
	Best practices dissemination	Sharing successful case studies and methodologies in bioeconomy to promote effective and sustainable practices among stakeholders
	Innovation networks	Creating platforms for stakeholders to collaborate on research and innovative solutions to bioeconomic challenges, such as waste-to-energy technologies
Policy and Regulation (Gondouin et al., 2024)	Regulatory frameworks	Understanding existing policies and regulations affecting bioeconomy stakeholders, such as biofuel mandates, biomass extraction, labour laws, taxes and fines
	Policy advocacy	Engaging stakeholders in the process of influencing policy development to align with bioeconomic goals and promote sustainable practices
Equity and Social Justice (Fedorova et al., 2019); (Branca et al., 2016)	Access to resources	Addressing disparities in access to land, technology, and funding among different stakeholder groups involved in the bioeconomy
	Inclusive decision-making	Ensuring that marginalized and underrepresented groups have a voice in governance and decision-making processes within bioeconomy initiatives
	Benefit distribution	Analyzing how benefits derived from bioeconomy initiatives (e.g., jobs, profits) are shared among different stakeholders to promote fairness and equity
	Awareness raising	Educating stakeholders about social justice issues within the bioeconomy to foster understanding of the impacts on various communities
	Conflict resolution	Developing mechanisms to address and resolve conflicts among stakeholders, ensuring collaborative relationships in the bioeconomy sector

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Some research gaps can be identified within the stakeholder theory literature focusing on the bioeconomy. Existing scholarly work has not focused on shifts in power dynamics amidst stakeholders due to scale up of bioeconomy projects. Conversely, it has also not been studied how stakeholder power dynamics affect bioeconomy interactions and outcomes. Stakeholders' involvement in adaptive management, such as responding to sudden environmental, political and social changes, has also not been highlighted in the literature.

2.3. Value chain mapping and analysis of LLab #1: ALC Bio-Hub

2.3.1. Interviewees

1. Eugenia Requena (Operations Director, ALC Bioproductors)
2. Sami Ritmi (now former R&D Director, ALC Bioproductors)
3. Jordi Jove Areste (CEO, ALC Bioproductors)
4. Miquel Serra (Farmer, entrepreneur, former Major of Alcarras, Board member of ALC Bioproductors)
5. German Ibars (Farmer, Board member of ALC Bioproductors Compost)
6. Ricard Godia (Farmer, Board member of ALC Bioproductors)
7. Carlos Ribot (Farmer, President of the Cow Producers' Association, Board member of ALC Bioproductors)
8. Sergi Gilart (Farmer, Board member of ALC Bioproductors)
9. Robert Ibars (Farmer, Board member of ALC Bioproductors)

2.3.2. About Alcarras Bioproductors (ALC)

Alcarras Bioproductors SAT (ALC) is a company created in 2022 by the aggregated investment of 150 family businesses from the village of Alcarras. It is located in a rural area in Alcarras in the province of Lleida, Spain. ALC Bioproductors is driven by farmers (that own farms of pigs) and ranchers (that own farms of cows). The main business of ALC Bioproductors is a composting plant that is supplied by the dejection of cattle, pig slurry and cow manure. The feedstocks are collected weekly by trucks from the supply farms at Alcarras. The main commercialized products are three different types of fertilizers, with one of them being a certified biofertilizer. In 2024, ALC is expanding its activity by installing a new biogas plant with two anaerobic digesters that will be supplied by the same shareholders and suppliers, the farmers and ranchers of Alcarras. The main end products that they aim to commercialize are thermal energy and bio-methane, with two options: Compressed Natural Gas (CNG) and Liquid Natual Gas (LNG). ALC Bioproductors' Living Lab is an ongoing business that is expanding and testing new products and the value chain. The composting products are already in the market, and the biogas value chain aims for a **TRL 3-5** as part of the PRIMED project.

2.3.3. About Alcarras Bioproductors' value chains

The project started twenty years ago when 150 families of farmers and ranchers from Alcarras created a joint venture integrated by two main associations: ADS (Association of defense of porcine of Alcarràs and Torres de Segre) and ARD (Association of farmers of bovine). The main purpose of the joint venture was to buy some rural land where ALC BIoproductors' facilities could be located. They succeeded in investing in the property and this is where the compost and biogas plants are located now. The main goal of the farmers and ranchers of Alcarras was to solve a collective problem: the management of the dejections of the cattle. Pig slurry and cow manure pollute the land and groundwaters. The EU, national and regional governments have increasingly encouraged the farmers and ranchers to manage their waste: it is now mandatory by law for the farmers to manage their compost and avoid pollution.

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In 2022, they finally built a composting plant to solve the cattle dejections' challenge. The two associations as well as the farmers and ranchers own the property via the joint venture and they are also the main shareholders and the core suppliers of ALC Bioproductors.

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 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.

ALC Bioproductors has **one main value chain, divided into two sub-businesses: composting and biogas production**. The value chain includes all the stages from the raw materials and feedstocks to the final products and services going into markets. The key aspects of this value chain are described below:

- **Shareholders and supply of animal dejection feedstocks as raw materials:** ALC Bioproductors Compost and ALC Bioproductors Biogas have been launched and are owned by farmers and ranchers who supply feedstocks and cattle dejections that come from Alcarras farms. In total, 150 families owned the land, 71 farmers invested in and supply to the composting plant, and 41 farmers invested and supply to the biogas plant.
- **Procurement of organic feedstocks and other services:** ALC Bioproductors have established partnerships with other suppliers of vegetal feedstock, such as municipalities, gardening associations, fruit companies and agricultural companies that provide vegetal organic feedstock and organic waste to combine with dejections and produce compost and biogas.
- **Partnerships for R&D and business development:** They also have partnerships with renewable energy companies, water supply, and technology providers for equipment provision in each plant.
- **Compost generation:** The solid dejection feedstocks from pig slurry and cow manure are received weekly by trucks from 71 Alcarras farms and are processed and treated to create compost. The process includes different stages beginning at the procurement and validation of the feedstock, leading up to the separation of the dejections in the process to produce different types of fertilizers.
- **Biogas generation:** The liquid dejection feedstocks from cow manure and pig slurry are received daily by truck from 41 Alcarras farms and will be processed and treated at two anaerobic digestors to generate thermal energy and biogas that will be converted in bio-methane.
- **Biogas transformation:** They need to convert biogas into thermal electricity, heat, bio-methane, CNG and/or LNG. The generated energy will be managed and utilised for various purposes.
- **End-products:** Both businesses have developed and explored different products and services. ALC Bioproductors Compost has developed three new products: an organic porcine fertilizer, a porcine fertilizer and a bovine-porcine fertilizer. ALC Bioproductors Biogas will explore the development of products like bio-methane and thermal energy.
- **Regulatory Compliance:** ALC Bioproductors ensures compliance with local, regional, national and EU regulations related to compost production, waste management, and biogas generation.
- **Community Engagement:** ALC Bioproductors is the main actor engaging with the local community through initiatives, educational programs and events that promote sustainable farming practices and environmental responsibility. They work together with the local administration to ensure the acceptance of the population, which is of vital importance in these projects.
- **Bioeconomy network development:** ALC Bioproductors have a collaboration with the local municipality of Alcarras, the Diputacio of Lleida and the Hub de Bioeconomy of Catalonia [BioHubCat] of Generalitat of Catalonia, as it is a reference project. ALC Bioproductors' initiative has been funded by EU's

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Territorial Specialization and Competitiveness Project (PECT) GREEN & CIRCULAR PONENT. They are also partners in EU (such as PRIMED) and national projects, working with research and development partners.

2.3.4. Key processes and value chain actors

ALC Bioproductors has created a series of business units. The first one is already in operation at the ALC Bioproductors Compost plant; the second ALC Bioproductors Biogas plant is still in the development phase. In addition, ALC Bioproductors also have another future vision which could at some point develop into a business at some future point.

ALC Bioproductors bio-composting plant

The first business is the composting plant launched on 2nd June 2022. The owners/shareholders are 71 farmers and ranchers (from the original 150 families) that privately invested €1,500,000 in the plant, since they could not get public or other private investment. Each farmer invested keeping in mind the quantity of feedstock they expected to bring for composting annually. Originally, farmers invested 54€/tonne of feedstock. 8-10 farmers were selected for the governing body, the work of which has a volunteering model. To run the business, a management team has been created, consisting of a CEO (member of the governing body and farmer) and supported by an R&D manager, operations manager and several operators of the plant.

ALC Bioproductors Compost receives feedstock (animal waste) from cow manure (85% solid fraction) and pig slurry (10% solid fraction) to generate compost. In 2021, the 71 farmers planned for a capacity of 27,000 tonnes/year. The procurement amount of Cow manure (solid fraction) is 22,5000 tonnes/year (procured from 30-35 farmers) and the amount of pig slurry is less than 4,500 tonnes/year (procured from 10-15 families). Further, to improve the composting process, they have also include 2000 tonnes/year of vegetal residues (from local fruit tree pruning), mainly to avoid the compost compaction.

ALC Bioproductors' composting process follows the aerobic method of decomposing organic solid cattle dejections, cow manure and pig slurry waste from Alcarras' farms. Aerobic biological decomposition requires oxygen for the biological decomposition of organic materials by microorganisms. ALC Bioproducts' composting includes organic (carbon-based) vegetal waste materials in the mixture to prepare the compost pile during the composting process. Microorganisms use carbon and nitrogen to grow and reproduce, water to digest the materials and oxygen to breathe. They also adopt an aeration process which aids the decomposition process by providing oxygen that microorganisms need to breathe. ALC selected a design, technologies and trenches for the plant that include a system of humidification and aeration, which allow for controlling of each pile's temperature. The aeration design and technology allow the decomposition of organic material into a humus-like material to run quicker and have better safety measures. They also ensure that the compost is of premium quality.

The plant has a scale large enough to measure the incoming dejections, a warehouse for collecting the dejections and preparing them to be trenched, seven large open-air composting trenches and a final open-air treatment area. They gather rainwater fo

usage in the composting processes in the trenches, alongside piped water.

The wastewater from the trenches that contain leachates is reused for the mixture for the new pile preparation. Since this wastewater is polluted with coli, they use it in the first stage of pretreatment itself.

The key processes of the ALC composting plant are described below:

- Planning of a new pile, for which they need 30 trucks per week.

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- Organization and planning with farmers to collect the dejection from each farm with external trucks. They collect the dejection from farmers without any cost to the farmers.
- Once the dejections have been procured, they test them and prepare them for the composting process.
- They separate the piles with solid fraction from cow manure and pig slurry to produce three types of fertilizers.
- They mix the dejections with organic feedstock to prepare the mixture of a new pile with water humidification and aeration.
- Decomposing process (first stage): Each pile is put on the trench for four weeks.
- Decomposing process (second stage): Each pile is put on the next trench for six weeks for aerobic biological decomposition and aeration.
- Every 3 months, they do lab tests at the plant for Ph-levels, maturity, conductivity, NPK-levels (Nitrogen, Phosphorus and Potassium) and heavy metals. They do external microbiology lab tests of for each pile to check that there are no bacteria. If the results are positive, they start the process again.
- When the pile on the trench is ready, they move it for the preparation of the final product.
- They make a cribbage by filtering each pile to separate large vegetable scraps and the waste matter. The vegetable waste is reused in new piles and thus, there is no waste matter that is not used. They include small pieces of straw or wood to make the compost: the final compost comprises of oxygen, carbon and other structures.

End products and markets

The compost plant produces three types of end-products: ecological fertilizer from bovine, fertilizer for bovine and fertilizer from bovine/porcine, all of which are of premium quality. The brand of the fertilisers is named as ALC Bioproductors. they already hold several product certificates at both national and European level. They sell fertilizers directly from the facility to the local farmers and businesses. Some other customers include private users in the region. ALC Bioproductors also have a distributor who recommends the product and sells it to farmer networks. They do not have a consolidated marketing strategy or a webpage, but they use Instagram and their own personal networks to reach out to new end-users.

They plan to improve the end-products by making them rich with organic minerals, pelletizing and organic substrate. They also want to improve the quality of the fertilizers by including gallinacean in the vegetable feedstock.

Growing of the composting capacity

At the beginning of 2023, the compost plant was only processing 18,000 tonnes/year, which was below its full capacity. The farmers had the ambition of reaching 27,000 tonnes/year by the end of 2024, yet they were already operating at an estimated 30,000 tonnes/year (April 2024). Currently, their main goal is to increase the capacity of the plant and to improve the quality of the fertilizers, the efficiency of the process and of the technology as well as the health and safety measures. Finally, they are exploring the possibility of generating a new product, i.e. biochar.

In 2024, they have planned to expand production, doubling the capacity to 56,000 tonnes/year. After receiving the permission of the joint venture (comprising of two associations), they have opened a new investment process calling for new shareholders and suppliers of the plant. Originally, they opened the call to the 150 farmer families in Alcarras but since that was not sufficient, they have called for new farmers from surrounding villages and towns in Lleida region. There are two possibilities to join the ALC Bioproductors Compost: (1) as shareholders, and/or (2) as suppliers/users of the plant.

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ALC Bioproductors Biogas plant

In 2024, ALC Bioproductors SAT started the second business, expanding its activities by installing two anaerobic digesters (with a volume of approximately 5600 m3 each) in two phases. The first one will be constructed in 2024-25, and the second in 2026. The main goal is to use the liquid part of the cattle dejections that were not used by the compost. The goal is to generate new end-products: thermal electricity in the first phase and bio-methane (CNG or LNG) in the second phase. The biogas plant is being constructed besides the composting plant and will supply electricity to the compost process. It covers an area of 60,000 m2.

ALC Bioproductors Biogas has a new set of shareholders: 41 farmers from the original 150 families. They have invested €3,000,000 in 2024. The investment for the second phase in 2026 is estimated to be at €2,000,000. In this second business, ALC Bioproductors Biogas has a credit from private bank and a public financing institution (Institut Catala de Finances). ALC Bioproductors Biogas has a new governing body of 8-10 members selected from the 41 farmers shareholders.

The anaerobic digestion will generate biogas and a digestate. The latter will undergo a separation process to recover the solid fraction (10-15% of the original biomass) that will be transferred to the composting plant. The liquid fraction will be collected in a pool and can be used in agricultural processes after getting the required certifications, including complying with the relevant European norms. The biogas from the anaerobic digestion will be upgraded to generate bio-methane. To commercialize bio-methane, two strategies are possible: by processing and selling it as Compressed Natural Gas (CNG) or as Liquid Natural Gas (LNG).

The 41 farmers of ALC Bioproductors Biogas will supply 74,000 tonnes/year of liquid dejections. The treatment capacity of the first digestor will reach 74,000 tonnes/year. Distributed in 12,000 tonnes/year for cow manure and 62,000 tonnes/year of pig slurry. Both dejections will be mixed to ensure homogeneity. The mixture would be combined with 10,000 tonnes/year of vegetal streams procured from the region, comprised of pruning residues, vegetable biomass and garden/park waste. Given its large quantity, this stream must be pre-treated (sorting/removal, milling/cutting) before processing. During this first part, the feedstock mixture (manure, slurry, vegetal biomass) will be optimised to get maximal biogas production.

Table 6 gives the volumes of biogas that will be produced by the first ALC Biogas digester (corresponding to about 734000 m3 bio-methane). In addition, about 75,000 tonnes of bio-fertiliser will be generated.

Table 6: *Biogas generation from ALC feedstocks*

Digester alimentation	tonnes/year (t/y)	t/day	m3 biogas/t	m3 biogas/y
Cow manure	12000	33	60	700000
Pork slurry	62000	173	8	500000
TOTAL	74000	206	68	1220000

The final products will be thermal energy (electricity). Part of this electricity will be used for self-consumption at the composting plant and the rest will be sold to the grid. They will also produce ammonic sulphate, a by-product of reducing water nutrients from the denitrified liquid pig slurry fraction.

In the second phase of the biogas plant, the second digester will be built starting from 2025, and the biomass feedstock will be increased in amount and diversity. The second digestor will comprise an area of 100,000 m2 (extended from 40,000 m2). The goal is to upgrade the biogas and scale up the business to bio-methane gas. They aim for 400m3 of brut bio-methane gas that can be sold to the grid. However, the grid is located at a distance of 8-9 km from the biogas plant. As it is too expensive to build the gas pipe, they would need a truck(s) to transport

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the bio-methane to the grid. An alternative would be to supply bio-methane to fuel stations that are located nearby. Negotiations with biogas companies are ongoing for this arrangement.

They have also considered exploring other products, such as biomethane that can be used in beverages or slaughterhouses.

The following figure 22 shows the local region from where the feedstocks are sourced for the ALC Bioproductors Compost and Biogas plants:

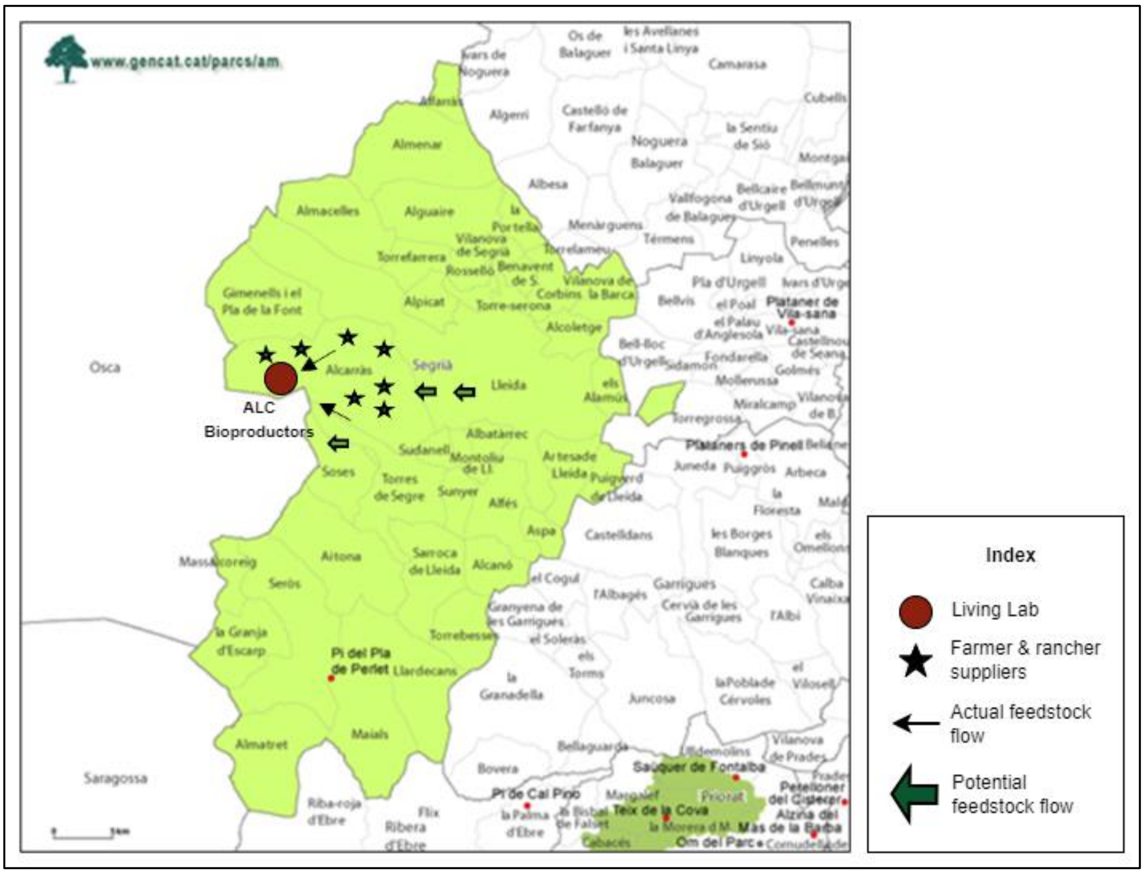

Figure 22: *Location of the ALC Bioproductors and their suppliers*

Closing the loop of waste valorisation and utilisation between the composting and biogas processes

The main goal here is to set up the reuse of waste between the two plants. These are the main processes by which ALC Bioproductors envision doing the same:

- The residual solids and liquids created in biogas production are known as digestate. This digestate goes into a post-digestion reactor and then into storage tanks. ALC Bioproductors will use this digestate as an input in the composting process. Digestates are well suited for uses such as the fertilization of fields, which could be a prospective source of revenue.
- The ammonic sulfate generated by the biogas plant will be used to improve the quality of the compost with organic mineral.
- The thermal electricity generated by the biogas plant will be used for the composting plant.

Both the value chains of ALC Bio-Hub can be visualized in the following figure 23:

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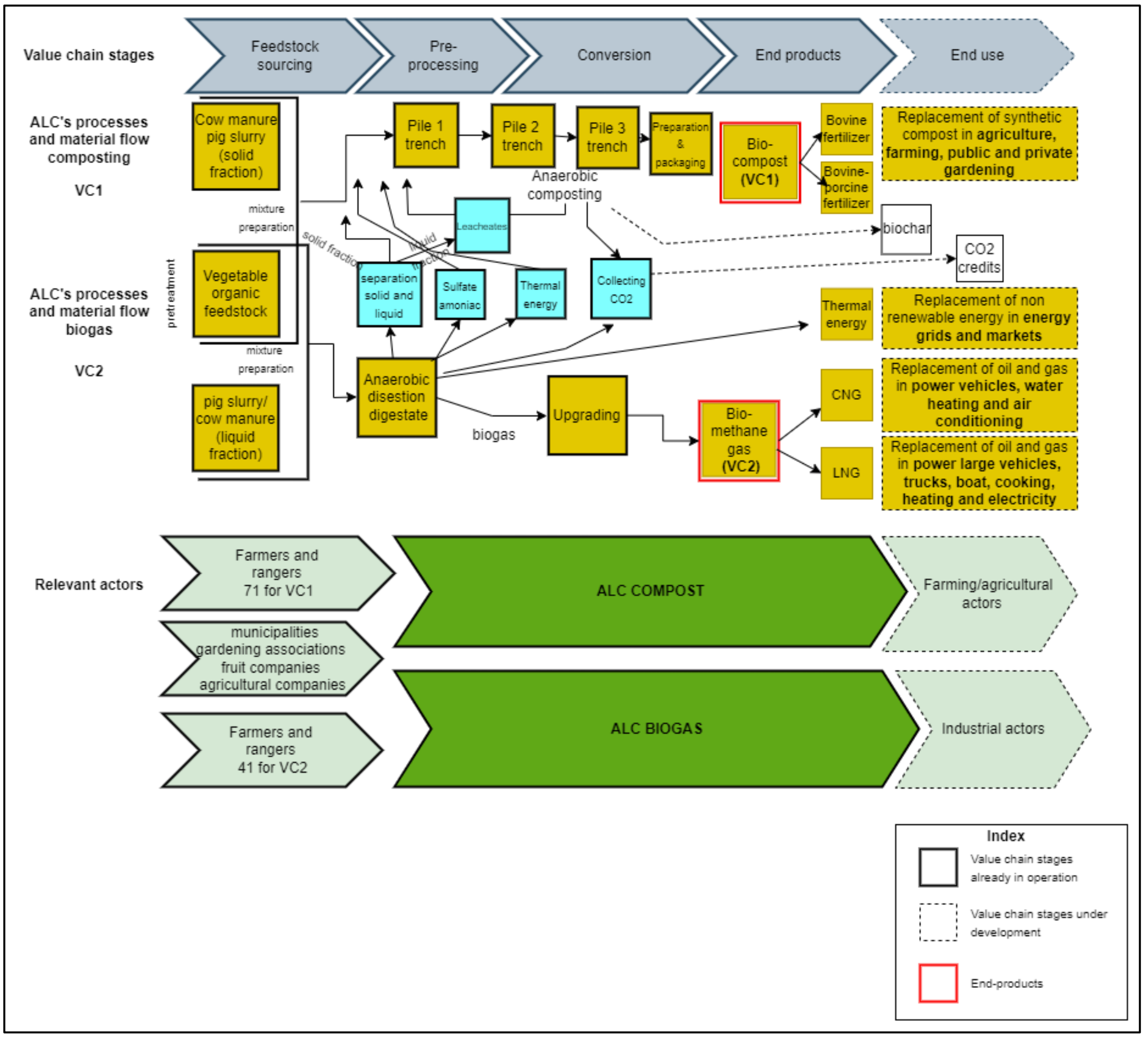

Figure 23: *Bioeconomy map of ALC Bioproductors: value chain stages, actors and flows*

The vision of BioHub Alcarras

ALC Bioproductors has planned to build a bioeconomy hub in the property, following the model of bioeconomy hubs in the Netherlands (e.g., the one located in TU Delft). ALC Bioproductors own 30 hectares and plan to rent more land. Their goal is to call for bio-based companies to assemble in BioHub Alcarras and create an industrial bioeconomy hub. They have contacted universities, such as the University of Lleida and have also started to consolidate agreements with international bioeconomy companies.

Governance within ALC Bioproductors

The governance of ALC Bioproductors is complex because the region comprises of 150 farmers, who are members of two farmers associations. The land is owned by the joint venture of the two associations: ADS (Association of defense of porcine) and ARD (Association of farmers of bovine). The venture of both the associations has the right to decide about the usage of the land and any future constructions on it. This joint venture has a senior board of directors that are selected by the members of each association. The board comprises of five members from each association. The board follows a volunteering model.

When ALC Bioproductors Compost was created, only 71 farmers and ranchers agreed to be shareholders and suppliers of the business. They have the right to send the dejections and get benefits from the composting plant.

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A similar process has been adopted with the ALC Bioproductors Biogas plant. They had opened the investment to 150 families: finally, 41 farmers and ranchers of the associations became shareholders and suppliers. They have the right to send the dejections to the new biogas plant and get benefits from the biogas plant in the future.

Regarding the governance, shareholders of both the compost and biogas plants have the right to participate in the decision-making processes through the annual meetings of shareholders. The compost plant has a general assembly of 71 farmers and ranchers and have voted and selected a governing board for ALC Bioproductors Compost which includes 8-10 shareholders. This governing board, which runs on an volunteering basis, meets weekly to make executive decisions. One of them acts as the CEO. Their management team includes the CEO, R&D Manager, Operations Manager, two operators of the compost plant and one administrative secretary. Accounting services are carried out by an external accounting company.

With the new biogas plant, the 41 farmers and ranchers have become shareholders and have the right to participate in decision-making processes though the annual meeting of shareholders. They have selected a governing board for ALC Bioproductors Biogas which includes 8-10 shareholders that meet weekly and make executive decisions on a volunteering basis. The CEO and the management team are the same for both the business units. When the biogas plant will be fully functional, there is scope for the management team to grow depending on the new knowledge and roles needed.

2.3.5. Key strengths

- **Cooperative ownership model:** The main strength of ALC Bioproductors is the cooperation of the 150 farming families in Alcarras, and mainly the leadership of the core governing teams built by 10-20 farmers, who work voluntarily to build the SAT and its future vision. Originally, the compost plant was not designed as a business but as a solution for the waste problem that the farmers and ranchers were facing.
- ALC Bioproductors has managed to make the the farmers and ranchers cooperate towards a common business, showing them that their investment is useful to solve the dejection problem and to run a successful entreprise. They got the members' investment as well as some external funding for the new biogas plant. They have been able to procure the relevant technology and designs for both the plants and sell the compost products in the markets. Currently, they are working on expanding the scope of the Lab to also focus on BioHub Alcarras.
- **Public support and recognition:** They have received the support of public government bodies such as Alcarras City Council, Diputacio of Lleida and the Catalan Bioeconomy Strategy 2030. In doing so, ALC Bioproductors has become a benchmark bioeconomy project in Catalonia and Spain.

2.3.6. Key challenges

- **Lack of business capabilities:** The project is driven by 150 farmers and ranchers from Alcarras who set out to solve a waste problem, not to find a business opportunity. With the support of the municipality of Alcarras and Diputacio de Lleida, they have received training and have visited international bioeconomy centres, such as ones in the Netherlands and Ireland. They have also used their network to select the requisite technologies, plant designs and to sell the products. They have participated in national and EU projects. Yet, it is important for ALC Bioproductors to be able to deepen their business knowledge through relevant training to extend their value chains and build robust circular business models for bioeconomy. By doing so, they can expand their markets and distribute their products beyond their local region, which is crucial to sustain and grow their business.
- **Cooperative ownership model:** The land and the business are owned jointly by a diversity of farmer and ranchers. This is a collective project that depends on a network of farmers and ranchers that have conflicts of interests and different approaches towards the future. The governing bodies of each business

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are the most active entrepreneurs and leaders amongst these farmers and ranchers and have been able to convince and bring together all the other farmers and ranchers. However, there are still important future visions for which alignment is needed: the growing of the markets, the competitiveness of each business and the project of BioHub Alcarras. Currently the ownership and executive structure is complex and requires the alignment at various levels of decision-making. These levels include the joint venture (two associations with 150 families managing the property of the land) and the governing bodies of each business with different shareholders. There is a possibility that conflicts emerge in this setting.

- **Competitiveness in growing markets:** The third challenge is about the capabilities of ALC Bioproductors to compete, sustain and grow in the complex environment of growing bioeconomy business models and value chains. The composting plant has a limited capacity, which limits the scope of the value chain to expand to new suppliers across the regions or beyond. Bioeconomy business models have become complex and require advanced levels of technology and knowledge about business and technology. This requires a professionalization of operations and processes that ALC Bioproductors has started adopting.

2.3.7. Key risks and possible mitigation measures

- **Limitations of feedstock supply:** The main risk is the limited supply of new dejections for the composting plant to work at its full capacity. ALC Bioproductors are searching to expand beyond original farmers and ranchers to new owners and users in the region. The process is not easy as it requires new farmers to join the project in different conditions than was the case with the original shareholders. ALC Bioproductors have tried to mitigate the risk of limited supply by adopting clear rules about the shareholders and users of the plant and propagating this amidst other potential farmer and rancher stakeholders.
- **Competition and markets:** Another main risk is sustaining the competitiveness in the markets of ALC Bioproductors and generating a marketing strategy, with a strong brand presence to extend to new markets and customers nationally and even internationally. It is important to improve the quality of products, get relevant certifications, set up distribution channels, and tap into new markets. Networking among competitors is important to create the right, non-aggressive development environment
- **Growth of the management team:** A key risk is the growing and professionalization of the management team that would be required with the growth of the compost and biogas plants, ensuring that both businesses are sustained successfully. The mitigation measure adopted by ALC Bioproductors is having set up different governing bodies for both the business units, so that the decision-making processes can be carried out separately for each, despite any possible disruption in one of them.
- **Water supply and climate change:** Climate change impacts and extreme weather events have increased in the Mediterranean area over the years. Because of this, Alcarras is often affected by drought. Such crises can disrupt the operations of the plant. However, ALC Bioproductors plan to regenerate water as a by-product in their plants (having 15% nitrogen, phosphor and potassium contents). This will not just enable the businesses to be resilient during times of crisis, but also or them to bring the water to neighbourhood farmers in such situations.
- **Future vision of BioHub Alcarras:** Conceiving BioHub Alcarras would turn out to be an ambitious project since it includes developing a complex interconnected bioeconomy hub in Alcarras. This would require buying/renting new land, procuring investment, contacting international corporations and startups. A number of roadblocks might come along the way and to ensure its smooth conception and implementation, it is important to design a startegic plan with a roadmap.

2.3.8. Summary table

The following table summarises the key aspects of both the value chains of Alcarras Bioproductors:

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Table 7: Key value chain aspects of Alcarras Bioproductors

	Feedstock sourcing	Pre-processing	Conversion	End use
Inputs	Cow manure and pig slurry solid waste **(VC1);** Pig slurry and cow manure liquid waste **(VC2)**	Sorted and cut feedstock mixture waste Cow manure, pig slurry solid waste and vegetable feedstocks **(VC1);** Pig slurry and cow manure liquid waste and vegetable feedstocks **(VC2)**	Composting mixture **(VC1);** Biogas mixture **(VC2)**	Fertilisers and potentially biochar **(VC1);** Biomethane, electricity and ammonic sulphate **(VC2)**
Activities	Farmer governance; Collection and supply of waste	Sorting/removal; Miling/Cutting	Aerobic composting **(VC1);** Anaerobic digestion of feedstock mixture waste **(VC2)**	Farmer usage of fertilisers in their farmland **(VC1);** Potential energy usage by other entities and selling carbon credits under EU ETS **(VC2)**
Actors	71 farmer and rancher families (ALC Bioproductors Compost) **(VC1);** 41 farmer and rancher families (ALC Bioproductors Biogas) **(VC2)**	ALC Bioproductors Compost **(VC1);** ALC Bioproductors Biogas **(VC2)**	ALC Bioproductors Compost **(VC1);** ALC Bioproductors Biogas **(VC2)**	Farmers and private users in the Lleida region **(VC1);** Potentially the electricity and gas grid, fuel stations and companies **(VC2)**
Challenges & risks	Cooperative ownership of land: requires convincing farmers and resolution of conflicts		Cooperative ownership of land: requires convincing farmers and resolution of conflicts	Lack of business capabilities of farmers; Fertilisers are not very competitive locally
Potential solutions			Possibility to regenerate water from animal waste in their plants	Usage of farmer networks to sell their products

2.4. Value chain mapping and analysis of LLab #2: Bio-Silica Lab, CeNTI

2.4.1. Interviewees

- Mariana Ornelas (Team Leader - Nanotechnology, Functional Materials, CeNTI)
- Filipa Gomes (Researcher, Expert on waste recycling and valorization, sustainable process development, new material synthesis, CeNTI)

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- Andreia Monteiro (International Management Officer, CeNTI)

2.4.2. About CeNTI

CeNTI - Centre for Nanotechnology and Advanced Materials, is a private, non-profit, recognized Centre for Technology and Innovation, with multi-sectoral and multidisciplinary orientation, located in the North of Portugal (Vila Nova de Famalicão, Braga). Founded in 2006, CeNTI's mission is to support and boost industrial and business technological infrastructure both nationally and internationally, with a focus on Sustainability, Bioeconomy, Decarbonisation, Performance and Technological Innovation, and the Digital Transformation of Materials and Processes.

CeNTI develops and promotes applied R&D activities for industrial endogenization, product engineering, and technology transfer of disruptive technologies in the fields of Nanotechnology, Advanced Materials and Smart Systems for the business ecosystem.

2.4.3. About Bio-Silica Lab and its value chains

The Bio-Silica Lab, one of the Living Labs focused on the PRIMED project, is one out of the many research focus areas of CeNTI. This Lab is currently working on two main value chains:

The Lab is researching the processes involved in producing silica particles from the digestion of bio-based feedstocks like rice husk. The end product, bio-silica, could replace synthetic silica in a wide range of industries, including those in the automotive, construction and textile sectors. The bio-silica production process is currently at a preparedness level of TRL 6-7.
The Lab is also looking into producing modified bio-silica with different functionalities, e.g. flame retardant, antimicrobial and/or hydrophobic properties. The modified bio-silica can be used in various industries, such as those related to coatings, polymers and fibers in the automotive, construction and textile sectors. Although this modified bio-silica is also being produced at a TRL 6-7, further functional properties are also being explored and developed at a TRL 2-3.

Bio-silica extracted from agroindustrial waste offers several advantages over silica obtained through common methods, such as:

- Bio-silica is obtained from agroindustrial waste, making it a renewable and eco-friendly resource, which contrasts with significant amounts of CO2 released in traditional methods for the production of silica (for example, mining from quartz);
- The extraction of silica from rice husks typically requires less energy compared to the high-temperature melting of quartz sand used in conventional methods
- Agroindustrial byproducts are a low-cost alternative to conventional silica sources
- The traditional methods to produce silica imply the use of hazardous chemicals harmful to the environment, such as CTAB, or costly techniques (by the use of TEOS, specifically)

CeNTI's Living Lab focuses on the recovery of silica from agroindustrial residues and its further modification, targeting different functional properties such as hyrophobicity, flame retardancy and/or antimicrobial activity. The Bio-Silica Lab offers the opportunity to test the amount of silica available in different raw materials (specifically agroindustrial residues/byproducts) and it also allows potential end-users the opportunity to test the incorporation of bio-silica particles in their processes and/or products (whether by producing pre-series for validation assessment on relevant industries, or by developing prototypes for performance evaluation and characterization of relevant properties).

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2.4.4. Key processes and value chain actors

Among the various bio-based feedstocks tested, rice husk provided the highest bio-silica yield (10%, i.e. 10 kilograms of rice husk yields a kilogram of bio-silica). Although CeNTI continues to search for other silica-rich residues, rice husk is currently the key feedstock that the Bio-Silica Lab is focusing its research on and this is where the Bio-Silica Lab's processes start from.

- **Rice husk procurement:** The Bio-Silica Lab has sourced the feedstock from two different suppliers that are located in Central Portugal: Supplier 1, a rice farmer association located in Alcácer do Sal and Supplier 2, a food production company based out of Coruche. Both suppliers have the required equipment to peel the husk from the rice grain and thus, are the collection point for the farmers or the rice farmer associations to send their produce. The Bio-Silica Lab has only required small quantities of this rice husk for its research purposes and thus, this sourcing does not disrupt the traditional usage of rice husk in the local communities, e.g. animal bedding and bioenergy production (as rice husk can be used as fuel for biomass boilers). Last year, the Lab sourced approximately 50 kg of rice husk for their research purposes and the procurement quantity for this year is estimated to be close to 100 kg. The following figure 24 shows the rice husk flow related to CeNTI's processes on the Portuguese map:

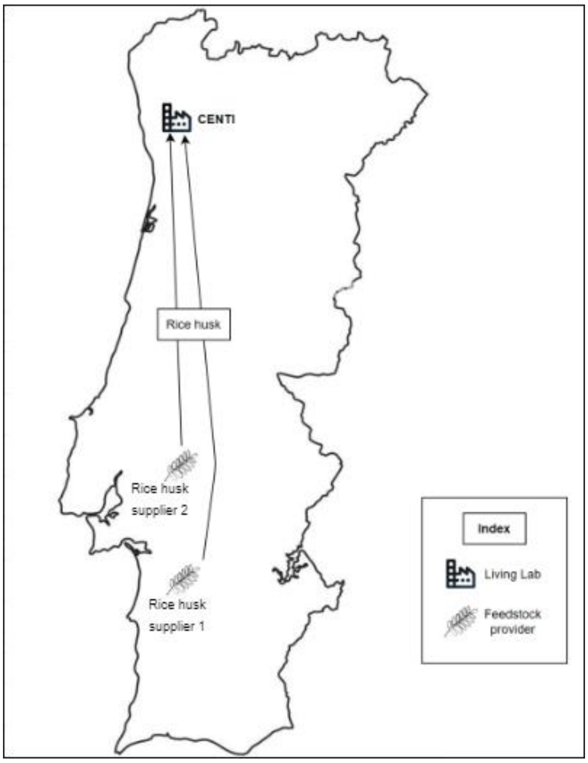

Figure 24: *Supply of rice husk feedstock for Bio-Silica Lab in Portugal*

- **Rice husk conversion to bio-silica:** After procuring the rice husk, the Bio-Silica Lab researchers commence the conversion process firstly by burning the rice husk and then digesting the resulting ash in an alkaline medium. The silica in the resulting mix is then precipitated and finally washed and recovered.

- **Bio-silica's potential applications:** At this point, this bio-silica is ready to be tested in various industrial processes and if needed, the Living Lab could take on an advisory/consultancy role with the industrial actors to help them make the application of this material viable. The end goal would be to integrate this material into the relevant processes of industrial actors.

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The value chains of the Bio-Silica Lab can be visualized in the following figure 25:

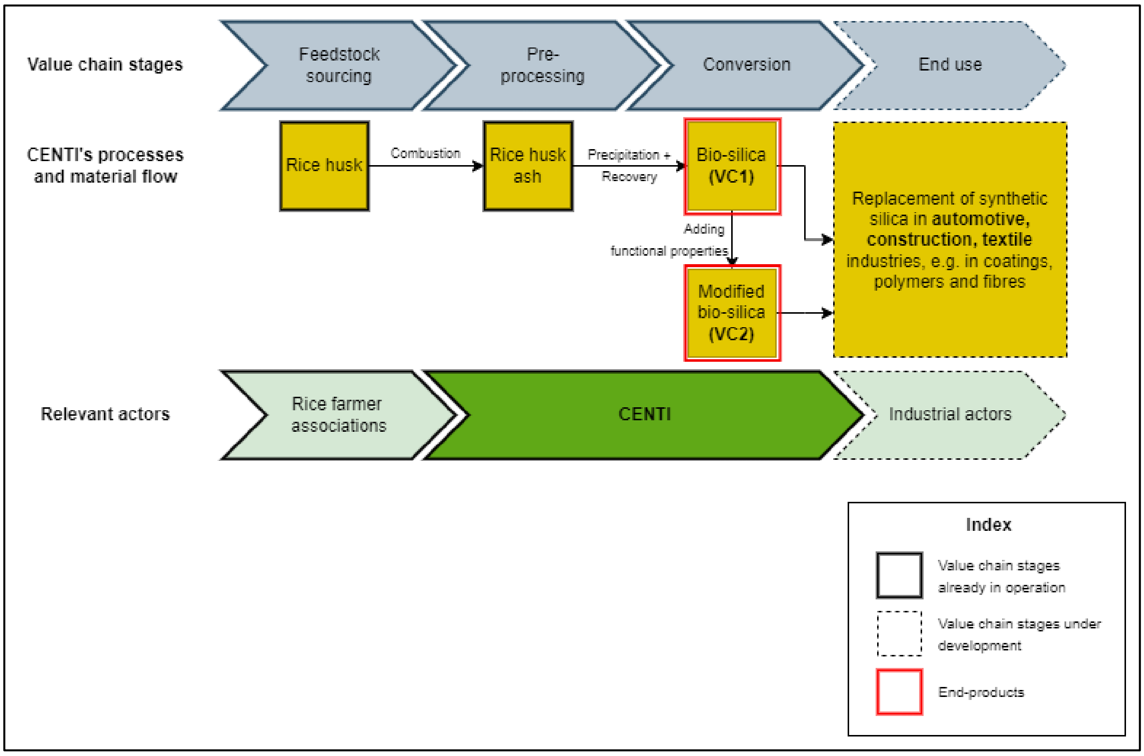

***Figure 25:** Bioeconomy map of the Bio-Silica Lab: value chain stages, actors and flows*

2.4.5. Key strengths

- **Scientific flexibility for experimentation:** The Bio-Silica Lab identifies its biggest strength as the flexibility of its facilities to easily test the extraction of silica materials from different agro-industrial waste streams. This could help them diversify by sourcing and experimenting with a variety of feedstocks, leading them to not be dependent on merely a single feedstock like rice husk.

- **Diversified chemical properties of modified bio-silica:** The Lab also has capabilities to research on/develop different functional properties of bio-silica. This means that, in addition to flame retardancy, antimicrobial, and hydrophobic properties, the Bio-silica Lab can also impart other properties to bio-silica, such as anti-fingerprint and UV resistance, among others.

- **Research on industrial application:** The Bio-Silica Lab has been working to make sure that its material can be incorporated into manufacturing processes of a range of different industries (like automotive, construction, textiles, furniture and bedding, among others), which is crucial for bio-silica to be as competitive as synthetic silica.

2.4.6. Key challenges

- **Rice husk burning difficulties:** The main challenge that the Bio-Silica Lab researchers identified is related to the burning of the rice husk. Due to the oven capacity, this step currently takes a long time and thus, significantly delays the entire process. To reduce the duration of this process, the Lab is trying to find companies or associations that produce and/or sell rice husk ash. Unfortunately, up to this moment,

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they could not find any relevant actors nearby: even though they found several such actors in Asia, the logistics cost of transporting the ash over such a long distance was not deemed to be financially optimal. The Lab is now looking for companies within Portugal who have biomass boilers (not exclusively for rice husk) and would be able to supply ashes to the Lab for them to check for the silica content in these. The Lab has managed to find two such companies: one has already provided them with some ash for testing while the other is exploring the possibility and timeline for making their currently non-operational boiler operational again.

- **Industrial integration of bio-silica:** Another challenge was regarding integration of the particles drying process at industrial scale. The researchers mentioned that even if they find industrial partners to test this process with, the latter may be worried about carrying out the particle drying process in their large industrial ovens due to potential contamination with the particles. Indeed, if silica particles are not an additive/raw-material already used in the industrial partner processes or product fabrication, the manufacturing facilities may be cautious of taking on unanticipated contamination risks.

- **Low yield rate of bio-silica recovery:** Finally, the researchers identified the low yield rate of bio-silica recovery as a challenge. Rice husk itself has a silica component of only 9-15% and thus, the majority of it is already recovered in the process. This concern may become more salient when an industrial actor would want to use bio-silica at industrial scale and may find it difficult to manage procurement and logistical considerations related to large quantities of rice husk.

2.4.7. Key risks and possible mitigation measures

- **Industrial application uncertainty:** Since industrial application of the bio-silica particles has not yet been validated, there is significant uncertainty around possible incompatibilities with industrial processes, e.g. difficulty in dispersing the laboratory-made bio-silica particles into industrial applications. The Bio-Silica Lab researchers believe that seeking support from CeNTI's pool of experts, who are knowledgeable about a range of processes across industries (e.g. biomaterials, nanotechnology, functional surfaces and circular processes), would be key in mitigating this risk of industrial incompatibility since they can provide additional support to potential end-users to ensure smooth integration while also providing further insight to the Bio-Silica Lab's researchers in improving their bio-silica production processes.

- **Industrial scaling of processes:** Further, the Lab researchers anticipate risks in scaling the bio-silica production process itself. The centrifugation and functionalisation steps take a lot of time to be executed due to limited centrifugation capacity and the requirement of low temperatures for the drying respectively (increasing the drying time). The researchers state that at the laboratory scale, these do not present much of a problem but these concerns could magnify into risks at larger industrial scales where the production time could be a major drawback for the bio-silica production. Moreover, locating specialized equipment capable of processing nanoparticles at an industrial scale can be quite challenging.

2.4.8. Summary table

The following table 8 summarises the key aspects of both the value chains of the Bio-Silica Lab:

Table 8: Key value chain aspects of CeNTI's Bio-Silica Lab

	Feedstock sourcing	Pre-processing	Conversion	End use
Inputs	Rice husk	Rice husk	Digested rice husk ash	Bio-silica **(VC1);** Modified bio-silica **(VC2)**
Activities	Procurement of rice husk from rice farmer associations or equivalent	Burning of rice husk; Digestion of rice husk ash in chemical medium	Precipitation and recovery of silica	Manufacturing component (e.g. can be used as additive)
Actors	Rice farmer associations	Bio-Silica Lab	Bio-Silica Lab	Industries like textile, automotive, construction **(VC1)** and **(VC2)**
Challenges & risks		Long duration of rice husk burning	Potential industrial process incompatibilities	Potential industrial process incompatibilities; Possible contamination of industrial ovens during particle drying; Big bulk of feedstock required due to low yield
Potential solutions		Finding partners who can burn rice husk in their boilers and supply the ash		Seeking technical guidance from CeNTI's pool of cross-disciplinary experts

2.5. Value chain mapping and analysis of LLab #3: Liguria Bio-Lab, FILSE

2.5.1. Interviewees

1. Pietro De Martino (Incubation and Entrepreneurship Expert, FILSE)
2. Valeria Rainisio (Public and Media Relations Department, FILSE)

FILSE partners interviewed:
1. Marco Monti (Polymer Scientist, Proplast)
2. Raffaella Boggia (Department of Pharmacy, Food Chemist Group, University of Genoa)
3. Junio Rombi (Food Safety and Quality Manager, MICAMO)
4. Sofia Bodra (Staff coordinator and project manager, Il Rastrello)
5. Valentina Pirillo (R&D Specialist, THEMIS)
6. Matteo Cresci (Chemical scientist, SAES Packaging)
7. Gaetano Campanella (Flexible Films Labs Manager, SAES Group)
8. Giorgio Saio (Managing Director, TICASS)

2.5.2. About FILSE

FILSE, located in the Liguria region of Italy, is a technical entity that provides support to different actors within Liguria to enable optimal economic growth and development of the region. These actors range from businesses to governmental bodies, and FILSE works with them to plan and implement various policies and interventions as

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per the region's developmental priorities. FILSE supports with adequate financial, planning and organizational resources, entrepreneurial initiatives, innovation, technology transfer and the creation of new business.

2.5.3. About Liguria Bio-Lab and its value chains

The Liguria Bio-Lab is a part of the EcoeFISHent project which is being led by FILSE and supported by another EU project (financed by H2020-LC-GD-2020-3), that has the purpose to demonstrate a replicable systemic and sustainable cluster implementing systemic solutions through multilevel circular value chain for eco-efficient valorizations of side streams. FILSE acts as the orchestrator of the Liguria Bio-Lab by linking the relevant researchers, developers, service and technology providers as well as end-users.

The Liguria Bio-Lab aims to work on the following two value chains:

1. The first value chain looks into valorising fish side-streams sourced from fish-based industries located in the Liguria region. These fish side-streams (such as fish skin, bones and scraps) are converted to bio-actives and gelatine that have varied uses, for instance, in the food supplements, cosmetics, plastic packaging component, fertilizer, biodiesel and automotive component industries. The end-product application in the packaging industry has been better explored by EcoeFISHent and they see the replacement of synthetic plastic with this bio-based component in the packaging industry as a step towards enhancing the recyclability and biodegradability of packaging material. This value chain is being led by FILSE and their Spanish partner Proplast, with a current **TRL 5** (which is expected to increase to **TRL 7** by the end of the PRIMED project in 2026).
2. The second value chain will look into valorising food and agro waste (from both urban and farm sources), such as waste coming from sources such as fruits, vegetables and flowers. This value chain is still under development and the specific feedstocks would be chosen during the course of the project PRIMED.

EcoeFISHent has 37 partners working collectively in the Liguria region on innovative biomass pre-treatment and extraction technologies in certain pilot plants, to realise the potential of these value chains. Some of these actor are involved in developing the Liguria Bio-Lab.

2.5.4. Key processes and value chain actors

The main focus of the Liguria Bio-Lab is to fully develop its first value chain, with the most significant progress having been made on converting fish side-streams to plastic biodegradables and compostable barriers layers for packaging components of food and cosmetics products. Other expected process outputs can be bio-actives and gelatine for high value-added food supplements and skin care products, fertilizers, biodiesel, components for cosmetics applications, polymer-based automotive constituents.

This EcoeFISHent project, from which the Living Lab takes a cue, originates at the point where the fish side-streams are generated, since they serve as the key feedstocks in this process. This and the following processes are described below:

- **Fish side-streams' procurement:** The fish side-streams are primarily being sourced from two sites: the AQUA aquaculture farm (doing sea brim and seabass farming) and COOP stores, a company selling fish products in Genoa. AQUA provides the bulk of the feedstock since they have an annual fish production of 800 tonnes which leads to them generating several kilograms of byproducts each week, which are of relevance to the Liguria Bio-Lab. However, since AQUA is still a relatively small entity, they do not sort their waste and the waste is taken as it is by the Liguria Bio-Lab.

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- **Transport and logistics of the fish side-streams:** Il Rastrello, Liguria Bio-Lab's logistics and transportation provider, are responsible for procuring this feedstock. They visit AQUA and the COOP store with a refrigerated truck, collect the fish side-streams and transport it to further actors. In addition to transporting the material, Il Rastrello also uses sensors in its facilities to monitor temperature and other metrics, in adherence with sanitary rules. This data is then made available to all value chain actors which can be used for monitoring purposes by ensuring traceability.

- **Distillation of the fish side-streams:** THEMIS, which is the Liguria Bio-Lab partner providing their technologies and plants for different waste recovery and waste valorisation processes, is the first actor to receive the feedstock transported by Il Rastrello and uses a machine to distil the liquid element of the material from the solid product (90% of the original material is recovered in this process).

- **Nutritional and quality analyses of dry matter:** After THEMIS' machine drying process, the dry matter goes for research purposes to MICAMO, a biotechnology research company which is a spinoff from the University of Genoa. MICAMO conducts a nutritional and quality analysis on the material and tries to find the optimal quality parameters that would be appropriate for packaging and safety considerations. After these determinations, the material is passed on to researchers at University of Genoa for the extraction process.

- **Extraction of value compounds:** University of Genoa researchers check the microbial, chemical and nutritional characteristics of this unsorted mix of dry matter with a focus on oxidation properties. They then use certain green technologies to implement the extraction process, separating the value compounds (certain peptides) to be refined and stabilised.

- **Material safety analysis:** These compounds are then sent to MICAMO where they once again check for safety paramaters, with a focus on analysing for contaminants like heavy metals. At this point, the product is ready for application in the packaging manufacturing process and goes to the next actor (SAES).

- **Testing for industrial applicability:** The SAES Group, located near Milan, looks into conducting research and development (R&D) related to novel packaging products. SAES, in collaboration with the University of Genoa, aims to conduct an industrial pilot test of the material by performing the packaging material coating up until the volume capacity of 100 litres. This will be conducted at their hydrolisis pilot plant that works on bioactive gelatine extraction.

To further complement this value chain, other pilot plants are under development in the Liguria region with different functions, such as biomass pre-treatment, bio-actives extraction, bioconversion, biopolymer foams production and finally, cleaning and material recycling of polyamide from fishing nets. Liguria Bio-Lab estimates that once the pilot plants are in operation, they may be dealing with upto a tonne of fish side-streams per day.

The value flow across different partners within the Liguria Bio-Lab can be represented in the following figure 26:

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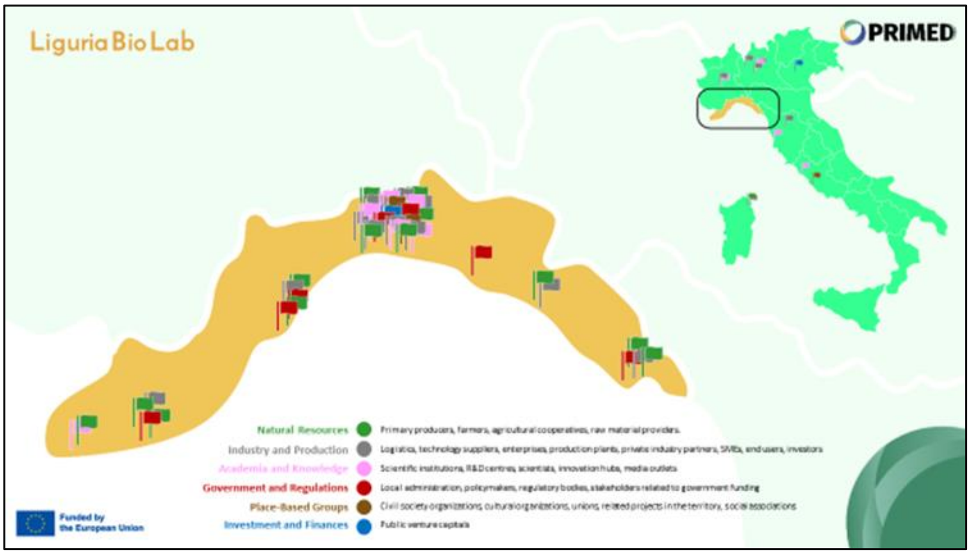

Figure 26: Value flow of the Liguria Bio-Lab on the Italian map

Further, this value chain of the Liguria Bio-Lab can be visualized in the following figure 27:

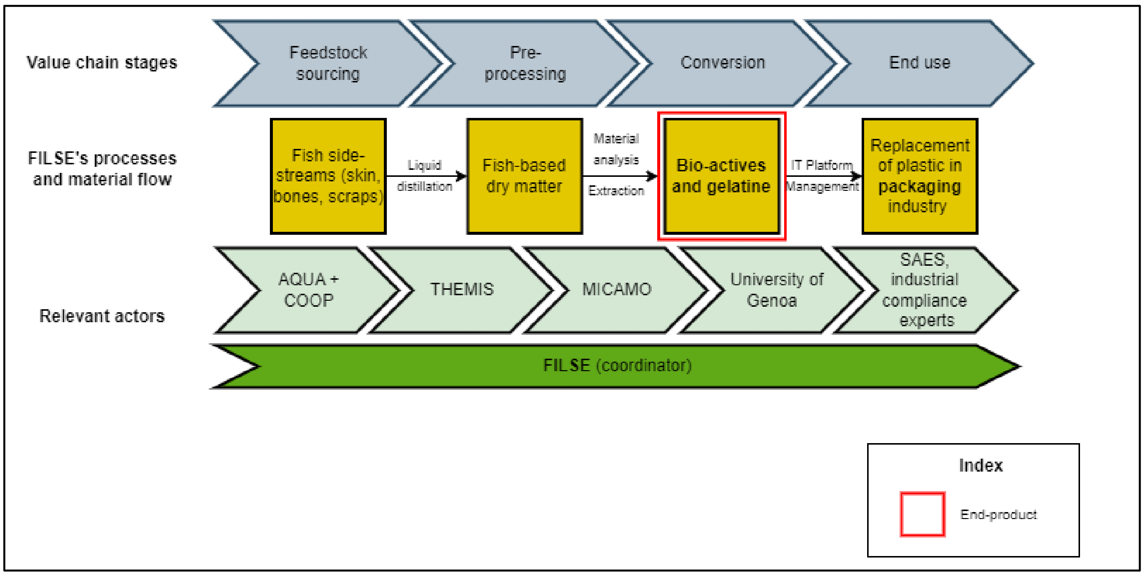

Figure 27: Bioeconomy map of FILSE's Liguria Bio-Lab: value chain stages, actors and flows

2.5.5. Key strengths

- **Large network of technical entities:** The Liguria Bio-Lab identifies its biggest strength as being able to bring together several relevant technical entities required to bring a bioeconomy ecosystem as well as the high level of interconnectedness and cooperation between them. The Lab believes that this synergy is crucial to synthesise a wide range of knowledge and expertise (that would normally operate more independently) which could contribute to holistic development of the region and local communities.

- **Creation of a benchmark model of regional cooperation:** The Liguria Bio-lab considers its model's uniqueness and novelty in bringing together scientific expertise, local cooperation and regional development. The Lab feels that this is particularly noteworthy since this model can serve as a reference example to other similar actors in other regions/projects and can be scaled and replicated elsewhere within and beyond Europe.

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2.5.6. Key challenges

- **Regulation discouraging industrial application of waste streams:** Regulatory aspects seem to present the most significant barrier to the Liguria Bio-Lab. As per certain EU regulations (specifically the EU Regulation (CE) n. 853/2004 Sections XIV and XV of Annex III), actors are allowed to use fish skins and bones to make gelatine like the Liguria Bio-Lab is trying to do, but not fish finns, especially for food purposes (although such restriction has not been identified for cosmetic-based uses). This restricts the volume of fish industry side-streams that an actor may be able to use when considering scaling the manufacturing of this material to the industrial scale. Further, animal waste-based gelatine coating layer in packaging may be discouraged from being in direct contact with food products: since this regulatory landscape is still evolving, there is uncertainty regarding whether or not this is disallowed, based on certain tests that may have to be conducted on the material. Further, as per Italian regulation, fish side-streams are classified as waste and waste can only be used for research purposes, not for profit-oriented industrial applications. These regulatory aspects threaten to limit the scaling potential of Liguria Bio-Lab's value chain, especially given how the Lab has estimated that the amount of raw material availability is not sufficient for industrial scale production, which is a challenge of its own. The Liguria Bio-Lab is trying to influence the policy and regulatory landscape, for example, by working with the EU Working Group on Food Regulation.

- **Expensive logistics in fish side-stream procurement:** The logistics cost of sourcing the fish waste from AQUA to the THEMIS lab, has not been optimal because of the long distance between the two. This is expected to be a problem that will persist since most aquaculture spots are close to touristic sites and thus, policies discourage scientific facilities from being located close to these places.

- **Lack of financial self-sufficiency:** The Liguria Bio-Lab and the larger EcoeFISHent project are mostly driven by financial grants and does not have a self-sufficient financial pipeline. This is seen as another challenge that could hamper the future sustenance of the value chain.

- **High process cost and low yield:** The Liguria Bio-Lab identifies its overall process cost as relatively high and its extraction yield as low, leading to profitability-related concerns for cases where the material will be considered for integration into industrial processes.

2.5.7. Key risks and possible mitigation measures

- **Lack of market uptake of products:** Since the value chains of the Liguria Bio-Lab are still their initial developmental stages, the end-products have not been commercialized and market users have not been found who have demanded these products. This means that the risk of there not being a reliable source of market demand and thus, the viability of these products, is still present and needs to be addressed. FILSE, as the coordinator of the Liguria Bio-Lab, is trying to find relevant end-users who could indicate a clear pathway for the market uptake of the products being produced by the Lab.

- **Risk of non-participation of local actors:** Since the basis of the Liguria Bio-Lab's work is collaboration between regional actors which requires heavy alignment and coordination of priorities and channelization of resources, it is possible that some local actors may not want to put in this requisite effort and might want to work independently. This could be prove to be disruptive to the current sustenance and future development of the Liguria Bio-Lab. To mitigate this, FILSE attempts to reach out

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to as many relevant stakeholders as possible, maintains a stream of effective communication with them and serves as the critical coordinating point for effective alignment between all necessary partners.

2.5.8. Summary table

The following table 9 summarises the key aspects of FILSE's Liguria Bio-Lab's value chain 1:

***Table 9:** Key value chain aspects of FILSE's Liguria Bio Lab*

	Feedstock sourcing	Pre-processing	Conversion	End use
Inputs	Fish side-streams (fish skin, bones and scraps)	Fish side-streams (fish skin, bones and scraps)	Fish-based dry matter	Bioactives and gelatine
Activities	Fish side-stream procurement & refrigeration; Temperature and quality monitoring	Distillation of liquid from solid matter; Nutritional, microbial, chemical & quality analyses	Extraction, separation of peptides, refinement and stabilisation	Packaging material coating (research and industrial piloting)
Actors	AQUA; COPPA store; Il Rastrello	THEMIS; MICAMO; University of Genoa	University of Genoa	SAES
Challenges & risks	Large logistics cost due to policies discouraging labs/facililties from being located close to aquaculture sites because of tourism; Risk of non-participation of local actors		High process costs and low exraction yield	EU Regulation discouraging use of fish finns for gelatine production; EU regulation discouraging animal waste-based material to be used in packaging that is in contact with food; Italian regulation discouraging commercialization of animal waste-based processes; Grant-driven processes and lack of financial self-sustenance; Lack of market uptake of end-products
Potential solutions	FILSE is trying to reach out to actors, coordinate and be the central channel of communication			Working with policy and regulatory bodies, e.g. EU Working Group on Food Regulation;

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			FILSE is trying to find suitable end-users to test market viability

2.6. Value chain mapping and analysis of LLab #4: BioEire Lab, IBF

2.6.1. Interviewees

1. Kevin Ryan (Senior project manager, IBF)

2. Sean O'Grady (Operations officer and waste valorisation expert, IBF)

3. Naveen Kumar (European project manager, IBF)

2.6.2. About Irish Bioeconomy Foundation (IBF)

The Irish Bioeconomy Foundation (IBF), located in the National Bioeconomy Campus in Lisheen, Ireland, is a non-profit organisation that supports its member organisations and researchers to strengthen their role in the bioeconomy by focusing on competitiveness as well as local development. A key part of IBF's vision is making the National Bioeconomy campus flourish, by making it the common point where all Irish bioeconomy researchers operate and collaborate. IBF supports the Irish bioeconomy by conducting mapping exercises for relevant industries, working on bioeconomy financing for startups, innovating on bio-based solutions, facilitating relationships to create requisite bioeconomy network, generating synergies, supporting project implementation and working towards generating a collective ecosystem by promoting asset pooling and ambition alignment. IBF also works on some technical projects like applied research on valorisation of biomass, waste slurries and dairy sludges.

2.6.3. About BioEire Lab and its value chains

The BioEire Lab aims to promote bioeconomy actors working on valorising side-streams from the dairy and forestry industries, by providing them with a pilot plant facility for experimentation purposes, helping them source the relevant biomass feedstock and providing them with technical expertise on the conversion processes.

These facilities will focus mainly on the development of two kinds of value chains:

1. Developing pyrolysis-based processes to convert forestry residues into bioenergy

2. Developing fermentation processes to convert dairy industry by-products into biochemicals

Even though the aforementioned plant has been built over an area of 40000 sq ft and has 10-12 bioreactors, IBF has not opened it up to actors as yet since some capacity is still being developed. The facility is expected to be opened in 2025. IBF specifies the ambition of making the BioEire Lab self-sustaining and hopes to make it possible by encouraging actors beyond merely researchers, such as companies, to use the facilities at scale. The ambition of the BioEire Lab through the course of the PRIMED project is to accelerate the research on bio-based conversion processes from the laboratory scale (**TRL 4**) to the pilot scale (**TRL 7**) by utilizing its facilities.

2.6.4. Key processes and value chain actors

- **Technology and equipment procurement:** Since the BioEire Lab is currently under development, the key actors at this stage are the technology and equipment suppliers who are providing IBF with the requisite capacity required to build these facilities. Such equipment would include high-efficiency

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pyrolysis reactors, anaerobic digestion units, biochar production equipment, advanced separation technologies and bioreactors to enhance the conversion of by-products to bio-based chemicals.

- **Potential users:** Once the Lab is ready and open to IBF members to use, the key users are expected to be universities, research centres, government bodies and bioeconomy startups who are researching on several bioeconomy processes related to the forestry and dairy industries. These users would be expected to focus their research on pyrolysis processes related to bioenergy production (for instance, production of CHP, fuel and biochar) and/or fermentation processes for production of biochemicals (with a focus on application of these biochemicals in the plastics industries). A typical user would have already carried out some experimentation in their own lab and would be able to use the BioEire facility as an intermediate experimentation stage between the small-scale lab research and the large-scale industrial manufacturing.

- **Feedstock procurement:** During such experimentation processes, these actors are also expected to require larger quantities of feedstocks than they have been working with. IBF will help them procure the same through its network of forestry companies, dairy companies, farmer associations and other local cooperatives across several Irish regions. The key sidestreams that the BioEire Lab expects to source from the forestry companies would include primarily lignocellulosic biomass such as forest thinning material, wood chips and tree bark residues. Material sourced from the dairy companies would include whey permeate as well as some other dairy process residues.

- **Potential end-products:** End-products developed in these facilities could have applications across a range of industries, e.g. energy consumers (industrial and non-industrial), film, packaging, textile, adhesives and fertilisers, amongst many others.

- **IBF's technical support to users:** IBF will also provide the researchers technical guidance during these experimentation processes, using its own pool of scientific experts who specialise in different technicalities and processes of waste valorisation with respect to dairy and forestry side-streams. Some examples of the guidance that these experts would be able to provide include process optimization, quality control and life cycle analysis (LCA) studies.

The value chains of the BioEire Lab can be visualized in the following figure 28:

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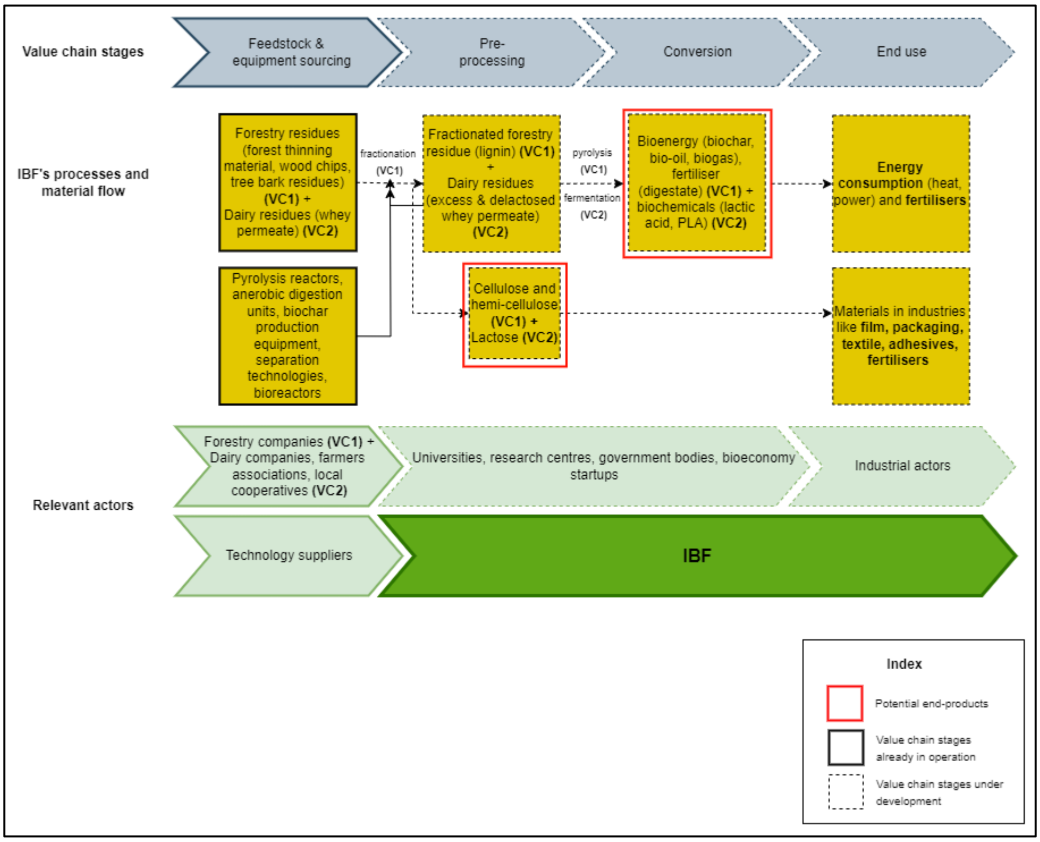

Figure 28: *Bioeconomy map of IBF's BioEire Lab: value chain stages, actors and flows*

2.6.5. Key strengths

- **Diversity of actors and value chains:** The BioEire Lab identifies the diversity of actors and value chains within the scope of its project, as its biggest strength. Partnering with different kinds of actors and processes underlines the robustness and utility of the Lab within the Irish bioeconomy ecosystem. Being a facilitator to a host of diverse actors also makes it resilient to changes and disruptions within individual value chains.

- **State-of-the-art technological capabilities:** The BioEire Lab perceives its technological capabilities as being state-of-the-art and also identifies this as a key strength.

2.6.6. Key challenges

- **EU Biochar Regulation:** IBF does not anticipate regulatory aspects to be a major challenge in the context of the BioEire Lab, since the Lab is just providing research facilities for other actors to use. However, since they will also be sourcing biochar from forestry industries as feedstock for the BioEire Lab, they anticipate that the EU regulations on biochar (for instance, the EU Fertilising Products Regulation (2019/1009), which allows for biochar usage in fertilizing products) which have detailed requirements related to biochar sourcing and usage, might be something to look into since it would help in scaling up biochar production but could also encourage streamlining the Lab's feedstock sourcing and processing to certain specific cases.

2.6.7. Key risks and possible mitigation measures

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- **Bio-based regulatory uncertainty:** The BioEire Lab anticipates that there could be upcoming regulatory changes in EU regulations related to biochar and other bio-based products. However, there is significant speculation and uncertainty regarding how the regulatory environment will evolve. If the regulatory requirements become stricter, they could pose a potential challenge to companies using biochar and other bio-based products, which could negatively impact scientific research on these products and subsequently, the usage of the BioEire Lab's facilities. The BioEire Lab aims to closely follow the regulatory developments at both the European and Irish levels and develop contingency plans to adapt to possibly adverse regulatory developments.

- **Technological scaling and pilot testing:** Experts at the BioEire Lab anticipate that scaling technologies for some of their processes might turn out to be challenging. To mitigate this, they aim to have a pilot-scale testing of the Lisheen facilities, understand their limitations and work to minimize them before the commercialization phase.

2.6.8. Summary table

The following table 10 summarises the key aspects of both the value chains of IBF's BioEire Lab:

Table 10: *Key value chain aspects of IBF's BioEire Lab*

	Feedstock sourcing	Pre-processing	Conversion	End use
Inputs	Forestry residues like forest thinning material, wood chips and tree bark residues **(VC1);** Dairy residues like whey permeate **(VC2);** Pyrolysis and fermentation machines **(VCs 1&2)**	Forestry residues like forest thinning material, wood chips and tree bark residues **(VC1);** Dairy residues like whey permeate **(VC2)**	Forestry residues like forest thinning material, wood chips and tree bark residues **(VC1);** Dairy residues like whey permeate **(VC2)**	Bioenergy **(VC1);** Biochemicals **(VC2)**
Activities	Feedstock sourcing and equipment installation	Pre-processing activities	High-efficiency pyrolysis, fermentation, anaerobic digestion, biochar production, advanced separation	Energy use **(VC1);** Use as manufacturing component **(VC2)**
Actors	Forestry companies **(VC1);** Dairy companies, farmers associations, local cooperatives **(VC2);**	BioEire Lab, universities, research centres, government bodies	BioEire Lab, universities, research centres, government bodies	Energy users (industrial and non-industrial) **(VC1);** Industries like film, packaging, textile, adhesives and fertilisers **(VC2)**

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	Technology suppliers **(VCs 1&2)**			
Challenges & risks	Scaling of specific new technologies is uncertain		Uncertainty regarding EU biochar & other bio-based product regulations	Uncertainty regarding EU biochar & other bio-based product regulations
Potential solutions	Pilot-scale testing of technologies		Closely following regulatory developments and framing contingency plans	

2.7. Value chain mapping and analysis of LLab #5: Cell Factory Lab, VTT

2.7.1. Interviewees

Anneli Ritala (Principal Scientist, VTT)

2.7.2. About VTT

VTT is a Finnish government-owned research institution that works on a broad range of scientific fields aimed at advancing and accelerating scientific and technological progress in industry and society. VTT conducts research, development and innovation activities on carbon neutral solutions, sustainable products and materials and digital technologies, and collaborates closely with the government and industry to enhance information flow, knowledge sharing, network building and a common vision.

2.7.3. About Cell Factory Living-Lab and its value chain

The Cell Factory Living-Lab run by VTT focuses on producing plant cell culture biomass using agriculture side-streams as feedstock to complement the ingredient portfolio for food and cosmetic industries with novel and sustainable alternatives. The current focus of the Living-Lab is on using liquid potato side-stream to generate the plant cell culture biomass, even though the Lab has ambitions to experiment with solid potato side-stream and other vegetable and fruit processing side streams towards the end of 2024 and early 2025. The resulting biomass is rich in protein and fibre, and has a plant-specific fatty acid profile high in unsaturated fatty acids. Thus, it is an interesting ingredient for cosmetics and novel food industries. Since the biomass can also be rich in antioxidants, depending on plant species and propagation conditions, it could be an opportunity for companies manufacturing vitamins and nutrient supplements as well. The preparedness of this technology has been identified to be currently around a **TRL 3-4**.

VTT owns the aforementioned cell lines and it aims to license these cell lines to relevant industrial clients who could make use of them. VTT is also willing to do technology transfer if seen appropriate. There are already companies like Solar Foods, Enifer and Onego Bio, all VTT spin-outs, that are using related cellular agriculture approaches by using microbial hosts to produce microbial biomass and to conduct precision fermentation of recombinant proteins.

VTT, and the Cell Factory Living-Lab, are also engaged in a more national-level strategic role making a cellular agriculture roadmap for Finland in collaboration with the Natural Resources Institute Finland (Luke), University of Helsinki and other stakeholders. Particularly of interest are the new value chains fostering circular economy

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principles in valorising the agri-food side streams in cascaded manner and taking full advantage of biotechnology, which is expected to play a significant role in the socio-economic development of the Finnish society.

2.7.4. Key processes and value chain actors

- **Potato side-stream procurement:** The Cell Factory Living-Lab produces its plant cell culture biomass using liquid potato side-stream as an first example, its value chain originates at the point of procurement of this side-stream, which is a potato processing factory (Finnamyl Ltd which is located in Kokemäki, Finland). Around 5000-8000 tons of this side-stream are produced at this site annually and the season for this production typically lasts between September and November. The procurement of this side-stream is carried out by a logistics provider that the potato processing factory uses.

The following figure 29 shows the feedstock flow related to the Cell Factory Living-Lab on the Finnish map. However, it should be noted that the future plant cell culture ingredient manufacturer company is forseen to be located closer to the origin of the feedstock. In addition, as already stated before, VTT is not a manufacturer but a technology provider and the Cell Factory Living-Lab under EU PRIMED is a demonstration of its nature.

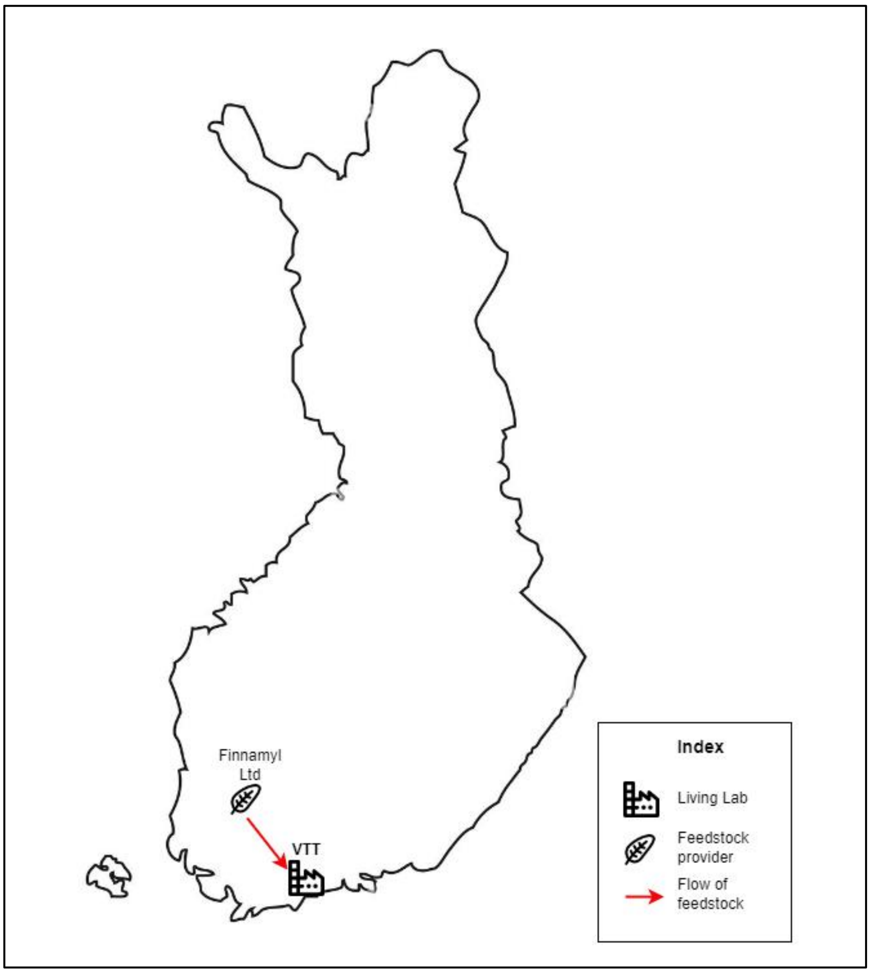

Figure 29: *Feedstock flow of VTT's Cell Factory Living-Lab*

- **Material analysis and validation:** After the procurement of this material, the logistics provider brings it to VTT's Cell Factory Lab located in VTT Future Hub (Espoo, Finland), where its basic properties are

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studied and analysed. This process is crucial to validate any of the agri-food side streams that the material is suitable to be used in the process as a feedstock.

- **Conversion processes:** After it has been ascertained that the material is fit to be used as a feedstock, the required pretreatment and stabilisation steps are taken, if needed. Next, the medium preparation and fermentation processes are conducted. The VTT facilities include food-grade fermentation capacity of up-to 100 litres, which allows the Living-Lab to experiment with larger quantities of the material.

- **Secondary ingredients and equipment:** Throughout the process, other complementing ingredients are also used such as sugars, other nutrients, growth factors and vitamins depending on the composition of the used agri-food side stream. There might also be need for an alkaline or enzymatic treatment (e.g. in cases where solid feedstocks are used) which are then sourced from certain chemical manufacturers like Merck and Sigma. In addition, the equipment used, such as fermenters, membranes and pipings are sourced from companies like Sartorius.

- **Plant cell biomass separation and stabilisation:** After the propagation of plant cell culture biomass in a fermenter, it is separated from the culture medium and e.g. frozen to ensure the stability, which is crucial for later usage of the cells in applications. Another option could be the drying of the biomass.

- **Industrial application scope:** The Cell Factory Living-Lab is creating an ingredient which can then be sold to industrial actors who can use and formulate products according to their specific use case. At the moment, one litre cultivation volume has typically been shown to yield around 200-500 grams of the biomass, while the actually quantity of feedstock would depend on the specific use case

The Cell Factory Living-Lab estimates that if this plant cell culture biomass production process is taken to an industrial scale, e.g. with a capacity of 100 000 litres fermentation tanks running 24x7, a total of at least 4-6 technical staff may be required to run the facilities.

The value chain of the Cell Factory Lab can be visualized in Figure 30:

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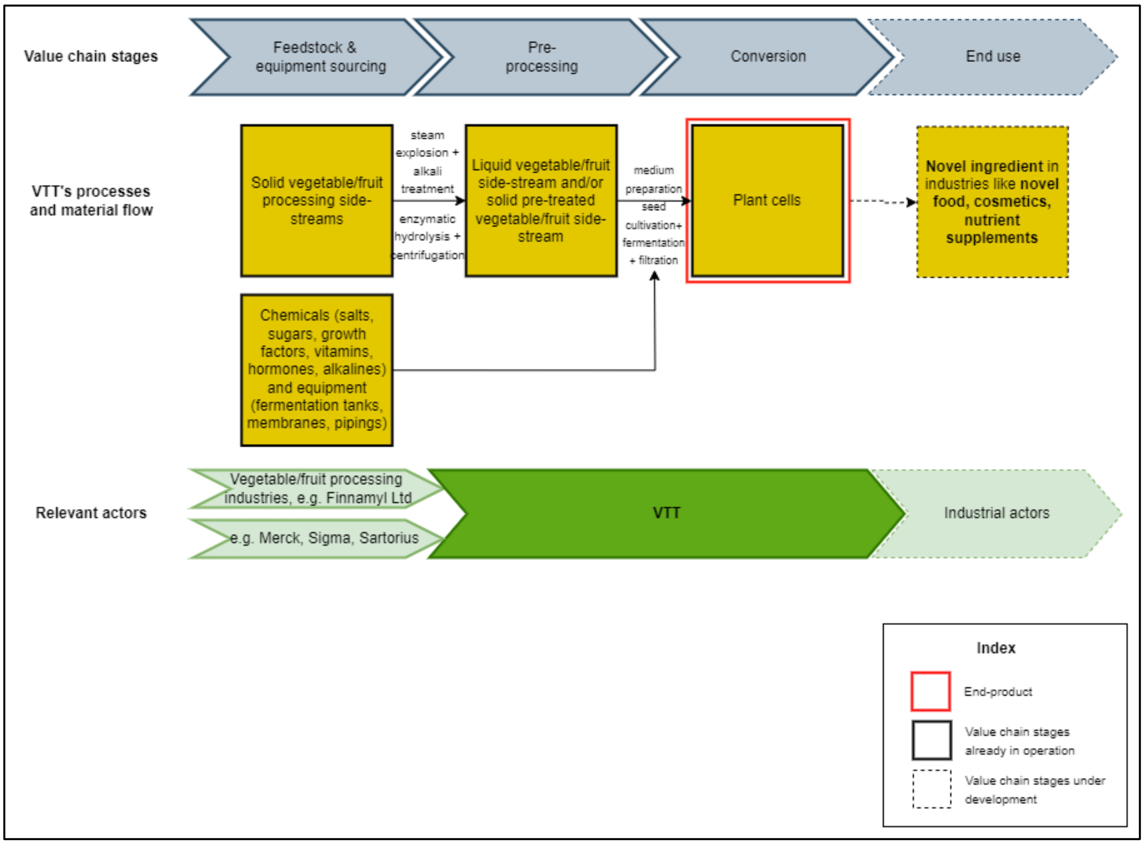

***Figure 30**: Bioeconomy map of VTT's Cell Factory Living-Lab: value chain stages, actors and flows*

2.7.5. Key strengths

- **Cellular agriculture expertise:** The Cell Factory Living-Lab identifies its know-how and experience in the area of cellular agriculture as their biggest strength. VTT is one of the biggest research organisations in Europe and has a long track record in biotechnology as well as in cellular agriculture. The Living-Lab holds all the needed scientific expertise and experience to advance the agenda of the Cell Factory.

- **Pilot testing ability:** The Living-Lab has the ability to scale up this research project to test it at the pilot scale. This would be a crucial prerequisite to achieve before industrial actors can be convinced of the viability of this technology.

- **Scientific and regulatory foresight:** The researchers identify their foresight as another key strength. They are well-informed about potential industrial end users and the regulatory aspects that could affect them. This foresight leads them to think of other futuristic ideas that could evolve from their current research and enable them to find other suitable applications.

2.7.6. Key challenges

- **EU Novel Food Regulation:** The EU Novel Food Regulation is the most significant challenge that could discourage the industrial uptake of this newly developed plant cell culture technology and of the biomass created with it. The regulation concerns extensive safety requirements for commercialisation of newly developed food components like the one developed by the Cell Factory Living-Lab and requires significant documentation. Most importantly, the regulatory approval process could cost upto a million euros and could take upto three to four years to be completed. Particularly the cost and time factors

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discourage industrial actors, especially smaller players who could possibly make use of the Cell Factory Living-Lab's cell lines, thus hampering commercialisation of this new ingredient.

- **Seasonality of vegetable and fruit production:** Since vegetables and fruits are not produced all year round, particularly in Finland, any actor who would want to scale up the production of this plant cell culture biomass would have to look into ensuring continuous supply of the agri-food side streams which serve as feedstock for this production process.

- **Process contamination risk:** The plant cell lines have been identified to be at risk of microbial contamination during the cultivation. However, this is nothing specific to fermentation-based production processes and the production process is constantly monitored from the start to the end.

2.7.7. Key risks and possible mitigation measures

- **Industrial competitiveness against other alternatives:** Since plant cell cultures are a new concept within cellular agriculture and enough research has not been generated on this as compared to, for instance, microbial production systems. The plant cell culture cultivation is still comparatively more difficult and more time-consuming when compared to microbial production processes, though easier than animal cell propagations in industrial scale. This might pose challenges regarding competitiveness vis-à-vis other alternatives like microbial production, especially at larger industrial scales.

- **Feedstock-related problems and exploration of other feedstocks:** In addition, plant cell cultures are more sensitive to inhibitors than more robust microbial counterparts. The usage of agricultural side streams as feedstock might cause also problems. To mitigate both these potential risks, the Cell Factory Lab researchers have the opportunity to experiment with different plant cell lines, available to them from VTT's cellular agriculture research expertise. Additionally, they also aim to explore other agri-food side-streams as feedstock for their cultivation so as to be able to find the most optimal and safe production process.

2.7.8. Summary table

The following table 11 summarises the key aspects of of VTT's Cell Factory Lab's value chain:

***Table 11**: Key value chain aspects of VTT's Cell Factory Lab*

	Feedstock sourcing	Pre-processing	Conversion	End use
Inputs	Liquid potato side-stream	Liquid potato side-stream	Liquid potato side-stream	Plant cells
Activities	Feedstock and chemicals' sourcing and equipment installation	Chemical properties' analysis	Medium preparation, cultivation, fermentation	Use as manufacturing component
Actors	Examples: Finnamyl Ltd; Merck and Sigma; Sartorius	Cell Factory Lab	Cell Factory Lab	Industries like food, cosmetics, nutrient supplements

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Challenges & risks	Potato production's seasonality impedes year-round supply of side-stream		Microbe contamination risk during cultivation; Sensitivity to inhibtors increased due to agricultural feedstock	EU Novel Food Regulation has strict requirements and expensive and long approval process; Competition with microbial production which is more manageable at industrial scale
Potential solutions			Regular safety checks at each conversion stage; Experimentation with different cell lines and agri-food feedstocks	

2.8. Summary and concluding remarks

The five Living Labs under the PRIMED project represent a wide diversity of actors at different developmental stages, each of which is evolving under their own unique circumstances. It could be insightful to compare and contrast the key aspects of each Living Lab's value chain (development stage, technological readiness, processes, actors and challenges).

The following table 12 sums up these key aspects of each Living Lab's value chain(s):

Table 12: *Summary table describing bioeconomy maps of all Living Labs*

	ALC Bio-Hub (ALC)	Bio-Silica Lab (CeNTI)	Liguria Bio-Lab (FILSE)	BioEire Lab (IBF)	Cell Factory Lab (VTT)
Feedstocks	Cow manure and pig slurry (solid fraction **(VC1)**, liquid fraction **(VC2)**), vegetable residues	Rice husk **(VCs 1 & 2)**	Fish side-stream **(VC1);** Food and agriculture waste **(VC2)**	Forestry residues **(VC1);** Dairy residues **(VC2)**	Vegetable/fruit side-streams
End-products	Bio-compost and fertilisers **(VC1);** Bioenergy **(VC2)**	Bio-silica **(VC1)**; Modified bio-silica **(VC2)**	Bio-actives and gelatine **(VC1);** To be determined for **VC2**	Bioenergy **(VC1);** Biochemicals **(VC2)**	Plant cells
End uses	Private and commerical usage of fertilisers in agriculture & gardening **(VC1);** Energy usage in electricity, mobility, cooking, water heating, air conditioning **(VC2)**	Manufacturing component in industries like automotive, construction or textile (for example as additives for coatings, polymers, fibers) **(VCs 1 & 2)**	Manufacturing component in industries like packaging, cosmetics, food supplements, fertilisers, biodiesel, automotive **(VC1);** To be determined for **VC2**	Usage of fertilisers in agriculture & gardening & energy usage **(VC1);** Manufacturing component in industries like film, textile, packaging, adhesives, fertilisers **(VC2)**	Novel ingredient in industries like novel food, cosmetics, nutrient supplements

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Technological Readiness Level (TRL)	TRL 9 for **VC1**; TRL 3-5 for **VC2**	TRL 6-7 for **VCs 1&2**	TRL 5 (expected 7 by 2026) for **VC1**; TRL not determined for **VC2**	Escalation from TRL 5 to TRL 7 for **VCs 1 & 2**	TRL 3-4
Existing processes	Farmer and rancher governance; Waste collection & separation; Anaerobic composting **(VC1)** & anaerobic digestion **(VC2);** Sale of compost and fertiliser end-products **(VC1)**	Rice husk procurement; Rice husk burning; Silica precipitation and recovery **(VC1)** & addition of functional properties **(VC2)**	Fish side-stream procurement **(VC1);** Liquid distillation and material analyses of dry matter; Extraction; Research on packaging industry application	Forestry **(VC1)** & dairy **(VC2)** residues procurement; Technology & equipment procurement & facility-building	Potato side-stream, chemicals & equipment procurement; Treatment, hydrolysis & centrifugation; Medium preparation, seed cultivation, fermentation, filtration
Potential processes	Circular usage of by-products within the facilities; Acquiring carbon rights & sale of carbon credits in EU ETS; BioHub Alcarras	Testing facility for end-users & consulting; Partnerships for industrial application of bio-silica (modified or not)	Industrial application of bioactives and gelatine	Usage of facilities by end-users for pilot testing	Industrial application of plant cells; Experimenting usage of solid potato side-stream as feedstock
Key strengths	Cooperative ownership model; Public support & recognition	Scientific flexibility for experimentation with other feedstocks; Diversified functional properties of modified bio-silica; Research on industrial application	Large network of technical entities; Benchmark model of regional cooperation for bioeconomy development	Diversity of actors & value chains; State-of-the-art technological capabilities	Cellular agriculture expertise; Pilot testing abilities; Scientific & regulatory foresight
Key challenges and risks	Lack of business capabilites & commercial competition in growing markets; Governance of larger number of actors; Limitations of feedstock supply	Long duration of rice husk burning process; Industrial production of bio-silica may require specialized equipment; Industrial application of bio-silica may require further validation; Low yield rate	Regulation discouraging industrial application of fish waste; Costly logistics in fish side-stream procurement; Lack of financial self-sufficiency; High process cost & low yield rate; Lack of market uptake of products; Risk of non-participation of local actors	Bio-based regulatory uncertainty; Technological scaling issues	EU Novel Food Regulation; Seasonality of vegetable & fruit production; Process contamination risk; Industrial competition with other alternatives; Feedstock-specific issues

This table highlights the various similarities and differences across these value chains, which we can synthesise to obtain and certain key learnings.

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First, although all these LLabs are working on valorising waste streams from conventional sectors of the economy, they are targeting several different end-use purposes: the ALC Bio-Hub is producing products like fertilisers and energy (which can be used by industrial and non-industrial consumers as they are), others are producing products like bio-silica, gelatine, bioactives and plant cells (which can be used by industrial actors as manufacturing components to create other products to be used by other consumers), whereas the BioEire Lab is not manufacturing an end-product but rather, providing a service in terms of its facility for the usage of other bioeconomy researchers. As a result, we can say that they have very different approaches to waste valorization and bioeconomy, connected to private initiatives and ownerships and public organizations, local, regional or national networks and end use and final products.

Second, the processes that govern these value chains also differ based on the problems they are attempting to address and their end-use cases. Farmer and rancher governance is key to the ALC Bio-Hub's value chains because of the land and facilities being owned by several independent farmer families and because of the feedstock being collected from all of them. This case is unlike the other LLabs, each of which is governed under one ownership structure and needs to collect its feedstock only from one or very few actors. While ALC Bio-Hub's feedstock is scattered across different actors, its process becomes integrated under the umbrella of Alcarras Bioproductors once the feedstock procurement has been done. However, the Liguria Bio-Lab's entire process is distributed amidst different actors across (and even outside) the Liguria region, with each step, starting from the feedstock procurement, pre-analysis, pre-processing, extraction until the end-use research, is carried out by a distinct actor. Unlike in the case of Alcarras Bioproductors, FILSE does not have common ownership over these independent scientific entities and is not the decision-maker of the process but rather, the facilitator and coordinator. The Bio-Silica Lab and the Cell Factory Living-Lab are more focused on their scientific processes, since each of them has concentrated points of feedstock procurement and also because each of them is owned by a common scientific entity. Lastly, the BioEire Lab, due to its positioning as a service provider of bioeconomy research piloting facilities, can get involved in catalysing several independent research projects and value chains, thus enaging in and networking with all bioeconomy actors in the Irish region instead of aligning with just a few on a common process. These differences in the LLabs' foci on governing their value chains, explain the different strengths each of them identify for themselves: the ALC Bio-Hub and Liguria Bio-Lab pride themselves on being able to bring together several different actors and make them cooperate towards one unified agenda, the BioEire Lab finds the diversity of its actors, value chains and processes as making them resilient against any disruptions. Finally, being part of larger scientific institutions, the Bio-Silica Lab and the Cell Factory Living-Lab identify their scientific expertise as being their biggest strength, seeing themselves as researchers promoting scientific progress within the bioeconomy domain.

The differences in ownership structures and in governance approaches can be highlighted further by the following table 13:

Table 13: *Governance aspects of all Living Labs*

	ALC Bio-Hub (ALC)	Bio-Silica Lab (CeNTI)	Liguria Bio-Lab (FILSE)	BioEire Lab (IBF)	Cell Factory Lab (VTT)
Ownership structure/ property rights	Private associations of farmers and ranchers with common ownership of land and facilities	Private non-profit R&D institute with private ownership of the technology	Public funded entity to support local economic development	Membership-based organization promoting national and local development with privately	Public funded R&D organization

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				owned technological setup	
Governance of value chain (Professionalization)	Community-based network with volunteering roles for collective decision-making	National science and innovation institution with professionalization of decision-making	Regional network with coordinated cooperative roles	National coordination and facilitation role	National science and innovation institution with professionalization of decision-making

These differences also manifest in what the LLabs encounter as some of their most significant challenges. ALC Bio-Hub and Liguria Bio-Lab recognise that governing such a wide variety of actors includes the risk of non-cooperation from any of them, hampering unified decision-making processes. The BioEire Lab considers finding suitable end-users to utilise its facilities for their research purposes, as a potential challenge. The Bio-Silica Lab and the Cell Factory Lab are more concerned about industrial process difficulties (like contamination and incompatibilites) that might arise when their components are transferred from the laboratory scale to the industrial scale.

Despite these differences, the LLabs seem to be united by several common challenges. The most significant and cross-cutting one of these seems to be finding end-users for their products/services, especially since all of them are still relatively in the early stages of their development. This also relates to many of them identifying high process costs as a big issue, since they have not been able to take advantage of cost-cutting efficiencies that arise out of industrial scaling. As multiple LLabs highlighted, regulatory uncertainty regarding industrial integration of products made from waste valorisation, is a major issue that contributes to industrial uptake being a slow and expensive process. These are some issues that bioeconomy practitioners, alongside scholars and regulatory bodies, should pay attention to, for the effective integration of the bioeconomy into the traditional economy.

Finally, the main learnings of this work package regarding the state-of-the-art of the Living Labs' value chains and actors, relate to the heterogeneity and complexity of actors, initiatives, processes, ownership and governance issues. We have seen how beyond some of the core issues in the bioeconomy such as technological development, market development, investment and funding as well as business models design, the emergence and development of new value and co-creation in the bioeconomy depend on a synthesis of various actors, along with an initiative uniquely aligned with their contextually relevant challenges, while using waste and technological sourcing. This requires exploring new forms of cooperation, facilitation and collective action, and the support of regulation and policymaking, with actors overcoming siloed contexts and needs, and exploring new forms of collective engagement, valorizing the feedstocks at different levels (local, regional or national). The emergence and growth of PRIMED's Living Labs show how building value chains in the bioeconomy are the starting point of complex circular bioeconomy business models (based on cascading use of value) and new markets.

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3. Bioeconomy Policy Analysis

3.1. Introduction

As part of the Work Package (WP) 2 - Establishing Framework Conditions, EuropaBio - the European Association for Bioindustries (EUBIO) is responsible for carrying a policy analysis, in order to identify impact and barriers of policies related to bioeconomy: Subtask 2.2.3 Policies Analysis.

The scope of the analysis is limited to the final products developed and produced by the five Living Labs (LLs), as well as to policies that impact investment to scale or market access and uptake. Therefore, it addresses the production and market stages of the value chains. Additionally, it has a higher focus on policies and legislation implemented at EU level, due to the fact that innovative and breakthrough technologies tend to be firstly regulated at European level and to the central importance of the EU Single Market.

This EU level approach leads to a broader but consistent policy analysis which allows the results to be used and applied in any Member State (MS) within the EU, making the results useful and accessible to a larger community of stakeholders.

The subtask is divided into two stages: policy mapping and policy analysis. In the first stage, EUBIO collects and compiles a set of EU and national policies that are either signed as important for the LLs or the result of EUBIO activities and research. In the second stage, the main gaps or opportunities are identified and analyzed in a holistic way, providing a general overview and potential actions points to improve the policy landscape. Lastly, EUBIO conducts individual consultations with the LLs to validate and fine tune the results obtained from the analysis.

3.1.1. Living Labs & Final Products

The table below summarizes the expected or manufactured final products from the different LLs, in order to provide a baseline for the policy mapping.

Country	Living Lab	Products
Portugal	CeNTI	Biosilica or modified-biosilica for construction, water treatment, soild remediation, and textiles, among others
Finland	VTT	Ingredients for food and cosmetics
Ireland	IBF	Fatty acids, biochemicals, bioactives, bioplastics, biochar, biomethane
Spain	ALC	Biogas or compressed natural gas or liquid natural gas, biomethane, fertilizers
Italy	FILSE	Bio-actives and gelatine for high value-added food/cosmetics, fertilizers, biodiesel, bioplastics

The LLs are all integrated in bioeconomy value-chains, share some of the final products and the EU Single Market and therefore, are regulated and impacted by the same legislation. Nevertheless, despite the similarities, differences such as feedstock and feedstock origin, manufacturing processes and geographical location introduce variability and may impact the policy mapping and further analysis.

3.2. Policy Mapping

The policy mapping integrates policies from EU and national levels that impact directly or indirectly on one or more value-chains. The mapping covers a large scope due to the diversity of countries, primary sector activities, and final products. Due to the innovative nature of the value-chains as well as the breakthrough technologies,

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EUBIO anticipates the possibility of encountering loopholes in policy frameworks, which will be addressed during the analysis by providing potential policy pathways.

3.2.1. Framework

In order to introduce a systematic approach to policy mapping, EUBIO decided to adopt a research framework to support the categorization of the different relevant policies identified. The framework is based on the work "The choice of innovation policy instruments" by Susana Borrás and Charles Edquist in 2013. **It broadly classifies policies into three different types of instruments: (1) regulatory, (2) economic and financial, and (3) soft.** Regulatory instruments use legal tools to regulate social and market interactions, and can take form of laws, rules or directives and have always an obligatory nature backed by sanctions in case of noncompliance. Economic and financial instruments aim to promote or discourage specific social and economic activities, and examples are funds, grants or tax reductions or exemptions. Soft instruments are voluntary and non-coercive, and may take very different formats such as campaigns, codes of conduct, voluntary agreements, labels. The main goal of these instruments is to inform and persuade based on cooperation between different stakeholders. The table below summarises the policy instrument type and its definition. **In the case that a policy integrates more than one type of instrument, it is categorized as hybrid.**

Policy Instrument	Definition
Regulatory	Mandatory legislation or regulation with possibility of enforcement.
Economic & Financial	Policies that use or leverage financial or economic resources.
Soft	Voluntary instruments that aim to inform and persuade stakeholders.
Hybrid	Policies that integrate more than one type of instrument.

3.2.2. Mapping

EU Policies

The policy map includes **policies that impact investment to scale or market access** and uptake of the final products developed by the five LLs. The policies compiled in the table below were referred to by the LLs or identified by EUBIO as relevant legislation to the value-chains. Following, they were categorized according to the research framework (1.2) and its impact on the LLs noted with an "X" in the respective LL column. The table also includes relevant links to explanatory material or the legislation itself.

Policy		Living Labs				
Type	Name	CeNTI	ALC	FILSE	IBF	VTT
Regulatory	The European Bioeconomy Strategy - 2018 Update	X	X	X	X	X
	Common Agricultural Policy (CAP)	X	X		X	X
	Common Fisheries Policy (CFP)			X		
	Waste Framework Directive - Directive (EU) 2008/98	X	X	X	X	X
	Packaging and Packaging Waste - Directive (EU) 2019/904	X		X	X	
	Plastics Strategy			X	X	
	EU policy framework on biobased, biodegradable and compostable plastics - Communication	X		X	X	
	Single-use Plastics - Directive (EU) 2019/904			X	X	

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	Ecodesign for Sustainable Products Regulation - Regulation (EU) 2024/1781	X		X	X	
	Biofuels and Biogas - Directive (EU) 2023/2413		X	X	X	
	Fertilising Products - Regulation (EU) 2019/1009	X	X	X		
	Ecodesign for Sustainable Products Regulation	X	X	X	X	X
	Cosmetic Products - Regulation (EC) No 1223/2009			X		X
	Novel Foods - Regulation (EU) 2015/2283			X		X
	Food additives - Regulation (EC) No 1331/2008			X		X
	Food additives - Regulation (EC) No 1333/2008			X		X
	Food additives - Regulation (EC) No 1334/2008			X		X
	Good Manufacturing Practices for materials in contact with food - Regulation (EC) No 2023/2006			X		X
	GMO Framework - Regulation 1829/2003				X	
	Animal By-products - Regulation (EC) No 1069/2009			X	X	
	Net Zero Industry Act - Regulation (EU) 2024/1735		X		X	
Economic & Financial	Sustainable Europe Investment Plan (SEIP)	X	X	X	X	X
	EU Taxonomy - Regulation (EU) 2020/852	X	X	X	X	X
	Strategic Technologies for Europe Platform (STEP) - Regulation (EU) 2024/795		X	X		
	European Agricultural Fund for Rural Development	X	X		X	X
Soft	EU Ecolabel	X	X	X	X	X
	Green Public Procurement (GPP)	X	X	X	X	X
Hybrid	Fit for 55 Package	X	X	X		
Total	Policy Instruments per Living Lab	13	13	23	17	15

The policy map includes 28 policies, and all the four types of instruments introduced in the framework are represented, with a majority of 20 being classified as regulatory. In terms of distribution of policies impacting the different LLs, the minimum observed is 11 for CeNTI and the maximum is 23 for FILSE, which is closely linked to the maturity of the products produced by each LL. Another highlight is the existence of five overarching policies with a footprint in all the LLs which are The European Bioeconomy Strategy, Ecodesign for Sustainable Products Regulation, SEIP, EU Ecolabel and GPP.

The map covers EU policies from a time frame of more than 20 years, with instruments from 2003 such as the GMO Framework to 2024 such as the STEP Regulation. Nonetheless, given that most of the final products produced by the LLs are set to take part as ingredients in consumer products, the map may not include all the potential applications and therefore sectors, which is a limitation of the current mapping. Lastly, due to its innovative nature, value-chains and markets may be impacted by policies that are currently under development and will be implemented during this project time frame.

National Policies

All the countries where the LLs are located have a dedicated national bioeconomy strategy, which provides a broad strategic orientation for the development of industrial and business activities. This general framework allows stakeholders to anticipate and identify national policies and targets for the novel value-chains, as well as the relevant institutional stakeholders to engage with in order to discuss challenges and opportunities.

Policy		Living Labs				
Type	Name	CeNTI	ALC	FILSE	IBF	VTT

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Regulatory	Bioeconomy Strategy - Portugal	X				
	Bioeconomy Strategy - Spain		X			
	Bioeconomy Strategy - Italy			X		
	Bioeconomy Strategy - Ireland				X	
	Bioeconomy Strategy - Finland					X

3.3. Policy Analysis

The policy analysis, in line with the policy mapping, combines inputs and views derived from the LLs and EuropaBio's work at EU level and therefore, includes bottom-up and top-down perspectives. The analysis is divided into five categories: **supply-chain, regulatory, investment, public understanding and EU-National alignment**. In each category, current and potential hurdles and opportunities are highlighted and supported by examples or connected to specific policy instruments. Lastly, the analysis does not provide recommendations but rather identifies points in which new or updated policies may be able to enable investments at scale and market access, and therefore, support the development of these new value chains.

3.3.1. Supply-chain

The creation of new supply chains on a scale is a challenging and long-term task and therefore needs to be driven by stable and clear incentives for the different stakeholders involved. In this case, incentives should address primary producers and potential manufacturers or industries, to ensure a level-playing field for the new bio-based products to enter the market, in comparison with the existing ones. Additionally, incentives should prioritize sustainability criteria to ensure that side streams and by-products have a cascaded use, such as food-feed-fertilizers. First, soft policy instruments may for instance, promote the creation of regional and national networks of primary producers and industries to foster connection and collaboration between parties. This link is key to ensure a reliable source of feedstock, and it is showcased in this project by **CeNTI**'s strong connection with Portuguese rice producers. Second, bio-based feedstock has high price fluctuation, due to its seasonality, availability and inputs' costs which may undermine the entire value-chain. Therefore, financial policy instruments are of key importance to, during the supply-chain development, maintain a competitive price range to benefit all stakeholders and support bioeconomy development. An example highlighted by **ALCARAS** is the impact of organic fertilizers price and quality on farmers' activities and the importance of remaining competitive in a global market. Policy instruments, such as **CAP** and **CFP** should cover and/or reinforce these points, in order to support the development of the primary sector through an optimization of its supply chains and a diversification of its activities.

3.3.2. Regulatory

Innovative products face regulatory challenges, as they may have difficulty adapting to existing regulations or falling under multiple, incompatible regulations. This hurdle is observed in different parts of the value chain from feedstock permissions to market access. In addition, existing regulations can have different levels, such as national and EU, which leads to a complex situation to be navigated by stakeholders. The access to raw materials from the primary sector should be well defined and cover the diversity of sources, as well as their main priority uses in order to provide stakeholders with a clear and stable framework. In this project and as an example, **ALCARAS** noted the need to comply with national register requirements and to ensure compliance with multiple regulations related to compost production, waste management, and biogas generation. An example of a policy instrument addressing this is the **Waste Framework Directive**. Additionally, in the feedstock topic, **FILSE** also highlights the lack or inadequate regulation that limits the use of **Animal By-products** in the food sector, leading to a missed opportunity and additional burden to the industry for upstream processing. Furthermore, an updated

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GMO Framework could lead to the inclusion of this technology in existing processes such as the ones conducted by **IBF** or **VTT** and potentially lead to their optimization. On the other end of the value-chain, innovative products such as **Novel Foods**, which may result from **FILSE** and **VTT**, face a regulatory burden that leads to high levels of bureaucracy and a slow regulatory process. This obstacle might disincentivize stakeholders to innovate and invest in Europe, compared to other geographies that show more flexible and updated regulations such as the US or Singapore. Additionally, also in the food sector, **FILSE** points out the need to create a definition of "food loss", improve the definition of "food waste" and the inclusion of upcycling criteria to build an adequate regulatory framework and promote the valorisation of waste and by-product streams, to obtain new value-added products.

3.3.3. Investment

The creation of new supply chains requires the scaling-up of technologies and facilities in order to transfer laboratory processes into industrial ones. Furthermore, the level of technological intensity linked to the conversion processes demands a highly skilled workforce. As an example, **VTT** points out that equipment for piloting scale already costs around 1M euros, including fermenters and downstream processors. Moreover, **IBF** plan to build a full-scale biorefinery also demands the attraction of investment. The availability of financial policy instruments is therefore key for stakeholders to develop and grow their activities. Additionally, these instruments need to be adapted, and tailor made to the sector needs, considering that processes are technology and research intensive and may require high volumes of capital during a long-time spam, in order to refine and deploy the process to an industrial scale. Recently, the European Commission launched the **STEP Regulation** which is an answer to this challenge and supports biotechnologies. However, a longer term and overarching solution is to apply the **EU Taxonomy** in all the different sectors, including food, and promote the bioeconomy as a whole.

3.3.4. Public Understanding

Public understanding of the technologies and products emerging from these value-chains is an important step to promote market uptake and the bioeconomy. Therefore, the ability to involve a broader stakeholder group and civil society within the product development process and create feedback loops may produce significant benefits in the long run. Nevertheless, the technologies' complexity and the innovative nature of feedstock (e.g., waste) are challenges that require equally innovative approaches and ways to communicate science. **CeNTI** noted the importance of public understanding of the comparative results of biosilica vs synthetic silica. In line with that, **VTT** also pointed out the need to involve citizens in the process as consumer products are made with novel ingredients that were recently introduced into the markets and with which civil society may not be familiar with yet. To address this, soft policy instruments are essential tools to improve awareness and understanding and require a concerted effort from public and private stakeholders in order to be effective. Examples of existing instruments are the **EU ECO Label**.

3.3.5. EU-National Alignment

A successful approach to value-chains creation and specifically for investment to scale and market access needs to ensure alignment between the product/project, national strategy and EU strategy. On one hand, stakeholders need to ensure that their product complies and is supported by national policies, which is noted by **CeNTI** alignment with the Portuguese Government in terms of "efficient and rational use of natural resources, reducing dependence on imported resources, creating new economic opportunities and contributing to long-term competitiveness" and by **IBF** alignment with the Irish Government's Climate Action Plan. On another hand, policymakers at National and EU levels need to coordinate strategies and actions in order to ensure a smooth deployment from EU policies to national implementation, as well as effective feedback from national governments to EU policy makers. As observed, all five countries where LLs are located have bioeconomy

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strategies in place and so does the EU with **The European Bioeconomy Strategy** and therefore, their alignment is key. The EU strategy needs to be reflected into national strategies and simultaneously, evolve from guidelines into actionable policy instruments in order to provide a clear framework for implementation at regional and local levels and support stakeholders like SMEs and researchers in their activities.

3.4. Conclusion

Overall, the EU is already promoting the development of new value-chains for the bioeconomy through policies such as the EU Bioeconomy Strategy, Waste Framework Directive or Green Public Procurement. Nevertheless, other policies need to be updated or adapted such as GMO Framework, Novel Foods and Taxonomy to follow the latest scientific updates, make processes faster and more agile and financially support the shift to the bioeconomy. The LLs are a source of evidence to support future policymaking.

4. Investment Options In Bioeconomy

In this section, we will conduct a thorough analysis of **investment opportunities** in the bioeconomy, focusing on **potential risks** and **barriers** to entry. We will provide tailored recommendations for investors interested in this sector, helping them navigate the complexities of bioeconomy investments. Additionally, the report will identify key partners and stakeholders, including research institutions and government agencies, that can offer support and collaboration opportunities for investors. This information will help us to take it into account in the development of CBMBs.

4.1.1. Investment opportunities

The bioeconomy in the EU offers a range of investment opportunities, driven by the need for sustainable and renewable resources.[1] Key areas include:

- Bio-based products and processes: Investments in bio-based materials, chemicals, and bioplastics are growing due to their potential to replace fossil-based products.
- Bioenergy: Renewable energy sources such as biofuels and biogas are crucial for reducing carbon emissions.
- Food Systems: Innovations in sustainable agriculture, aquaculture, and food processing offer significant opportunities.
- Circular Bioeconomy: Projects that focus on waste management and recycling of biological materials are gaining traction.
- Regional Innovation Valleys: Initiatives like the Regional Innovation Valleys for Bioeconomy and Food Systems (RIV4BFS) aim to support local bioeconomies and create new value chains.

There are many Bioeconomy Financing Programmes in place that allow to finance project at different development stages, and in the third phase of the project development, the project promoter can assess the different funding types and their potential risks. The Circular City Funding Guide, provides an overview of funding types that are applicable for projects at different development stages with varying risk profiles, including for example Equity, Grants, and Debt.

[1] Strategy, U. B. (2018). A sustainable bioeconomy for Europe: strengthening the connection between economy, society and the environment. European Commission. –2018.

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Figure 31 shows the many funding choices that the bioeconomy project coordinator may select based on the project's level of development.

Making a distinction between public and private financing options is crucial when determining which type(s) of funding will best support the development of the project. Applications for grants differ significantly from those for other forms of support, and this distinction must be taken into account. For instance, some of the most popular public funding programs in Europe are LIFE, Interreg: European Territorial Cooperation, Horizon 2020 and Horizon Europe, European Institute of Innovation and Technology (EIT), European Structural & Investment Funds, and Urban Innovation Actions (UIA). For a comprehensive overview the reader can refer to the list of relevant grant programmes to Circular City initiatives.

Other forms of financing are typically less regulated and dependent on a financial institution. Options include addressing EU financial institutions like the European Investment Bank (EIB) or the European Bank for Reconstruction and Development (EBRD), as well as taking into account financial institutions in the private sector (e.g., banks, investors, vendor financiers).

Debt

- A contractual agreement between a borrower (project/company) and lender (often banks). The borrower pays back the loan before a specified date, usually with a specified (annual) interest rate.
- Suitable for CSS from "scale-up" to "Mature" level

Equity

- Funding type in which the founder invest money for a share in a project gaining a return from dividends or sales at increased value
- Suitable for CSSs from "R&D" to "Growth" level

Quasi-equity (venture debt)

- Financing instrument that combines the elements of equity and debt, and where the capital is paid back based on the performance of the project
- Quasi-equity is specially applicable to (innovative) SMEs and mid-caps seeking to invest in R&D. Due to the equity component, the firm is given a more generous schedule for repayment of the loan than would be the case with a traditional loan.

Grants and subsidies

- Grants and subsidies are offered by governments as different governing levels (local, national, EU) and imply that the funder gives money to support a project stimulating necessary developments. Projects usually do not need to repay the money back, provided that the grantee complies with the contractual agreements
- Especially suitable for "R&D" and "Start-up" CSS level

Alternative forms of funding

- Alternative forms of funding including: crowdfunding, lease financing, social impact bonds (SIB) and other financial instruments (e.g. green bonds, revolving loan facilities)
- Especially suitable for "R&D" CSS level

Guarantee

- Loan guarantees and commitments in which a third party takes over (part of) the debt obligations in the cast the borrower defaults (i.e., fails to repay the debt). Thereby, guarantees enable financial institutions to invest in business or initiatives showing higher default risk, such a highly innovative Circular City initiatives.
- Generally suitable for "R&D" and "Start-up" CSS level

Figure 31.Funding options (elaborated on the Circular City Funding Guide). Adapted from the CCRI methodology.[Error! Bookmark not defined.]

Some of the most important financing programmes at EU level are the following:

HORIZON EUROPE - CLUSTER 6 (Food, Bioeconomy, Natural Resources, Agriculture and Environment): This cluster addresses the interlinked challenges of safeguarding the natural resource base, resilient biodiversity and ecosystem services, restoring and sustaining the health of our planet, sustainable agricultural, forest, marine and freshwater production, promoting alternatives to fossil-based economies, sustainable consumption, closing nutrient cycles, and food and nutrition security.

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At its heart is the circular economy, which aims to maintain the value of land, products, materials, and resources for as long as possible through a cascade of dematerialisation and sustainable use by design, reuse, remanufacture and recycling of materials. It is an essential contribution to the EU's efforts to develop a sustainable, low-carbon, resource-efficient and competitive economy. A sustainable bioeconomy is the renewable segment of the circular economy.

The Commission has proposed that R&I priorities for Horizon Europe will be on Environmental Observation, Biodiversity and Natural Capital, Agriculture, Forestry and Rural Areas, Circular Systems, Bio-based Innovation Systems, Food Systems, and Seas, Oceans and Inland Waters. Together these priorities address key aspects and enablers within a circular and sustainable bioeconomy.

HORIZON EUROPE - CLUSTER 5 (Climate, Energy, and Mobility): This clusters aims to fight climate change by better understanding its causes, evolution, risks, impacts and opportunities, and by making the energy and transport sectors more climate and environment-friendly, more efficient and competitive, smarter, safer and more resilient.

The areas of intervention consist on the following: climate science and solutions, energy supply, energy systems and grids, buildings and industrial facilities in energy transition, communities and cities, industrial competitiveness in transport, clean, safe and accessible transport and mobility, smart mobility, energy storage.

BIO-BASED INDUSTRIES JOINT UNDERTAKING: was a partnership between the European Union and the Bio-based Industries Consortium (BIC), established in 2014. It aimed to invest €3.7 billion by the end of 2024, with €975 million from the Horizon 2020 budget and the rest from industry. By the time the last Horizon 2020 call was completed, BBI JU had funded over 140 projects and was on track to achieve a leveraging effect of 2.8. The focus had been on scalability and replicability, particularly through larger budget, higher Technology Readiness Level (TRL) Demo and Flagship projects.

In November 2021, the CBE JU - Circular Bio-based Europe Joint Undertaking took over the activities of the BBI JU. This new Joint Undertaking is operating under the rules of Horizon Europe, the EU’s research and innovation programme, for the 2021-2031 period.

CIRCULAR BIO-BASED EUROPE JOINT UNDERTAKING: CBE JU is a €2 billion partnership between the **European Union** and the **Bio-based Industries Consortium (BIC)** that funds projects advancing competitive circular bio-based industries under Horizon Europe, the EU’s research and innovation programme.

LIFE is the European Programme for co-financing projects that demonstrate or pilot solutions that tackle environmental (including circular economy, nature and biodiversity) or climate issues. The general objective of the programme is to contribute to the implementation, update, and development of effective policies and legislation in these areas. LIFE was created already in 1992 and has an active budget of EUR 3.4 billion for the period of 2014-2020. The instrument is structured in sub-programmes: one for Environment (representing 75% of the total budget) and one for Climate Action (representing 25%). Both are structured by three priority areas.

INNOVATION FUND is one of the world’s largest funding programmes for the demonstration of innovative low-carbon technologies. The funding originates from credits of the Emission Trading Scheme (ETS). The Innovation Fund can be seen as one of the key funding instruments for delivering the EU’s economy-wide commitments under the Paris Agreement and supporting the European Commission’s strategic vision of a climate-neutral Europe by 2050.

The Innovation Fund supports cross-cutting projects on innovative low-carbon solutions that lead to emission reductions in multiple sectors, for example through renewable energy generation or industrial symbiosis. Since transitioning to a circular economy can involve energy-intensive practices, such as recycling and recovering

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materials, the demand for clean energy technologies will increase. The Innovation Fund can therefore contribute significantly to speeding up the circular economy transition.

The Common Agricultural Policy (CAP) was launched in 1962 and it is a partnership between Europe and its farmers targeting to assist farmers and enhance agricultural productivity to ensure a consistent supply of affordable food, protect EU farmers' livelihoods, address climate change and sustainably manage natural resources, preserve rural areas and landscapes throughout the EU, and sustain the rural economy by fostering employment in farming, agri-food industries, and related sectors. The CAP is managed and funded at European level from the resources of the EU's budget. It is financed by two funds the European Agricultural Guarantee Fund and the European Agricultural Fund for Rural Development with a planned budget of 264.1 billion € between 2023 and 2027.

CAP is taking the following actions to meet the objectives:

- Income support, by providing direct payments, it guarantees income stability for farmers and compensates them for practicing eco-friendly farming and offering public services
- Market measures, to deal with difficult market situations
- Rural development measures, with national and regional efforts to tackle the unique needs and challenges of rural areas

The loans and equity programmes that apply to the bioeconomy are:

The **European Investment Bank Group** consists in the European Investment Bank (EIB) and the European Investment Fund (EIF).

The **European Investment Bank** is the lending arm of the EU, aiming to speed up the green transition, enhance tech innovation, strengthen security and defence, and improve regional unity and social infrastructure. The EIB provides loans up to 50% of the total costs in projects of the primary sector like agriculture and forestry, blue economy and solid waste management. The minimum amount of loan is 7.5 M for projects of 15 M€.

- The European Fund for Strategic Investments (EFSI), started by the EC and EIB in 2015, offers guarantees for funding high-risk projects like those in agriculture and bioeconomy that the EIB wouldn't normally fund.
    - In April 2020 it was launched the **Agricultural and Bioeconomy Programme Loans** under EFSI supporting SMEs and Mid-Caps operating throughout the value chains of production and processing of food, bio-based materials and bioenergy. Direct loans for private sector investments range from €15 million to €200 million, with EIB loans starting at €7.5 million and going up to €50 million.
- InnovFin - EU Finance for Innovators is a partnership between the European Investment Bank Group and the EC under Horizon 2020. It offers direct or indirect funding for research and innovation to both small and large innovative companies through various InnovFin products. The funding range is between 25000€ and 500 million € through direct financing for larger business or indirect financing for early-stage enterprises and SMEs.
    - The **European Circular Bioeconomy Fund** supported by an InnovFin guarantee, it aims for a total of €250 million, with the EIB contributing up to €100 million funding bioeconomy projects and companies in demonstration and commercial development phases.

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- The **Natural Capital Financing Facility** is a financial tool from the EIB and EC that supports bioeconomy projects focused on biodiversity and climate adaptation with customized loans and investments.

4.1.2. Potential risks and barriers

Bio-based industries (BBI) and Blue Economy (BE) are the key focus sectors to the Bioeconomy strategy. BBI refers to the sector that utilizes renewable biological resources to create bio-based products and biofuels. BE refers to the number of economic activities referred directly it indirectly in maritime environments.

BBI and BE projects face **issues** to access to private capital. This is due to the lack of interest from the private sector because the absence of understanding they have on bioeconomy. There also perceive the **market as very risky due to the information asymmetry and the technological risk**. Private investors prefer to invest in more mature and technologically advanced projects but at the same time they perceived operational and technological risks coupled with a lack of information. Additionally, they grasp the instability of the market and the fluctuating demand for its products.

The regulation of the market and the demand framework are the most important incentives to promote the bioeconomy, but they also have the major risks suck as:

- **Market and demand risks**: The major business risk for BBI and BE investments is the **lack of developed markets** and **insufficient demand**, influenced by regulation.
- **Regulatory risks:** The second highest business risk and the main challenge for BBI and BE activities is the **absence of a stable, supportive EU regulatory framework**.
- **Financial market concerns**: While recognizing the need for a stable regulatory framework, financial market participants worry about **potential market distortions**.
- **Operational and technological risks**: For BBI projects, risks during the **demonstration phase and scaling up to flagship operations are significant**, along with **complex legal procedures** for BE projects.
- **Financial risks:** Bioeconomy projects face financial risks due to **low or volatile profitability** and cash flow because of the **variable prices of the inputs** (feedstock) and **outputs** (products), **especially in early stages**, and the large capital expenditures required.
- **Societal challenges**: Public perception and the green premium (the additional cost of clean-technology or clean energy production) on bioeconomy products affect access to finance.
- **Public funding issues**: Public funding mainly targets R&D phases, with complicated application procedures and insufficient size and terms, limiting its effectiveness in mobilizing private capital for later project phases.

Another barrier of the bioeconomy is the funding gaps, European programmes like grants are usually not sufficient to finance all the project because of the increase of size and technological maturity in the projects and there is a need to find funding in the private sector, whereas said before there is a lack of interest.

- This problem is usually present in projects that they move from the pilot to the demonstration plant phase, and, especially in BBI moving from demonstration to industrial-scale phase.[2]

[2] https://www.eib.org/attachments/pj/access_to_finance_study_on_bioeconomy_en.pdf

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4.1.3. Solutions to this potential risks

To the risks presented above, there are some solutions identified.

Bioeconomy strategies are a key trigger for private capital. Programmes such as grants, equities and debts together with the Bioeconomy strategy help to accelerate the deployment of a sustainable circular business models. The action plan of these programmes is to strengthen and scale up the biobased sector unlocking investments and markets, deploy local bioeconomies rapidly across Europe and understand its ecological boundaries.[2] [3]

It is essential to establish an effective regulatory framework for BBI and BE at EU level. Reducing regulatory uncertainty can lessen market and demand risks. Policies should show a long-term commitment to supporting green alternatives to fossil-based products across the entire value chain, while still allowing market forces to function. These policies should focus on ensuring stable prices and availability of biomass inputs, as well as creating consistent demand.

Another initiative that would help mitigate the different risks is to reinforce awareness of the different EU project that help funding circular business model in bioeconomy. Interviews with project promoters and investors reveal that, apart from grant funding, many project promoters are not well aware of available EU-level risk-sharing funding tools. Many bioeconomy promoters lack familiarity with EIB-EC financing schemes like InnovFin and EFSI, indicating information gaps and the need for more targeted outreach.

It is also necessary to develop an EU risk-sharing financial instrument dedicated to circular business model in bioeconomy, capable of addressing the multiple types of identified project risks of variable intensity, across different stages of projects' technological maturity, and be flexible in terms of size to cover both small and larger project capital needs. It needs to be in form of debt or similar creating a new investment platform dedicated to bioeconomy. Which offers flexible investment criteria and the ability to combine multiple funding sources. It can also implement stage-based mechanisms that adjust risk absorption according to the project's stage and technological maturity, addressing funding gaps identified in the study.

Finally, another possible solution is to create EU-wide network where share all the information and knowledge about the sector and facilitate contact between projects promoters, researchers, industry experts and authorities. An EU platform could significantly aid the shift to a bioeconomy by increasing awareness among project promoters and investors, enhancing project bankability, optimizing the use of existing EIB tools, and evaluating the need for new financing mechanisms. The European Commission's leadership, supported by the EIB, and potential member states ministries, would show a strong commitment to green alternatives to fossil-based products through clear signals and policy action.[2]

4.1.4. Potential partners and stakeholders for support and collaboration

To expand and promote bioeconomy projects, in particular, circular business models, there is a need for partnerships to invest, support and collaborate in this project to help develop them. In addition, to search for stakeholders to help finance them.

Some companies dedicated to boost bioeconomy projects are:

- Wolaria: This is an acceleration program aimed at companies and entrepreneurs in the field of the bioeconomy in Castilla y León.

[3] https://research-and-innovation.ec.europa.eu/research-area/environment/bioeconomy/bioeconomy-strategy_en

- Jamk: It is a University in Finland that serves as a global partner for organizations looking to develop their personnel or enhance their entire education systems. It has a programme dedicated to boost bioeconomy projects
- Ainia: It is a company that boosts company competitiveness through innovation. It has joined the Spanish Ministerio de Agricultura, Pesca y Alimentación to start StartBEC, a mentoring and technological support program that provides selected companies with the necessary tools to identify, plan, and solve technical challenges throughout the development and launch of innovative products to the market.

There are also some EU projects to accelerate the development of bioeconomy projects:

- Bioboosters: It brings together bio-based businesses in rural areas to share the know-how in circular production and trigger green business opportunities.
- Bioboost (agriculture): It aims to inspire, connect and stimulate biobased initiatives with horticulture worldwide.
- Bioboost: The program offers support services for bioeconomy projects and technological innovation, aiming to mobilize 30 million euros in additional investment for the Catalan bioeconomy sector by 2026.
- Bioeconomy and Circular Economy High Tech Incubator: It provides facilities, scientific and technological equipment, and advanced services to support the creation of new tech-based companies and accelerate bioeconomy and circular economy projects.

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5. Impact Monitoring Indicators And Methodologies

In this section, we will conduct a comprehensive review of the existing knowledge base on **impact monitoring indicators and methodologies** within the bioeconomy sector. This task is crucial as it will help us assess the current state of knowledge by examining academic literature, industry reports, and other relevant sources. Our focus will be on identifying key impact monitoring indicators—such as **economic, social, and environmental indicators**—and the methodologies used to evaluate them, both qualitative and quantitative. Additionally, we will analyse the strengths and weaknesses of these methodologies, identifying gaps and opportunities for improvement. This thorough review will provide a solid foundation for enhancing impact monitoring practices in the bioeconomy sector.

To achieve this, we propose a set of **economic, social, and environmental indicators** specifically designed to evaluate the new value chains developed during the PRIMED project. These indicators are tailored to the distinct sectors under consideration—**agriculture, forestry, and fisheries**—as primary producers are key stakeholders in the **Circular Bio-based Business Models (CBMBs)**. This approach is crucial for capturing the unique dynamics of each sector and ensuring that the circular bioeconomy model effectively integrates primary producers.

To monitor the impact of the new CBMBs, we will utilize the indicators outlined in the following subsections.

5.1. Key economic indicators for monitoring a bioeconomy project

The selection of economic indicators for a bioeconomy project must be aligned with the project's type, scale, and objectives. Below, we outline key economic indicators specifically designed for monitoring real-world bioeconomy projects, focusing on both project performance and broader economic impacts. These indicators assess the economic benefits for primary producers, including changes in income and cost savings at both the project and regional levels. Additionally, we will consider market-level dynamics and sustainable economic indicators to capture long-term economic viability.

5.1.1. Project-Level Economic Indicators

These indicators focus on the direct economic contributions of the project itself. They are listed by importance.

- ***Project-Specific Gross Value Added (GVA):*** Measures the economic value generated directly by the project.[i] This includes the value of the bio-based products or services minus the cost of intermediate inputs. It reflects the project's contribution to regional or national economic output.
- ***Revenue Growth from Bio-Based Products:*** Tracks the project income from selling bio-based products or services over time[ii]. This indicator helps assess market demand and the competitiveness of the bio-based products compared to conventional alternatives.
- ***Return on Investment (ROI):*** Measures the financial return of the project compared to the initial investment.[iii] This indicator is critical for evaluating the economic viability of bioeconomy ventures and attracting further investment. The advantage of using ROI is its straightforwardness; stakeholders can quickly understand the financial returns relative to their investments, which is crucial for attracting investors and securing funding. However, calculating ROI can be complex, especially when accounting for externalities or long-term benefits that are not immediately quantifiable.
- ***Cost of Production:*** Monitors the cost of producing bio-based products or energy per unit.[3] This includes inputs such as raw biological materials, energy, water, labor, and capital. Tracking this indicator helps assess whether production is becoming more efficient over time.

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- ***Energy and Material Use Efficiency:*** Tracks how efficiently the project converts raw biological inputs into finished products or energy.[iv] Improving efficiency reduces costs and increases competitiveness, while also contributing to environmental sustainability.
- ***Number of Jobs Created:*** Assesses the direct employment generated by the project. This includes jobs in production, R&D, logistics, and marketing. Employment creation is a critical indicator, especially in rural or economically disadvantaged regions.
- ***Local Supply Chain Development:*** Monitors how much of the project's supply chain is sourced locally. This indicator captures the project's capacity to stimulate local economic activity by purchasing goods and services from nearby suppliers, creating secondary economic benefits.
- ***Expenditure on Research and Development (R&D):*** Tracks how much the project is investing in innovation, product development, and technological advancements. Bioeconomy projects often require continuous R&D to improve efficiency and create new bio-based products.

5.1.2. Regional/Community-Level Economic Indicators

These indicators assess the project's broader economic impact on the local or regional economy.

- ***Indirect and Induced Employment (Multiplier Effect):*** Evaluates the number of jobs created indirectly through the project’s supply chain (e.g., agriculture, logistics, maintenance) and through induced economic activity in the region, including production, services and retail.[v] These ripple effects extend the economic benefits beyond the project itself. However, measuring the indirect and induced employment can be challenging, as it often relies on complex economic models and assumptions about consumer behaviour. The difficulty in quantifying these effects can lead to overestimations, resulting in inflated expectations about job creation[vi].
- ***Contribution to Local Tax Revenue:*** Monitors the taxes generated by the project for local and regional governments.[vii] This includes taxes on wages, profits, and property, which support public services and infrastructure. By illustrating this financial contribution, the indicator can serve as a persuasive tool for justifying public investments and incentives.
- ***Infrastructure Development:*** Tracks improvements in local infrastructure (roads, utilities, internet) catalyzed by the project[viii]. These developments often benefit not only the bioeconomy project but also the broader local economy. Nevertheless, these infrastructure improvements typically require significant upfront investments and may not yield immediate benefits. There is also the risk that such developments may not be evenly distributed among all community members, potentially leading to disparities in access and benefits.
- ***Economic Diversification:*** Measures the extent to which the project contributes to diversifying the local or regional economy.[ix] In many cases, bioeconomy projects can help reduce reliance on a single sector (e.g., traditional agriculture or fossil fuels) by creating new bio-based industries. This diversification can enhance economic resilience, fostering innovation and the growth of new industries that contribute to long-term sustainability. Economic diversification is often a gradual process, and the immediate benefits may not always be evident.

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5.1.3. Market-Level Economic Indicators

These indicators measure the project's impact on the broader bioeconomy market and its competitiveness.

- ***Market Share of Bio-Based Products:*** Tracks the project's ability to gain market share in specific bioeconomy sectors, such as bioenergy, bioplastics, or bio-based chemicals.[x] This reflects the project's competitiveness and ability to replace fossil-based or conventional alternatives.
- ***Added Value of Bio-Based Products:*** Measures the added value created by bio-based products. [xi]
- ***Price Competitiveness of Bio-Based Products:*** Monitors the price of bio-based products compared to traditional products.[xii] A competitive price is critical for bioeconomy projects to penetrate the market and achieve broader adoption.
- ***Export Growth of Bio-Based Products:*** If applicable, this indicator monitors the expansion of bio-based products into international markets.[xiii] It reflects the project's success in accessing global demand and generating foreign income.
- ***Technology Transfer and Patents:*** Assesses the project's ability to generate new technologies and intellectual property (IP) in the form of patents or technology transfers.[xiv] A strong IP portfolio can enhance the project's market position and attract investors.

5.1.4. Sustainability-Linked Economic Indicators

Given that bioeconomy projects often emphasize sustainability, it is important to track economic performance alongside sustainability metrics.

- ***Cost Savings from Resource Efficiency (Circular Bioeconomy):*** Measures how much the project is saving by reducing, reusing, or recycling materials and waste.[xv] Circular bioeconomy initiatives often yield cost savings, improving the project's economic and environmental sustainability.
- ***Green Financing Attracted:*** Tracks the level of investment from sustainable finance sources, such as green bonds, impact investors, or government grants tied to sustainability performance.[xvi,xvii] Access to green financing is a sign of the project's credibility and alignment with sustainability goals.
- ***Revenue from Carbon Credits* or *Ecosystem Services:*** If the project contributes to carbon sequestration[xviii] or the provision of ecosystem services[xix] (e.g., water purification, soil restoration), this indicator tracks income from carbon credits or payments for ecosystem services. This can provide an additional revenue stream for the project.

5.1.5. Discussion of Economic Indicators

Developing CBMBs requires a careful selection of economic indicators that align with both the goals of sustainability and the practicalities of economic viability. Each category of indicators—project-level, regional/community-level, market-level, and sustainability-linked—offers valuable insights into various aspects of bioeconomy projects. However, some indicators are more pivotal than others when it comes to the successful implementation and scaling of CBMs. In addition, Kulakovskaya et al. (2023)[xx], who performed a critical review of these indicators, argued that, differently to the environmental methods such as LCA or MFA, systematic methods are missing for the economic analysis of CBMBs on a value-chain level. We therefore comment here the 4 other levels of indicators presented above, discussing their advantages and drawbacks.

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Among the **Project-Level Economic Indicators**, *Project-Specific GVA* and *Revenue Growth from Bio-Based Products* are paramount. GVA captures the economic value generated directly by the project, providing stakeholders with a clear understanding of its contribution to local or national economies. This is particularly important for justifying investments and policy support for bioeconomy initiatives. *Revenue growth* is equally crucial as it directly indicates market demand and competitiveness. Both indicators help in establishing a strong business case for bio-based products and can drive further investment. *ROI* is also significant but may present challenges in terms of complexity in calculation. It is vital for attracting investment; however, it often requires robust data on future benefits and externalities. While *Cost of Production* and *Energy and Material Use Efficiency* are important for assessing operational viability, they primarily serve to refine and optimize existing processes rather than drive initial investment decisions. Similarly, while *Local Supply Chain Development* and *Expenditure on Research and Development (R&D)* are essential for long-term sustainability and innovation, they may not provide immediate economic insights as compared to GVA and revenue growth.

For assessing **Regional/Community-Level Economic Indicators**, *Indirect and Induced Employment* and *Economic Diversification* emerge as critical indicators. Indirect and induced employment capture the ripple effects of bioeconomy projects on the local economy, providing a more holistic view of the project's impact. This is particularly important in regions reliant on traditional industries, as the creation of jobs in new sectors can significantly enhance economic resilience. Contribution to *Local Tax Revenue* also plays a significant role in reinforcing community support for bioeconomy projects. Demonstrating that a project generates tax revenue can be a persuasive argument for obtaining public funding or subsidies. However, *Infrastructure Development* is more of a long-term benefit and may not yield immediate economic returns. While it enhances the capacity for future growth, the initial investments required can deter stakeholders focused on short-term gains.

In terms of **Market-Level Economic Indicators**, *Market Share of Bio-Based Products* and *Price Competitiveness* are the most crucial. *Market share* provides insights into how well a bioeconomy project is performing relative to conventional products, which is vital for assessing competitiveness and market acceptance. *Price Competitiveness* is similarly critical; without competitive pricing, bio-based products may struggle to penetrate the market. *Export Growth of Bio-Based Products* can also indicate a project's ability to access international markets, but it may not be as relevant for all bioeconomy projects, particularly those focusing on local supply chains*. Technology Transfer and Patents* are important for fostering innovation and securing a competitive edge but may not directly correlate with immediate market impact.

The **Sustainability-Linked Economic Indicators** are increasingly vital in a world focused on environmental impacts. *Cost Savings from Resource Efficiency* is essential for demonstrating the economic benefits of adopting circular practices. This indicator highlights how resource efficiency not only supports sustainability but also improves the project's bottom line. *Green Financing Attracted* is also significant, as access to sustainable finance can greatly enhance a project's capacity to invest in innovative solutions and technologies. The potential for generating *Revenue from Carbon Credits* or *Ecosystem Services* serves as a critical indicator of a project's alignment with environmental goals, creating an additional revenue stream that can significantly enhance economic viability.

In conclusion, while all indicators provide valuable insights into the economic viability of CBMB in the bioeconomy, the *Project-Specific GVA*, *Revenue Growth*, and *Indirect and Induced Employment* stand out as the most critical for driving initial investments and demonstrating broader economic impact. Market share and price competitiveness are also paramount for ensuring the long-term sustainability of bio-based products. Sustainability-linked indicators, particularly cost savings from resource efficiency and green financing, are increasingly important for securing financial support and aligning economic goals with environmental objectives.

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5.2. Key Social Indicators for Monitoring a Bioeconomy Project

These indicators help assess the social impacts of bioeconomy initiatives, focusing on aspects like employment, social inclusion, community well-being, and human capital development. They provide insight into how bioeconomy projects affect people and communities.[xxi, xxii]

- Employment Creation and Quality of Jobs
- ***Direct Employment Created:*** Measures the number of jobs directly generated by the bioeconomy project, including those in production, R&D, management, and sales.[xxiii] This indicator helps assess the project's contribution to local and regional employment levels. In particular, it is crucial to monitor the **engagement of entrepreneurs and young people**, as they play a vital role in driving innovation and ensuring the sustainability of the bioeconomy sector. Tracking job creation among these groups will provide insights into the project's ability to foster entrepreneurial initiatives, support startups, and create career opportunities for young professionals. This focus helps ensure that the project not only boosts employment but also nurtures a new generation of leaders and innovators within the bioeconomy.
- ***Quality of Jobs (Wages, Benefits, Job Security):*** Evaluates the quality of employment by monitoring wages, benefits, and job security provided to employees. A bioeconomy project should offer decent work conditions, contributing to workers' well-being and economic stability.

5.2.1. Social Inclusion and Gender Equality

- **Proportion of Jobs for Minorities:** Tracks the percentage of jobs in the bioeconomy project allocated to marginalized groups, including women, ethnic minorities, and disadvantaged individuals[xxiv]. This indicator reflects the project's contribution to social inclusion and equitable employment.
- **Gender Equality in Employment and Leadership:** Monitors the gender balance in the workforce and in leadership roles within the bioeconomy projectxxiv[xxiv]. It assesses whether the project promotes gender equity and provides equal opportunities for men and women.

5.2.2. Skill Development and Capacity Building

- **Training and Education Programs:** Measures the availability and scope of training, reskilling, and education programs provided by the bioeconomy project.[xxv] This indicator assesses the project's role in enhancing local human capital and preparing the workforce for bioeconomy-related jobs.
- **Number of People Receiving Bioeconomy-Related Education:** Tracks the number of employees or community members who receive formal education or training related to bioeconomy sectors (e.g., sustainable agriculture, bioenergy, or bio-based manufacturing).[xxv]

5.2.3. Community Engagement and Participation

- **Local Community Participation in Project Planning:** Monitors the involvement of local communities in the planning and decision-making processes of the bioeconomy project. This indicator measures the extent to which local stakeholders are consulted and have a say in project development.
- **Social License to Operate (Community Support):** Evaluates the level of support from the local community for the bioeconomy project. A strong social license to operate indicates that the project has broad-based community approval and minimal opposition.

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- **Education and trainings:** It measures the extent to which community members, including entrepreneurs and young people, are provided with opportunities to enhance their skills and knowledge in relevant fields such as sustainable practices, bio-based technologies, and circular economy principles.

5.2.4. Health and Safety of Workers and Communities

- **Workplace Health and Safety Incidents**: Tracks the number and severity of health and safety incidents occurring within the bioeconomy project's operations. This indicator reflects the project's commitment to providing a safe working environment.

- **Public Health Impacts of the Project:** Assesses any positive or negative impacts of the project on public health, particularly in local communities. This includes monitoring pollution, exposure to harmful chemicals, or improvements in local health outcomes.

5.2.5. Social Cohesion and Rural Development

- **Contribution to Rural Development:** Measures the project's role in stimulating economic and social development in rural or economically disadvantaged areas. This includes the creation of jobs, infrastructure development, and improved access to services.

- **Impact on Social Cohesion (Community Integration):** Evaluates how the project affects social cohesion in the local community. Positive impacts may include strengthened social bonds and community networks, while negative impacts could involve social displacement or conflict.

5.2.6. Access to Resources and Benefits Sharing

- **Equitable Access to Project Benefits:** Assesses how equitably the economic and social benefits of the bioeconomy project (e.g., income, jobs, infrastructure) are distributed among local stakeholders, particularly marginalized groups.

- **Improved Access to Essential Services (Energy, Water, Education):** Tracks the project's role in improving local access to essential services such as clean energy, water, healthcare, and education. This indicator measures the project's broader social impact on community well-being.

5.2.7. Cultural Heritage and Indigenous Rights

- **Protection of Cultural Heritage and Indigenous Knowledge:** Evaluates the project's respect for and protection of local cultural heritage, traditional knowledge, and indigenous rights. This indicator is particularly relevant in bioeconomy projects based in areas with indigenous populations.

- **Inclusion of Indigenous and Local Knowledge in Project Design:** Monitors the extent to which the project incorporates local and indigenous knowledge into its planning and operations, ensuring that traditional practices are respected and preserved.

5.2.8. Discussion of Social Indicators

The most important social indicators for CBMs in the bioeconomy are **employment creation and quality, social inclusion, skill development, and community participation**. These factors ensure that CBMs are not only economically viable but also socially inclusive, fair, and sustainable, helping to create long-lasting positive impacts on local communities.

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The **number of direct jobs created** is a key indicator, especially for rural areas. It measures the immediate economic impact of the project. However, the quality of jobs, including wages, benefits, and job security, is equally important for long-term social sustainability. High-quality employment ensures that the jobs contribute meaningfully to the well-being of workers and the overall community.

Social inclusion is critical for equitable development, particularly in ensuring opportunities for marginalized groups, such as women and ethnic minorities. Tracking the proportion of jobs for marginalized groups and gender equality in employment and leadership is essential for fostering diversity and fairness in CBMBs, aligning with broader sustainability goals. For the bioeconomy to thrive, a skilled workforce is essential. **Training and education programs** enhance the local workforce's capacity to engage in bioeconomy sectors. This indicator supports long-term economic resilience and innovation within CBMBs. **Local community participation** in project planning is vital to ensure that CBMBs have the support and buy-in of local stakeholders. This fosters a social license to operate, reducing the risk of opposition and enhancing project sustainability.

5.3. Key Environmental Indicators for Monitoring a Bioeconomy Project

5.3.1. Resource Efficiency and Circularity

These indicators assess how efficiently a bioeconomy project uses resources and closes material loops in line with circular economy principles.

- **Material Use Efficiency (Input-Output Ratio)**: Measures the efficiency with which biological inputs (e.g., biomass, agricultural residues) are converted into bio-based products or energy.[xxvi] It reflects the project's ability to minimize waste and optimize resource use.
- **Waste Reduction and Recycling Rates**: Tracks the amount of waste generated and the proportion that is recycled or reused.[xxvii] This indicator helps assess the project's commitment to circularity and resource recovery.
- **Energy Use Efficiency**: Evaluates the amount of energy consumed and the project's efforts to improve energy efficiency or shift to renewable energy sources.[xxviii]
- **Water Use Efficiency**: Monitors the amount of water consumed by the project and evaluates efforts to minimize water use through recycling and conservation techniques.[xxix]
- **Nitrogen Balance and Organic N rate produced:** The N balance includes inflows (N from chemical fertilizers, organic fertilizers, digestates, and sewage sludge) and outflows (N in harvested crops, N leaching, as well as losses of N-N_2O and N-NH_3+NOx. [xxx] The *Organic N rate produced*, accounts for all non-mineral sources locally produced out of the total N added to soils. This indicator expresses the degree of N circularity in the region by estimating the N fertilizer avoided.

5.3.2. Climate Impact

These indicators measure the project's contribution to mitigating or exacerbating climate change.

- **Greenhouse Gas (GHG) Emissions**: Tracks the amount of GHGs emitted by the project, including carbon dioxide, methane, and nitrous oxide.[xxxi] Reducing emissions is a key sustainability goal, especially in bioeconomy projects aimed at replacing fossil fuels.

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- **Carbon Sequestration**: Measures the amount of carbon dioxide captured and stored by the project, such as through afforestation or soil carbon storage[xxxi]. Projects focused on ecosystem services can contribute to climate change mitigation through carbon capture.
- **Lifecycle Carbon Footprint**: Assesses the total carbon emissions associated with the production, use, and disposal of bio-based products[xxxi]. This indicator provides a comprehensive view of the environmental impact over the entire product lifecycle.

5.3.3. Ecosystem and Biodiversity Impact

These indicators assess how bioeconomy projects affect local ecosystems, biodiversity, and land use.

- **Land Use Change**: Monitors the impact of the bioeconomy project on land use, such as deforestation, land degradation, or conversion of natural ecosystems.[xxxii] Projects should aim to minimize negative impacts on land.
- **Biodiversity Impact**: Evaluates the project's effects on local flora and fauna, tracking both positive contributions to biodiversity (e.g., habitat restoration) and negative impacts (e.g., habitat destruction).[xxxiii]
- **Soil Health and Fertility**: Tracks changes in soil quality, including nutrient levels, organic matter, and soil erosion rates. Sustainable bioeconomy projects should contribute to improved soil health, especially those involving agriculture or forestry.[xxxiv]

5.3.4. Sustainable Biomass Sourcing

These indicators ensure that the biomass used in bioeconomy projects is sourced sustainably, without harming ecosystems or depleting natural resources.

- **Sustainability of Biomass Supply**: Measures whether the biomass used by the project is sourced sustainably, following standards such as those from the Forest Stewardship Council (FSC), Organic Farming (OA) or Roundtable on Sustainable Biomaterials (RSB). Sustainable sourcing minimizes deforestation and habitat loss.
- **Renewable vs. Non-Renewable Resources Used**: Tracks the proportion of renewable materials (e.g., agricultural residues, forest waste) versus non-renewable materials used in the project. The goal is to maximize the use of renewable, bio-based resources.
- **Biomass Regeneration Rate**: Monitors the rate at which biomass used by the project is replenished, ensuring that the extraction of resources does not outpace their natural regeneration. Mostly pertinent for wood extraction from forestry, algae production and crop residues use.

5.3.5. Circular Economy Contribution

These indicators reflect the project's success in contributing to a circular economy by maintaining product value through reuse, recycling, and extending product lifecycles.

- **Product Lifecycle Extension**: Measures how effectively the project extends the lifecycle of bio-based products through strategies such as durability, reuse, remanufacturing, or recycling.

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- **Closed-Loop Production Processes**: Tracks the extent to which the project implements closed-loop systems, where materials are continuously reused and recycled, minimizing waste and virgin resource extraction.

5.3.6. Ecosystem Services and Natural Capital

Projects in the bioeconomy often generate or rely on ecosystem services, which can be both direct and indirect contributors to environmental sustainability.

- **Provision of Ecosystem Services (e.g., Water Purification, Pollination)**: Evaluates the project's contribution to maintaining or enhancing ecosystem services like water purification, soil conservation, and pollination[xxxii]. Positive contributions to these services can improve environmental quality and support biodiversity.
- **Natural Capital Impact (Depletion vs. Enhancement)**: Measures the impact of the project on natural capital, assessing whether it depletes or enhances resources like forests, soil, and water.[xxxv]

5.3.7. Discussion of Environmental Indicators

The selection of key environmental indicators for monitoring bioeconomy projects is highly dependent on the context of each project. Each type of bioeconomy initiative, from biorefineries to circular farming, presents different environmental challenges and opportunities.

Resource efficiency indicators are fundamental for all circular CBM projects but take on different importance depending on the context. For a biorefinery project, *Material Use Efficiency* is key to optimizing biomass conversion into multiple valuable outputs (e.g., biofuels, chemicals, and materials). In CBMs of organic urban biowaste recycling, *Waste reduction and recycling rates* would be essential to turn urban waste into valuable bio-based products or compost. Similarly, *Energy use efficiency* will be crucial in CBM including bioenergy to ensure that energy-intensive refining processes rely on renewables or are optimized to reduce consumption. In CBMs including agricultural activities and anaerobic digestion place a higher emphasis, estimating a proper *N balance* is key, since soils are a source and a sink of both elements.

The importance of **Climate Impact** indicators varies depending on the type of CBM project. For a CBM of a biorefinery or producing bioplastics, the *GHG emissions* during both production and disposal stages (especially in the case of biodegradable products) should be tracked. On the other hand, *Carbon sequestration* might be more relevant for circular farming and ecosystem restoration projects, where improving soil carbon content or afforestation contributes directly to mitigating climate change. Estimating *Carbon sequestration in soils* is a complex task that requires updated literature of the C storage capacity of each soil and climate, as well as the C stability of the biomaterials applied to the soil, particularly for biochar amendments[xxxvi]. CBMs that aim to replace petrochemicals must ensure that their *Lifecycle Carbon Footprint* is lower than conventional products to justify their environmental benefits. Also, in bioenergy and biofuels CBMs, the *Lifecycle Carbon Footprint* is paramount, as they are often promoted for their potential to reduce GHG emissions compared to fossil fuels. Monitoring the GHG emissions throughout the production chain is essential for ensuring that the bioenergy process is truly sustainable.

The **Ecosystem and Biodiversity** indicators are essential for CBMBs that interact directly with land and ecosystems. For a CBMBs including farming, *Soil Health* and *Biodiversity Impact* are equally critical as farms should encourage biodiversity and soil fertility. CBMBs with anaerobic digestion and organic urban biowaste recycling projects may have a lower direct impact on biodiversity, but the by-products of these processes (e.g., digestate or compost) can influence soil fertility and nutrient cycles. In these contexts, the emphasis should be

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placed on preventing contamination and promoting healthy ecosystems. *Land Use Change* is a significant factor in biomass sourcing for biorefineries or bioenergy. These CBMs should monitor how biomass harvesting affects natural ecosystems, ensuring that they avoid deforestation or degradation of critical habitats.

Indicators related to **Sustainable Biomass Sourcing** are critical for CBMBs that rely on large amounts of biomass, such as bioenergy, biorefineries, and bioplastics. For CBMBs dealing with bioenergy, *Sustainable Sourcing* is essential to avoid the depletion of forests, overharvesting, or the conversion of land that may have been previously used for food crops. This is particularly relevant in the production of biofuels, where biomass should be sourced sustainably to avoid negative environmental trade-offs. In farming and anaerobic digestion, *Sustainability of Biomass Supply* account to how manure, crop residues, or organic waste are collected and used within closed systems, ensuring that these resources are harvested in a way that soil and water are not depleted.

Circular Economy Contribution indicators apply to CBMBs looking to minimize waste and maximize product longevity. Organic urban biowaste recycling or anaerobic digestion CBMs are prime examples where *Closed-loop Systems* are paramount. The objective is to take urban organic waste, recycle it into compost or bioenergy, and reintegrate the outputs into local food systems or energy grids. In contrast, bioplastics and chemical transformation CBMs should focus on *Product Lifecycle Extension*, aiming to develop durable, reusable, or biodegradable products that minimize waste throughout the entire lifecycle. In this context, extending the durability of bioplastics and ensuring end-of-life recyclability would be a priority.

Ecosystem Services and Natural Capital are involved in CBMs with a direct environmental interface, such as farming and ecosystem restoration initiatives, where measuring how the project contributes to these services is vital to ensure that Ecosystem Services (e.g., pollination, water purification) and *Natural Capital* g the project are enhanced rather than degraded.

In **conclusion**, selecting appropriate environmental indicators requires careful consideration of the CBM type and its specific interactions with the environment. For instance, biorefinery and bioenergy projects might prioritize GHG emissions, energy efficiency, and sustainable biomass sourcing, while farming or organic waste recycling CBMs would place more emphasis on soil health, water efficiency, and waste recycling. Ultimately, the key is to align environmental monitoring with the core processes and impacts of each CBM, ensuring they contribute to both economic viability and environmental sustainability.

5.4. Methodologies for Circular Business Models Assessment

5.4.1. Multi-Criteria Decision Analysis (MCDA)

MCDA is a decision-making framework[xxxvii] used to evaluate complex projects by considering multiple criteria, including environmental, economic, and social factors. MCDA is useful for assessing CBMs as it allows for the inclusion of diverse sustainability indicators and stakeholder preferences[xxxviii]. It involves the comparison of several scenarios that may include the BAU (Business As Usual) as well as circular alternatives.

- **Key Steps**:
  - Criteria Selection: Identifying key performance indicators (KPIs) relevant to the bioeconomy project, such as resource efficiency, greenhouse gas emissions, costs, and social impacts.
  - Weighting: Assigning weights to each criterion based on their relative importance. For example, in a bioenergy project, greenhouse gas emissions may be more heavily weighted than other factors.
  - Scoring: Evaluating the performance of each option or business model based on the selected criteria.
  - Decision-Making: Integrating the scores and weights to rank the options and make an informed decision.

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- **Application to CBMs**:
  - Circular Farming Projects: MCDA helps farmers assess trade-offs between economic viability (e.g., yield, costs) and environmental sustainability (e.g., biodiversity, water use).
  - Biowaste Recycling: MCDA can be applied to choose the most appropriate biowaste recycling technology (e.g., composting, anaerobic digestion) by considering technical, environmental, and economic performance.
  - Bioenergy Projects: MCDA is useful for evaluating bioenergy options, comparing different feedstocks, conversion technologies, and their impacts on climate change, air quality, and economic returns.
- **Strengths**:
  - Combines quantitative and qualitative data, allowing a holistic evaluation of sustainability trade-offs.
  - Flexible and adaptable to different project contexts and stakeholder preferences.
  - Challenges:
  - Requires subjective judgment in assigning weights to different criteria.
  - The results may vary depending on the selected criteria and stakeholder input.

MCDA SWOT analysis

Strengths	Weaknesses
▪ *Versatility:* MCDA can incorporate a wide range of qualitative and quantitative criteria, making it suitable for evaluating sustainability, economic viability, and social impacts of circular business models. ▪ *Transparency and Structure:* MCDA provides a structured and transparent decision-making framework that can clarify trade-offs between competing objectives (e.g., between environmental and economic outcomes). ▪ *Stakeholder Engagement:* It allows the inclusion of various stakeholder preferences, enabling a participatory approach to decision-making. This is particularly relevant for projects with diverse community and industry stakeholders.	▪ *Subjectivity in Weighting:* One challenge of MCDA is that assigning weights to criteria can be subjective, often influenced by decision-makers' or stakeholders' preferences, leading to potential bias. ▪ *Data Intensity:* The quality of an MCDA heavily depends on the availability and reliability of data, and gathering comprehensive data across multiple criteria can be time-consuming and resource-intensive. ▪ *Complexity:* For large and complex projects, MCDA models can become highly complex, requiring advanced expertise to execute and interpret results effectively.
Opportunities	**Threats**
▪ *Integrating Circularity Goals:* MCDA can be adapted to prioritize circular economy principles, such as resource efficiency and waste reduction, in projects like organic urban biowaste recycling or bioenergy. ▪ *Policy Alignment:* MCDA can help bioeconomy projects align with sustainability policies, providing clear assessments that highlight their compliance with environmental or regulatory goals.	▪ *Complexity for Non-Experts:* Some MCDA methods may be too complex for stakeholders unfamiliar with decision-analysis techniques, which could limit stakeholder engagement, especially in projects involving marginalized communities (e.g., circular farming in rural areas). ▪ *Inconsistent Results:* Different MCDA methods can produce varying results, depending on the criteria chosen or the decision-making model used. This may lead to uncertainty in final decisions regarding investments or policy choices.

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5.4.2. Material Flow Analysis (MFA) / Substance Flow Analysis (SFA)

Material Flow Analysis (MFA) and **Substance Flow Analysis (SFA)** are both methods used to analyze the movement and use of materials or substances within specific systems. Both approaches are essential tools for understanding resource flows and identifying opportunities for improving efficiency in **circular business models (CBMs)**, such as biorefining, bioenergy, biowaste recycling, and circular farming. While these methods share many similarities, there are some key differences between them.

Material Flow Analysis (MFA)

- **Focus**: MFA focuses on **quantifying the flows and stocks of materials** within a defined system (e.g., city, region, sector, or country) during a specific time period[xxxix]. The "material" refers to any physical material (e.g., biomass, plastics, metals). The MFA cab be performed for one single material and also for different materials combined (Fig. 2).
- **Objective**: The goal of MFA is to provide a holistic view of how resources (e.g., raw materials, intermediate products, and waste) move through different processes within the system, identifying areas for resource efficiency, circularity, and environmental impact reduction.
- **Application**: MFA is often used in **bioeconomy projects** to monitor the use of biomass, agricultural residues, or bio-based products, tracking their inputs, outputs, and recycling potential. For instance, it could be applied in a **biorefinery** to assess biomass feedstock flows, or in **circular farming** to evaluate nutrient cycling (e.g., nitrogen, phosphorous).

Substance Flow Analysis (SFA)

- **Focus**: SFA is a more specific type of MFA, focusing on the **movement of a particular substance** (e.g., nitrogen, phosphorus, carbon, heavy metals, etc.) through the system. It tracks how the substance transforms chemically and physically as it passes through different processes[xl].
- **Objective**: The purpose of SFA is to study **the environmental impacts and risks associated with the substance**, such as pollution or resource depletion, rather than all materials in the system (Fig. 3). SFA aims to understand the fate of specific substances and identify critical points for intervention, such as reducing emissions, preventing leaks, or optimizing recycling.
- **Application**: SFA is particularly valuable in bioeconomy projects where understanding the flow of specific **nutrients or pollutants** is essential, such as in **bioenergy**, **anaerobic digestion**, or **wastewater treatment** systems where **nitrogen**, **phosphorus**, or **carbon** flows are critical for sustainability.

SWOT of MFA / SFA

Strengths	Weaknesses
▪ Offers quantitative insights into material and substance flows. ▪ Supports resource **efficiency** and circular economy goals. ▪ Useful for policy-making and sustainability strategies.	▪ Requires extensive data collection and modeling. ▪ MFA lacks specificity in terms of substance-level impacts (e.g., pollution), while SFA may overlook broader material use.
Opportunities	Threats

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▪ Can be **integrated** with LCA (Life Cycle Assessment) or MCDA for more comprehensive assessments. ▪ Increasing relevance in bioeconomy for tracking circularity, nutrient cycling, and emissions.	▪ Data availability may limit applicability in emerging sectors (e.g., new bio-based materials). ▪ **Complexity** of certain substances' behavior (e.g., nitrogen cycling in agriculture) may hinder straightforward interpretation.

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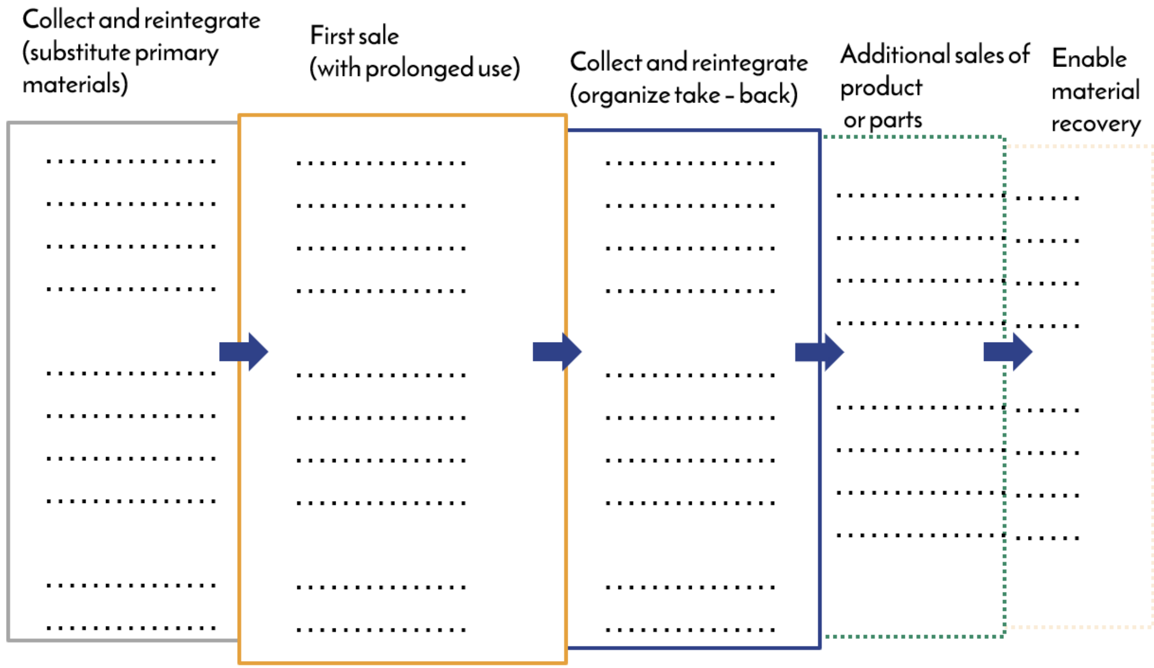
6. Appendix

7 Bioeconomy archetypes:

- Optimizing resource efficiency
- Value recovery from waste
- Innovation towards bio and renewable resources
- Establishing biorefineries
- Resource exchange
- Valuing the local economy
- Service- and result-oriented offers



Appendix 1. Merged Frameworks (Based on Nußholz, 2018 and Salvador et al., 2023)

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	Collect & Integrate		First sale	
Value proposition	Resource exchange; Valuing the local economy	exchange of waste, partner with local community	Optimizing Resource efficiency and use	maximize output from a given input to improve conditions for customers
	Establishing biorefineries	local disposal and utilization of waste	Service-and result oriented value offers	products to meet demand
	Value recoery from waste	bioproduction, value from organic waste		
Key activities	Resource exchange; Valuing the local economy	Logistics, picking up material, acquisition of local farmers resources	Optimizing Resource efficiency and use	R&D, increase efficiency by optimizing production
	Establishing biorefineries	extracting value, production	Service-and result oriented value offers	selling of products
	Value recoery from waste	managing resources, extracting value trough production processes		
Revenue flows	Resource exchange; Valuing the local economy	disposal of waste, local sales	Optimizing Resource efficiency and use	passively via improved product
	Establishing biorefineries	production, maintanance, logistics	Service-and result oriented value offers	Sales
	Value recoery from waste	Build and maintain refineries and the related knowledge needed		

Appendix 2. Alcarràs - Condensed table 1

Reintegrate		Additional Sale		Material Recovery	
Value recovery from waste	Deriving value from digestate ad turning it into fertilizer	Service-and result oriented value offers	Products from sustainable sources	Value recovery from waste	Heat and electricity from biological sources
Value recovery from waste	Rellocation of residual, composting, splitting of solid and liquid parts, refinement/purification of water and gas	Service-and result oriented value offers	selling of fertilizer, water and biomethane, marketing, logistics, operations	Value recovery from waste	generation of electricity and heat
Value recovery from waste	logistics and production	Service-and result oriented value offers	Sales	Value recovery from waste	sale of electricity

Appendix 3. Alcarràs - Condensed table 2 (Based on Nußholz, 2018 and Salvador et al., 2023)

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		Collect & Integrate		First sale		Material Recovery
Value Proposition	Value recovery from waste	Transforming fish into sustainable bio-products	Building biorefineries	Sale of manufactured bio-products	Value recovery from waste	Recovery of food and crop waste, creating a circular economy in order to reduce waste and enhance sustainability
	Innovation towards bio resources	Production and sale of sustainable and resource efficient products from fish waste	Value recovery from waste	Offering bio-products produced from waste that address procut-markets of high interest		
	Resource exchange	Sourcing resources and raw materials for the production trough exchange networks with regard to circularity and sustainability	Optimizing resource efficiency and use	Operating with the help of the latest technology for high yields		
	Local economy	Locally sourced raw materials for the production with respect to the relieve of local issues				
Value creation and delivery	Value recovery from waste	Collection, incorporation, prepocessing, coordination with partners, scouting for input sources	Building biorefineries	Construction and maintanance of relevant bio-plants	Value recovery from waste	Efforts for the collection, reintegration and processing of materials
	Innovation towards bio resources	Developing sustainable technologies to process fish waste into bio-products	Value recovery from waste	Efforts in production, quality control, marketing, sales and logistics		
	Resource exchange	The exchange of resources for the sake of circularity and sustainability	Optimizing resource efficiency and use	Efforts to streamline the processes and R&D		
	Local economy	Building local supply chains and sourcing input factors (technology, fish waste, labor)				
Value Capture	Value recovery from waste	Revenue flows from collection, networking and logistics	Building biorefineries	Costs from innitial investment, maintenance and R&D	Value recovery from waste	Costs for logistics, recycling/composting and infrastructure/plants
	Innovation towards bio resources	Costs from initial investment as well as R&D	Value recovery from waste	Sales trough different chanels and to a variety of customer groups		
	Resource exchange	Costs from networking and logistics of the exchange process	Optimizing resource efficiency and use	Additional revenue from enhanced efficiency		
	Local economy	Costs from networking and operation in coordination with other actors				

Appendix 4. FILSE - Condensed table (Based on Nußholz, 2018 and Salvador et al., 20

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