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D5.1 – D1.1 Regional Hub handbook for data collection and harmonization

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Abbreviations

ANRI	Alchemia-nova research & innovation gemeinnützige GmbH
ANTEJA	Anteja ECG D.O.O.
BABEG	Kärntner Betriebsansiedlungs- und Beteiligungsgesellschaft m.b.H.
CAGR	Compounded Average Growth Rate
CBE	Circular Bioeconomy
CMU	Cardiff Metropolitan University
FCTA	Fundación Corporación Tecnológica de Andalucía
GA	Grant Agreement
HI	Harvest Index
ISTAT	Istituto nazionale di statistica (Italian National Institute of Statistics)
LCA	Life Cycle Assessment
LGCA	Lombardy Green Chemistry Association
M	Month
MCDMA	Multi-Criteria Decision-Making Analysis
MFA	Material Flow Analysis
NACE	Statistical classification of economic activities in the European Community
PLA	Polylactic Acid
RP1	Reporting Period N. 1 (M1-M18)
RP2	Reporting Period N. 2 (M19-M36)
SERN	Startup Europe Regions Network
SYMBIO	Shaping symbiosis in bio-based industrial ecosystems based on circular by-design supply chains
WP(s)	Work Package(s)

Executive summary

The SYMBIO Regional Hub handbook for data collection and harmonisation (**D1.1**), an integral part of the **WP1** (**Task 1.1**) of the Work Plan aims to build an inventory of biological resources, technologies, facilities (**inputs**), **processes** and applications, finished products, markets (**outputs**) in **12 European pilot regions** (Lombardy, Piedmont, Veneto, Friuli-Venezia Giulia, Emilia-Romagna, Carinthia, Slovenia, Croatia, Andalusia, Brussels Capital, Wallonia, Flanders) to enable industrial symbiosis.

Transitioning to a circular bio-based economy is essential for sustainability, regional competitiveness, and achieving the European Green Deal and UN Sustainable Development Goals. This shift involves replacing fossil fuels with renewable biological resources, addressing climate change and resource scarcity while promoting green growth and job creation. The EU Circular Economy Strategy supports this by encouraging resource efficiency, industrial symbiosis, and the development of bio-based products, boosting Europe's economic and environmental resilience. Supply chain cooperation is crucial for managing climate risks and achieving emission reduction targets through sustainable solutions. Integrating multidisciplinary supply chains can create bio-based circular business models, but success depends on local biomass access, cultivation conditions, traceability, and competitive bioproducts. Industrial symbiosis enhances value by using biowaste from one process as raw material for another, minimising waste, and environmental impacts, thus supporting the European Green Deal's goals.

In this framework, D1.1 is considered the methodological pillar of SYMBIO aimed at developing 10 profitable, sustainable business models for bio-based products, creating zero-waste circular supply chains. Extending the mapping to several pilot regions maximises market access to mature technologies, enabling the assessment of the current state of resources and technological know-how infrastructure of regional industrial ecosystems, classified according to the NACE system.

The methodology, an integral part of the Regional Hub handbook, provides guidelines for using the data collection and selection criteria for specific biobased products and a standard for data harmonisation. The inventory process begins with the definition of mapping criteria and the design of a digital reporting system for each of the 12 pilot regions.

The following section presents in detail the main contents of D1.1, including:

1. Selection criteria for biobased products, biomass, and technologies.
2. Guidelines for the data collection, including instructions for accurately mapping data from the 12 pilot regions.
3. Data collection and harmonisation methodology, including guidance on identification of sources, data harmonisation methods, differences, and limitations.

With this document, SYMBIO employs a comprehensive methodology to identify promising biobased products, biomasses, and technologies. Twelve biobased products were selected based on market demand, price, characteristics, and accessibility. For each product, a detailed analysis identified suitable biomass sources, conversion technologies, market value, and application fields, including a SWOT assessment for strategic planning and informed investment decisions.

The Data collection mythology, focuses on regional availability of primary and secondary biomass and existing technologies in each region per company, is comprehensive but faces challenges in data availability, consistency, and regional applicability. A data harmonization process ensures uniformity and comparability across datasets, thanks to the use of standard guidelines agreed upon by all project partners.

1. Introduction

1.1. Industrial symbiosis in the EU Policy framework

The transition to a sustainable and circular economy involves a fundamental transformation of production and consumption, moving away from the reliance on finite fossil fuels and towards renewable biological resources. The bio-based economy offers a promising response to the pressing sustainability challenges of climate change and natural resource scarcity while providing opportunities for green growth, job creation, and rural regeneration[1].

According to the **EU Circular Economy Strategy**, the Circular Bioeconomy (CBE) is a systemic and innovative approach that aims to close the loop by becoming resource-efficient by developing and establishing industrial symbiosis while reducing pressure on the EU's natural capital[2]. This concept involves using biological resources such as biomass, biofuels, and bioproducts in a continuous loop, where waste is minimised, and the value of these resources is maximised, reducing the environmental impact of traditional linear economic systems. The CBE encourages the development of new technologies and industries that can convert biological waste into valuable products.

One key aspect of this transition is the development of **circular bio-based products** and **bio-based value chains** that embrace a 'valorisation and value-addition' approach. This involves a sophisticated network of processes and stakeholders that contribute to industrial competitiveness, with environmental and socio-economic benefits at the local and European levels[3]. The biobased products market and value chains in Europe are integral to the bioeconomy, promoting sustainability, circular practices, and innovation. The European Commission emphasises the significance of bio-based products in driving economic, social, and environmental benefits. These products, derived from biological sources like plants, animals, enzymes, and microorganisms, are crucial in reducing dependency on fossil-based resources and enhancing the EU's strategic autonomy and resilience. Bio-based product manufacturing in Europe creates 7.92 million jobs. It generates EUR 433 billion in value-added, representing 8.3% of its labour force and 4.71% of its GDP in 2019, according to the "EU Bioeconomy Strategy Progress Report" (2020). Bio-based chemicals and materials in Europe account for approximately 31% of the global market compared to fossil-based sectors. This data reveals the significant role that bioeconomy sectors play in creating economic wealth across Europe[4]. The EU Bioeconomy Strategy and Action Plan focuses on transitioning the European economy towards sustainable use of renewable resources, with a key pillar dedicated to developing markets and competitiveness in bioeconomy sectors. This involves increasing primary production sustainably, converting waste streams into value-added products through biorefineries, and enhancing resource efficiency. The **Circular Economy Action Plan** complements these efforts by promoting using bio-based materials and products to create a more sustainable and circular economy, where resources are utilised efficiently, products are designed for reuse and recycling, and minimises waste generation[5].

Supply chain cooperation is crucial for managing climate risks and achieving emission reduction targets due to the greater demand for sustainable solutions and products. By integrating multidisciplinary supply chains, sustainable bio-based circular business models can be created by closing the loop of bio-renewable raw materials and encouraging their cascading use. However, success in using biomass for industrial-scale production remains linked to several factors. First, there is local access to biomass or technologies, environmental and economical cultivation conditions, traceability throughout supply chains, and the development of competitive bioproducts closer to the market than fossil alternatives[6].

Industrial symbiosis allows for the overcoming of some of these problems and increases the economic value of final products, as it is based on the sharing of resources between facilities when biowaste or by-products of one industry or industrial process become the raw material for another. Creating zero-waste value chains guarantees more local supply chains, minimises material resources, and reduces environmental impacts on soil, water, air quality, biodiversity, and climate in all processes involved. The **European Green Deal**'s objectives can be achieved by developing low-impact value chains that convert all by-products into resources and involve different entities such as regional authorities, primary producers, biomass converters, end-user goods producers, NGOs, knowledge providers, and consumers. To achieve this, business models must be developed based on continuous biomass access, using proven technologies ready for upscaling and resilience.

1.2. Scope and rational building the Regional Hub handbook

SYMBIO provides European regional communities with tools and methodological approaches to **build bio-based business models** based on **circularity by design** and **industrial symbiosis**. Thanks to tools for integrating big data and artificial intelligence, SYMBIO shapes 10 symbiotic business models with high profitability and sustainability replicable at the EU level to increase the number of bio-based products on the market. It also provides a system to model, measure, and monitor the symbiosis, its social implications, and economic and environmental impacts. The SYMBIO methodology will be designed, tested and validated in **12 EU pilot regions** (Lombardy, Piedmont, Veneto, Friuli-Venezia Giulia, Emilia-Romagna, Carinthia, Slovenia, Croatia, Andalusia, Brussels Capital, Wallonia, Flanders) which have been selected based on the estimate of their biobased resources defined by the availability of raw materials, socioeconomic indicators, networks and intangible infrastructures and potential for development of supply chains close to the market and current trends. Engaging all supply chain actors in a **quadruplex approach** will help unlock and stimulate local development potential by promoting sustainable, innovative, tangible, and participatory pathways towards the green transition. In this context, the SYMBIO project aims to achieve the following main **objectives** (O):

O1. Identify and evaluate resources and technical solutions that allow industrial symbiosis and circularity right from design in the bio-based ecosystem.
O2. Shaping symbiotic value chains using a zero-waste approach through big data and artificial intelligence tools.
O3. Develop an integrated reporting system to measure and monitor industrial symbiosis based on regional multi-stakeholder co-creation approaches.
O4. Demonstrate zero-waste industrial symbiosis models' economic, social, and environmental impacts.

The project concept is based on the synergistic use of local biomass by creating **Regional Data Hubs** (WP1), which will support the design of **zero-waste value chains** (WP2) through big data solutions and artificial intelligence. To maximise the use of local resources, Material Flow Analysis (MFA) and Multi-Criteria Decision-Making Analysis (MCDMA) will identify the most promising symbiotic business models replicable in other EU regions. Sustainability performance will be shown through a reporting system, a decision support solution for all operators in the supply chain who can count on a system for measuring the competitive advantage of the symbiosis industrial model and consider it a monitoring tool (WP3). Finally, bio-based industrial facilities' social, environmental, and economic benefits will be measured (WP4), integrated into the AI digital platform and disseminated through communication actions and stakeholder engagement (WP5 and WP6).

In this framework, the SYMBIO Regional Hub handbook for data collection and harmonisation (**D1.1)** is considered the project's methodological pillar responsible for setting the selection criteria and data collection strategies for the most promising biomass and technologies to support the transition to a circular bio-based economy, enhancing regional competitiveness and contribute to the European New Green Deal objectives and the UN's Sustainable Development Goals. D1.1 as part of the WP1. "Mapping and assessing resources and technical solutions enabling industrial symbiosis", is a key step in evaluating state-of-the-art and perspectives of the most relevant biological resources, technologies, and facilities in each pilot region from the point of view of industrial symbiosis.

The exploration of regional ecosystems, measuring challenges and opportunities, is based on extensive mapping of the biomass, plants, technologies **(input**), **processes**, applications, finished products, and markets (**output**) of biobased products adapted to industrial sectors according to the NACE classification system. Assessing the potential regional or cross-regional symbiotic connection between raw material suppliers, technology suppliers, and brand owners (final products) will be enabled by Regional Hubs, inventory to understand the potential of the 12 pilot regions in terms of available biomass and territorially mature technologies involved in producing the most in-demand products in the market. The inventory is based on the systematisation of data collected from various sources, providing a detailed picture of local biobased supply chains.

In keeping with this purpose, D1.1 includes the following contributions:

1. Selection criteria for biobased products, biomass, and technologies.
2. Guidelines for the data collection, including instructions for accurately mapping data from the 12 pilot regions.
3. Data collection and harmonisation methodology, including guidance on identification of sources, data harmonisation methods, differences, and limitations.

D1.1 is crucial to SYMBIO since it provides guidelines for standardised data collection across pilot regions. This document sets the stage for successful data harmonisation and ensures comparability of collected data sets by providing insight into selecting specific items in the template.

2. Selection criteria for biobased products, biomass, and technologies

The selection of the most promising biobased products, biomasses, and related technologies is based on various criteria to ensure economic viability, environmental sustainability, and accessibility to stakeholders across the bioeconomy value chain. SYMBIO's methodology involved a multi-faceted approach that considered various factors such as market demand, technological feasibility and maturity, environmental sustainability, biomass availability, economic viability, potential risks and finally, accessibility and potential for scalability.

A breakdown of the most relevant aspects considered is shown below.

1. **Market Demand.** The primary consideration in selecting promising biobased products is the existing or growing demand from bioeconomy stakeholders. This demand can be driven by consumer preferences, regulatory mandates, sustainability goals, and market trends. Monitoring industry trends and market dynamics provides valuable insights into emerging opportunities and shifting demand patterns within the bioeconomy. Market research and analysis help identify niche markets, product niches, and untapped consumer segments that present growth opportunities for biobased products. Products with established or emerging market demand are prioritised to ensure their commercial viability and adoption by end-users. Understanding the potential applications of biobased products helps ensure there is a market demand for them. For this reason, the multiple applications of each of the 12 selected biobased products were considered, in order to also assess the economic availability and affordability.

2. **Technological Maturity.** Technological maturity is a critical criterion in selecting promising biobased products and biomasses. It refers to the development, validation, and readiness level of the technologies involved in converting biomass into final products. Technologies for biomass conversion should be well-established, reliable, and scalable to ensure efficient production processes. Products that rely on novel or experimental technologies may face greater risks and uncertainties, impacting their commercialisation potential.

3. **Biomass Availability.** The availability of suitable biomass feedstocks is critical in determining the feasibility of biobased products at scale. Biomass selected for each product should be abundant, renewable, and economically viable to procure or cultivate. Factors such as geographical distribution, seasonal variability, and competition with existing uses are considered when assessing biomass availability.

4. **Economic Viability.** The economic viability of biobased products is evaluated based on production costs, market prices, and potential revenue streams. Products with favourable cost-competitiveness compared to conventional alternatives are prioritised, as they are more likely to attract investment and achieve commercial success. Consideration is given to the entire value chain, including upstream biomass procurement, processing, distribution, and end-user markets.

5. **Environmental Sustainability.** Environmental sustainability is a fundamental criterion in selecting biobased products. It ensures climate change mitigation, reduces resource depletion, and minimises environmental impacts. Products with lower carbon footprints, reduced energy consumption, and less reliance on fossil resources are preferred.

6. **Accessibility and Scalability.** Consider the accessibility and scalability of biobased products, particularly in terms of their potential to reach large markets and be adopted on a commercial scale. Assessing the scale-up potential of biomass conversion technologies is essential for determining their ability to meet market demand and achieve economies of scale. Technologies that can be easily scaled up from laboratory or pilot-scale to commercial-scale production without significant modifications or performance degradation are preferred. The selection of promising biobased products and biomasses is guided by a comprehensive set of criteria encompassing market demand, technological maturity, biomass availability, conversion efficiency, economic viability, and environmental sustainability. By systematically evaluating these criteria, stakeholders can identify and prioritise investments in biobased innovations with the greatest potential for advancing the bioeconomy and achieving sustainability objectives.

2.1. Selected biobased products

Twelve promising products of biobased interest that represent significant or growing demand from bioeconomy stakeholders, according to price, characteristic, and accessibility, were selected. For each of the identified biobased products, a thorough analysis has been conducted to identify promising biomass sources that can be used as raw materials, the possible technologies, and processes for converting biomass into the biobased product, the market value of the biobased product, and potential application fields. The application field was classified according to the NACE classification (Rev. 2; 2007)[7], the European standard classification of productive economic activities.

Finally, conducting a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis also made it possible to create a comprehensive overview of the internal and external factors affecting the biobased product, facilitating well-rounded strategic planning. Understanding where the product stands in terms of strengths and opportunities ensures that resources are allocated efficiently to areas with the highest potential return on investment, equally being aware of the weaknesses and threats makes it possible to understand if it is reasonable to invest in the product and, if so, what approaches to use with its associated limits. This approach allows us to make informed decisions about investments and long-term strategies.

2.1.1. Lactic Acid

Product Description and Market Value

Lactic acid, or 2-Hydroxypropanoic acid, is a naturally occurring organic acid mainly used in industries such as chemicals, food, cosmetics, medical, and pharmaceuticals. The wide application is due to its being considered an environmentally friendly product, as it is produced using renewable resources and a sugar fermentation process, thanks to its growth properties and metabolic activity. In addition, the acid is frequently used to produce Polylactic Acid (PLA), a thermoplastic polymer that is compostable, biodegradable, and made from renewable sources. Therefore, lactic acid is a key platform chemical in the biobased economy with significant growth potential. The global market for lactic acid amounted to USD 6.09 billion in 2022 and is expected to increase from USD 7.14 billion in 2023 to USD 22.75 billion in 2030, with a CAGR of 18.0%[8].

Biomass

Lactic acid production from biomass involves utilizing various types of organic matter derived from organisms, including lignocellulosic biomass, food waste, and microalgae[9]. **Lignocellulosic biomass** is a prominent source of lactic acid production due to its abundance and renewable nature. It includes agricultural residues, forest biomass (wood and wood processing residues), Municipal Solid Waste (MSW), agro-waste and inedible plant materials. These sources are rich in cellulose and hemicellulose, which can be hydrolysed into fermentable sugars to produce lactic acid through fermentation processes[10]. The most promising agricultural residues are:

- **Barley Extract**: Nutrient source in the fermentation process for d-lactic acid production, providing essential nutrients lactic acid-producing bacteria require.
- **Whey Protein Hydrolysate**: Derived from the liquid remaining after milk has been curdled and strained, it serves as another nutrient source supporting the growth of lactic acid-producing bacteria.
- **Soybean Meal**: A byproduct of soybean oil extraction, utilized as a nitrogen source in the fermentation medium, promoting bacterial growth and lactic acid production.
- **Cottonseed Meal**: Like soybean meal, it is a fermented nutrient source. It is a byproduct of cottonseed oil extraction and provides essential nutrients for bacterial growth.
- **Alfalfa Fiber and Soya Fiber**: These fibres have been evaluated for their potential in lactic acid production through simultaneous saccharification and fermentation (SSF) processes. Alfalfa fibre and soya fibre have shown promising results in lactic acid yield when used as substrates[9].

Technologies and Production Process

The technologies and production processes for lactic acid include chemical synthesis and fermentation. Chemical synthesis involves the lactonitrile route, discovered in 1863, where hydrogen cyanide is added to liquid acetaldehyde to produce lactonitrile, which is then hydrolysed to lactic acid. Lactic acid can be produced by fermentation from biological feedstocks in the presence of either bacteria, fungi, or yeast. Conversely, fermentation is advantageous because it uses renewable and low-cost raw materials. After feedstock preparation, liquefaction, saccharification, fermentation, and downstream processes like precipitation, solvent extraction, and membrane separation are crucial for lactic acid recovery. These processes account for 50% of production costs and are essential for obtaining pure lactic acid for various food, pharmaceuticals, textiles, cosmetics, and chemical applications[9].

Applications

Based on the search results, the key applications of lactic acid include:

- **Food industry**: Acidifier, pH regulator, preservative, and flavouring agent in fermented foods like yoghurt, bread, beer, cheese, and pickles (NACE: 10,11).
- **Cosmetics and Personal Care industry**: Emulsifiers and moisturizers in cosmetic products, with their moisturizing, exfoliating, and antibacterial properties in skincare products, provide a smooth complexion and prevent wrinkles (NACE: 20.4).
- **Pharmaceutical industry**: Used in treating skin diseases and gastrointestinal issues and as a probiotic for digestive health (NACE: 21).

- **Agriculture sector**: As fertilizers, lactic acid bacteria can promote biodegradation, accelerate soil organic content, and produce organic acid and bacteriocin metabolites that enhance plant health and growth (NACE: 20.1, 20.2).
- **Chemical industry**: Lactic acid can be converted into various fuel compounds used in fuel production (i.e., 5-C 7 ketones) and plastic production, as a building block for synthesizing biodegradable polymers like polylactic acid (PLA), which produce eco-friendly materials (i.e., bioplastics, packaging) (NACE: 19.2, 20.1, 22)[11].

In summary, lactic acid's diverse applications span the food, cosmetics, pharmaceutical, agricultural, and environmental sectors, highlighting its versatility and importance in sustainable production processes.

***Table 1** Lactic Acid SWOT Analysis*

STRENGTHS	OPPORTUNITIES
▪ Consolidated value chain and a mature market for various food, chemical and medical applications. ▪ Bio-based production makes 100% organic products cheaper than other chemical alternatives.	▪ Building block for synthesising biodegradable polymers like polylactic acid (PLA): growing demand for PLA can boost production. ▪ Need to reduce single-use plastics (EU's Directive on single-use plastics[12]) and promote them as an alternative to fossil-based plastics.
WEAKNESSES	**THREATS**
▪ Selling price is double that of traditional polymers (high separation and purification costs) ▪ Strict regulations and safety requirements for the use of lactic acid in certain industries	▪ Food and land use competition (primary PLA feedstock is corn) and the consequent impact on food prices becoming higher. ▪ Lack of specific regulation on bioplastics. ▪ Performance Limitations as PLA-based products made from lactic acid may not meet the requirements of certain applications,

2.1.2. Glycerol

Product Description and Market Value

Glycerol, or glycerine, is a chemical compound with three hydroxyl groups. Due to its versatile applications and renewable nature, it plays a crucial role in the biobased industry. The global glycerol market was valued at $4.3 billion in 2021 and is projected to reach $5.1 billion by 2031, growing at a CAGR of 1.7% from 2022 to 2031[13].

Biomass

The production of glycerol involves using various vegetable oils and animal fats (transesterification and saponification). Some of the sources used for producing glycerol include:

- **Vegetable Oils**: Glycerol can be produced from vegetable oils such as canola, rapeseed, palm, and soybean oil.
- **Animal Fats**: Animal fats are also used to produce glycerol. These animal fats can include waste cooking oil (WCO), non-edible oils, and other sources[14,15].

Glycerol is also generated as a by-product of sugar fermentation to ethanol. The most commonly used **sugar sources** are:

- **Sugarcane and sugar beet**: major feedstocks for ethanol production, accounting for around 60% of global ethanol production
- **Corn** (maize): major starch-based feedstock used for ethanol production, especially in the United States. The starch is first hydrolysed to glucose before fermentation.
- **Molasses**: Byproduct of sugar production, and therefore, a low-cost feedstock used for ethanol fermentation. It contains high levels of sucrose that can be readily fermented[16].

Technologies and Production Process

In the biobased industry, glycerol is primarily generated as a by-product of biodiesel production, where it is obtained from the **transesterification** reaction between triacylglycerols (e.g., vegetable oil) and methanol. Crude glycerol, containing impurities like alcohol, catalyst traces, esters, and salts, is a common form of glycerol produced in this process. To enhance its value and usability, crude glycerol can be purified to different purity levels required for various applications in foods, pharmaceuticals, and personal care products. Glycerol is also produced as a by-product during soap production through **saponification** of glycerides. Glycerol and soap (fatty acid salts) are produced during the hydrolysis of oils and fats with alkaline hydroxides. This process has been known since 2800 B.C. However, it can be environmentally impactful, involving chemical catalysts rather than biological organisms to facilitate the reaction.

Microbial **fermentation** has emerged as an interesting route for glycerol production, using osmo-tolerant yeasts like *Saccharomyces cerevisiae*, bacteria such as *Bacillus subtilis*, and algae like *Dunaliella tertiolecta*. The fermentation process utilises biomass-derived sugars as feedstock; for example, in *Saccharomyces cerevisiae*, glycerol is generated as a by-product of sugar fermentation to ethanol, following a redox-neutral pathway[17]. Despite this evidence, there are no recent studies concerning this process.

Applications

Glycerol, a by-product of biodiesel production, is a bio-derived renewable raw material that has many applications due to its unique physical and chemical properties., as listed below:

- **Food Industry**: Added to food to increase water-coating ability, used as a sweetener, humectant, and solvent in foods and beverages (NACE: 10, 11).
- **Pharmaceutical and Cosmetic Industry**: Used as a lubricant, humectant, and emollient in pharmaceutical formulations and personal care products (i.e. creams, cosmetics, soaps, balsams), employed as a solvent, plasticizer, and sweetener in pharmaceuticals (NACE: 20.4, 21).
- **Other industries**: in the manufacture of papers, wrapping and packaging materials (as a softener, humectant, and lubricant), in the textile industry (as a solvent, humectant, plasticiser, and lubricant), in the rubber industry (plasticiser, humectant, and lubricant), in the automotive industry (as an antifreeze) etc. [18] (NACE: 13, 17, 22, etc.).

***Table 2** Glycerol SWOT Analysis*

STRENGTH	**OPPORTUNITIES**
▪ Green fuel production can be economically sustainable in the long term. It accounts for 10% of biodiesel production and becomes a secondary source of income[18].	Several EU policy recommendations are promoting its production, such as the “Circular Economy” action plan, the “EU Bioeconomy

- It is low-cost and versatile, making it a valuable ingredient in value-added products such as medical and food applications, industrial protective coatings, and paints.	Strategy", and the "Chemicals Strategy for Sustainability" of the EU Green Deal.
WEAKNESSES The conventional process's purification step leads to significant environmental problems, but using greener routes to purify glycerol is expensive.	**THREATS** The market price of glycerol has decreased due to the increased production and availability of it as a by-product of biodiesel[18].

2.1.3. Succinic Acid

Product Description and Market Value

Succinic acid is a natural and versatile four-carbon dicarboxylic acid. The global market value of succinic acid was estimated at USD 160.8 million in 2022, projected to reach USD 301.4 million at the end of 2032, with a predicted growth rate of 6.5% CAGR from 2022 to 2032[19].

Biomass

Lignocellulosic feedstocks like *forestry residues* (wood and wood processing residues), agricultural residues, and energy crops are attractive renewable resources for cost-effective succinic acid production via fermentation after pretreatment and hydrolysis to release fermentable sugars. In particular, the most common agricultural residues and energy crops used to produce succinic acid include:

- **Different crop stalk wastes**, including corn stalk and cotton stalk, are commonly enzymatically converted into a carbohydrate-rich feedstock for succinic acid production[20].
- **Different types of crop straws**, including wheat straw, rice straw, barley straw, and corn straw, are commonly used to produce succinic acid via fermentation. Also, miscanthus is a viable option.
- **Sugarcane Bagasse (SCB):** A viable alternative for the efficient production of succinic acid[21].

Finally, the organic fraction of Municipal Solid Waste (MSW), particularly the lignocellulosic biomass, serves as a valuable feedstock for succinic acid production through innovative processes, showcasing the potential for sustainable and cost-effective bio-based chemical production[22].

Technologies and Production Process

The production of succinic acid involves several processes, the most relevant:

- **Enzymatic Hydrolysis**: use of enzymes to break down lignocellulosic biomass into simpler sugars, which are then fermented to produce succinic acid.
- **Fermentation** is the use of microorganisms to convert carbohydrates into succinic acid. This process involves the microorganisms' fermentation of sugars from hydrolysates, which results in the production of succinic acid[23].

Applications

Succinic acid is a valuable organic acid with high commercial value in the biobased market, and its applications include:

- **Chemical Industry**: Chemical intermediate in the production of various compounds, such as 1,4-butanediol (BDO), tetrahydrofuran (THF), and γ-butyrolactone (GBL, building block is the solvent market), which are further utilized in the manufacturing of polymers, resins, and polyurethanes. Succinic acid is a key component in the production of biodegradable plastics, polyesters, and polyamides, offering a sustainable alternative to traditional petrochemical-based materials (NACE: 19.2, 20.1, 22 etc.).
- **Food and Beverage Industry:** Acidity regulator and flavouring agent and a building block for biodegradable polymers in food packaging (NACE: 10, 11).
- **Pharmaceuticals:** Active pharmaceutical ingredients (APIs) and excipient in drug formulations (NACE: 21).
- **Cosmetic Industry:** Due to its buffering and exfoliating properties, in personal care products it serves as skin creams, shampoos, and bath salts. It can also produce biopolymers, solvents, plasticizers, and fine chemicals (NACE: 20.4).

These applications demonstrate the versatility and potential of succinic acid as a renewable platform chemical with a wide range of uses across various industries[24].

***Table 3** Succinic Acid SWOT Analysis*

STRENGTHS It can replace several fossil-based chemicals in various applications.	**OPPORTUNITIES** Increased demand for bio-based chemicals and preference for environmentally friendly products drive its market growth.
WEAKNESSES ▪ The complex purification affects large-scale production[4]. ▪ Biobased succinic acid has a relatively small world market[25].	**THREATS** Sugar and starch crops are the main feedstock to produce bio-based succinic acid, leading to biomass competition with food.

2.1.4. Acetic Acid

Product Description and Market Value

Acetic acid, or ethanoic acid, is the second simplest carboxylic acid (after formic acid). It is an important chemical reagent and is produced on a large scale for various applications across various fields. In 2022, the global acetic acid market was valued at USD 12.89 billion and is expected to grow at a CAGR of 7.5% from 2023 to 2030[26].

Biomass

The biomasses used to produce acetic acid include a variety of **lignocellulosic biomass**, such as forestry residues (wood and wood processing residues), energy crops (Sugarcane Bagasse) and agricultural residues (i.e., wheat and barley straws, corn stoves and cops, poplar sawdust etc.)[27,28].

Technologies and Production Process

Worldwide, acetic acid is mainly produced through fossil-based processes like the Cavita process (carbonylation of methanol), aldehyde oxidation, and ethylene oxidation. Additionally, it can also be commercially produced by **fermentation** (bio-based pathway) using renewable carbon resources (after enzymatic hydrolysis). Acetic acid can be produced by two fermentation processes: i) oxidative (aerobic) fermentation of ethanol and ii) anaerobic fermentation of sugars. The fermentation process involves treating with yeast followed by acetic acid bacteria (AAB)[28].

Applications

Acetic acid, when produced through bio-based processes, finds a wide range of applications across various industries. Some of the key biobased applications of acetic acid include:

- **Food Industry**: It is an acidity regulator, preservative, and flavour enhancer in food products such as seasonings, vinegar, pickles, sauces, and mayonnaise (NACE: 10, 11).
- **Chemical Industry**: Raw material in the production of various industrial chemicals and solvents, i.e., raw material for the manufacturing of Purified Terephthalic Acid (PTA) and Vinyl Acetate Monomer (VAM), which are used in the production of plastics, adhesives, and textiles (NACE: 19.2, 29.1, 22 etc.).
- **Textile Industry**: It is utilised in textile processing and printing (NACE: 13).
- **Pharmaceutical Industry**: Acting as an acidifying agent in eardrops to treat outer ear bacterial or fungal infections (NACE: 21).
- **Health and Personal Care Industry**: It is used in hair care products, mouthwashes, breath fresheners, and skin care products. Additionally, it controls the pH of cosmetics and personal care items (NACE: 20.4)[29].

These applications demonstrate the versatility of bio-based acetic acid across multiple sectors, highlighting its importance as a sustainable raw material in various industries.

***Table 4** Acetic Acid SWOT Analysis*

STRENGTHS	**OPPORTUNITIES**
▪ It enables various applications from lignocellulosic biomass conversion with low toxicity and high biodegradability. ▪ Increasing consumption of bio-acetic acid in the food, beverage, and pharmaceutical sectors[30].	▪ The global acetic acid market is expected to grow due to increasing demand from end-use industries. ▪ Acetic acid can be used as a chemical intermediate to produce other valuable compounds like succinic acid. ▪ The development of new separation technologies may increase the production efficiency. ▪ The development of bacterial strains with higher pH tolerance may improve acetic acid yields.
WEAKNESSES The biological route has a low yield related to issues separating the acetic acid from the fermentation broth and distillation to glacial purity (99.8% acetic acid)[4,31].	**THREATS** Biomass availability due to competition with food, feed, and energy sources impacts acetic acid production from renewable resources.

2.1.5. Adipic Acid

Product Description and Market Value

Adipic acid, also known as hexanedioic acid, is an important organic compound and the most important dicarboxylic acid from an industrial perspective. According to recent studies, the global production of adipic acid is approximately 3-3.3 million tons per year[32]. The market value of adipic acid is projected to reach USD 11,213.99 million by 2030, with a compound annual growth rate (CAGR) of 5.1% during the forecast period. In 2023, the market was valued at around USD 7,916.64 million[33].

Biomass

Several types of biomasses are being explored as feedstocks to produce biobased adipic acid:

- The **sugar platform** derived from starch, cellulose, or hemicellulose, such as glucose streams from **lignocellulosic feedstocks**, i.e., forestry residues (wood and wood processing residues), corn stover and rice straw. Sugarcane bagasse has been used to produce adipic acid via fermentation after pretreatment[34].
- The **lignin platform**, which contains aromatic compounds. Lignin-derived phenolic compounds are being investigated as feedstocks, although still in developmental stages[35].
- The **fatty acid platform,** derived from lipids, oil crops (i.e., palm oil, coconut oil, canola oil, rapeseed oil) and glycerol (a biodiesel byproduct)[34].

The choice of biomass depends on availability and cost. Second-generation feedstocks like lignocellulosic biomass are promising but still mainly in the developmental phase, while most commercial processes use first-generation sugar feedstocks. Challenges remain in obtaining suitable feedstocks free of inhibitors and overcoming the limitations of gas-based fermentation.

Technologies and Production Process

The most economically feasible option to produce adipic acid is petrochemical routes. Most adipic acid is produced by oxidation of KA oil (cyclohexanol and cyclohexanone) catalysed by nitric acid. This option has an extreme environmental impact with the massive production of carbon dioxide/nitrous and nitrogen oxide. Suffice it to say that the adipic acid production in the US generated approximately 1.9 TgCO2 Eq in 2009. For this reason, researchers are working to find more renewable and sustainable adipic acid synthesis methods, and there is growing interest in developing biological production routes from renewable feedstocks like sugars and lignin to reduce the environmental impact. The biological production of adipic acid is estimated to account for 20-30% of total production in the long run[36]. **Fermentation** is the most promising technology used to biobased adipic acid from different types of biomass (sugars). It is possible to use direct fermentation of glucose extracted from lignocellulosic biomass and oil crops (pretreatment to fractionate the biomass, enzymatic hydrolysis to release glucose, and fermentation using engineered microbes) or indirect fermentation of glucose to muconic acid or glucaric acid, followed by chemical hydrogenation to produce adipic acid[34].

Applications

Adipic acid has several important industrial applications:

- **Chemistry Industry**: Adipic Acid is a key raw material for the production of nylon 6,6 (which is widely used in textiles, carpets, and engineering plastics), but is also used in the production of polyester polyols (which are then used to make polyurethane foams, coatings, and elastomers), plasticizers like dioctyl adipate (DOA) and diisononyl adipate (DINA) (which are used to increase the flexibility and durability of plastics like PVC), lubricants and greases with improved thermal and oxidative stability, and alkyd resins for paints and coatings (NACE: 19.2, 29.1, 22 etc.).
- **Food and Cosmetic Industry**: Adipic acid is used as an acidulant and flavouring agent in some foods and as a pH regulator in cosmetics (NACE: 10, 11, 20.4).
- **Pharmaceutical Industry**: Adipic acid is used as an excipient in some pharmaceutical formulations (NACE: 21) [37].

In summary, adipic acid is an important industrial chemical with major applications in producing nylon, polyurethanes, plasticisers, lubricants, and other specialty chemicals.

***Table 5** Adipic Acid SWOT Analysis*

STRENGTHS	**OPPORTUNITY**
Adipic acid is a key raw material used for a lot of applications (nylon 6,6, coatings and paints, polyester polyols, plasticizers).	▪ The increasing demand for eco-friendly and bio-based adipic acid is driving innovation and mergers & acquisitions among industry players to develop sustainable products. ▪ The development of new, more environmental processes may meet environmental attention and stricter government regulations on greenhouse gas.
WEAKNESSES	**THREATS**
Adipic acid production causes environmental pollution issues as it is insoluble in water and a greenhouse gas. Manufacturers need to invest in R&D to reduce the environmental impact.	Developing new chemicals that can substitute for adipic acid in certain applications could reduce demand. For example, bio-based succinic acid is being explored as a potential replacement in some polyurethane applications[38].

2.1.6. PLA

Product Description and Market Value

Poly (lactic acid) (PLA) is widely acknowledged as a biodegradable and biobased polyester. It has been extensively studied and is believed to be a promising substitute for petroleum-based polymers. This material has many applications across different industries, offering a more environmentally friendly alternative to conventional plastics. In particular, the PLA market was valued at $1.821 billion in 2022 and is projected to reach $5.186 billion, growing at a CAGR of 19.1% from 2022 to 2028[39].

Biomass

The main biomass feedstocks used to produce polylactic acid (PLA) are:

- **Corn/Corn starch** is commonly fermented to produce lactic acid, which is then polymerised to make PLA. Corn is one of the most widely used feedstocks for PLA production.
- **Sugarcane** is another major feedstock that produces lactic acid for PLA synthesis. The sucrose from sugarcane is fermented to obtain lactic acid.

- **Cassava/Cassava starch** can also be used as a feedstock for PLA production. The starch is first converted to glucose and then fermented to lactic acid.
- **Wheat starch** can also be used as a feedstock for PLA production. The starch is converted to glucose and fermented to lactic acid.
- **Sugar Beet/Sugar beet pulp**, a byproduct of sugar production, has been explored as a feedstock for PLA. The pulp's cellulose is hydrolysed to glucose, which is then fermented to lactic acid.
- **Lignocellulosic biomass/Wood biomass**, like wood pellets, has been investigated for PLA production. The biomass's cellulose and hemicellulose are broken down into sugars that can be fermented to lactic acid[40,41].

Technologies and Production Process

The production of Polylactic acid (PLA) involves several key steps:

- **Fermentation** of Lactic Acid: Lactic acid, the precursor to PLA, is typically produced through fermentation of glucose or sucrose. This lactic acid is then purified to obtain polymer-grade lactic acid.
- **Condensation** of Lactic Acid: The polycondensation process involves concentrating lactic acid to remove residual water and producing an oligomer of limited molecular weight. This prepolymer is then thermally depolymerised to form lactide, the cyclic dimer of lactic acid, which needs to be of high purity for polymerisation.
- **Polymerization**: This step combines a specially designed stirred-tank reactor and an efficient plug-flow reactor for ring-opening polymerisation. This step is crucial for producing high-quality PLA with low residual monomer content.
- **Stabilization and Demonomerization**: The polymer melt stabilise and removes any remaining lactide[40].

Applications

Polylactic acid (PLA) finds diverse applications across various industries due to its biocompatibility, biodegradability, and versatility. Some key applications of PLA include:

- **Medical and Pharmaceutical Industry**: PLA is used in healthcare for tissue engineering scaffolds, bioabsorbable medical implants, drug delivery systems, and covering membranes in medical devices (NACE: 21, 32,5)[42].
- **Food Packaging**: PLA is FDA-approved for food contact materials, making it suitable for containers, drinking cups, overwraps, and blister packages in the food industry (NACE: 17, 22).
- **Textile Industry**: PLA is utilised in textile fibre applications for shirts, carpets, bedding, mattresses, sportswear, and upholstery fabrics due to its low moisture absorption and UV resistance (NACE: 13).
- **3D Printing**: PLA is a popular filament for fused deposition modelling (FDM) in 3D printing due to its low melt temperature and ease of use.
- **Automotive and Structural Applications**: PLA and PLA composites are used in automotive, electrical, and electronics applications for parts like floor mats, safety helmets, pillar covers, and interior components of automobiles[43] (NACE: 27, 28, 29 etc.).

These applications highlight PLA's versatility and eco-friendly nature, making it a valuable material in modern industries ranging from healthcare to textiles and beyond.

***Table 6** PLA SWOT Analysis*

STRENGTHS	OPPORTUNITIES
▪ PLA is a widely researched biodegradable alternative in the packaging industry. ▪ PLA has low manufacturing costs and good moisture barrier properties comparable to petroleum-based plastics. ▪ It is used in various applications like medical implants, food packaging, and 3D printing due to its biocompatibility and ease of processing.	▪ Research is ongoing to improve PLA's biodegradability through various blends and enhancements. ▪ Companies are exploring new technologies like layer-by-layer deposition techniques to enhance PLA's barrier properties. ▪ PLA presents a sustainable alternative to conventional plastics, aligning with the increasing demand for eco-friendly materials in various industries.
WEAKNESSES	**THREATS**
▪ Recycling and composting PLA materials can be challenging, requiring specific composting conditions and separate composting facilities. ▪ PLA's biodegradability is limited to specific conditions and may not naturally degrade in the environment. ▪ Poor oxygen barrier properties compared to petroleum-based plastics like PET or PS	Competition from other biodegradable materials and the need for continuous innovation to enhance PLA's properties and overcome its weaknesses

2.1.7. PHAs

Product Description and Market Value

Polyhydroxyalkanoates (PHAs) are a family of bacterially synthesized biopolyesters with biodegradability, biocompatibility, thermoprocessibilty, and flexible strengths. They have attracted attention as an alternative source to petro-chemically derived plastics as they are biodegradable, renewable, biocompatible, and environmentally friendly. The market value of Polyhydroxyalkanoates (PHA) is expected to grow significantly in the coming years. As of 2023, the global PHA market was worth USD 65.4 million. This market is projected to register a CAGR of 11.8% from 2024 to 2029, reaching USD 127.71 million by 2029[44]. These figures indicate a growth trajectory for the PHA market, driven by factors such as the increasing demand for environmentally friendly materials, the push to reduce non-degradable plastics, and the rising investments in research, development, and production of PHAs. The market's expansion is also supported by the growing awareness of environmental concerns, government initiatives promoting sustainable development, and the shift towards bio-based materials in various industries.

Biomass

Polyhydroxyalkanoates (PHAs) are biodegradable polymers produced from various biobased materials and biomass. The search results indicate that PHAs can be produced from a wide range of feedstocks, including:

- **Agricultural Residues**: Abundant and low-cost lignocellulosic biomass, such as agricultural residues (i.e., sugarcane waste, corn, and wheat residues), forest residues (wood and wood processing residues), and agro-food processing waste, can be used as a carbon source for PHA production.
- **Food Crops**: Sugars and fatty acids extracted from food crops, such as corn starch, sugarcane, and vegetable oil (i.e., canola oil, palm oil, soybean oil), can serve as feedstocks for PHA production.

- **Other Biomass Sources**: Municipal Solid Waste (MSW)[45,46].

These diverse feedstocks contribute to the sustainable production of PHAs, offering an alternative to fossil fuel-based plastics and supporting the development of biorefineries and value-added materials.

Technologies and Production Process

PHAs are currently produced from the **fermentation** of sugars and fatty acids extracted from food crops like corn starch, sugarcane, and vegetable oil[45].

Applications

- **Packaging and food services**: Due to their good barrier properties, PHAs are used to make biodegradable packaging materials like bags, films, and containers. This helps reduce the environmental impact of conventional plastic packaging (NACE: 17, 22, etc.).
- **Biomedical Industry**: PHAs are used in biomedical applications such as drug delivery systems, surgical sutures, cardiac valves, tissue engineering scaffolds, and more due to their biodegradability, biocompatibility, and tuneable properties (NACE: 21, 32.5, etc.).
- **Textile Industry**: While still limited, PHAs are being explored for textiles as a more sustainable alternative to synthetic fibres (NACE: 13).
- **Automotive sector**: PHAs have applications in making biodegradable car components like interior trim and insulation (NACE: 13, 29, etc.).
- **Other industries**: PHAs also have potential uses in cosmetics, biofuels, feed additives, dye production, and industrial fermentation[47] (NACE: 10.9, 20.4, 35, etc.).

Table 7 *PHAs SWOT Analysis*

STRENGTHS	OPPORTUNITIES
▪ PHAs are biodegradable polyesters, making them environmentally friendly and reducing plastic pollution. ▪ PHAs can be produced through conversion of many different waste streams directly inside the microorganisms. ▪ PHAs have versatile applications (packaging, agriculture, biomedical, textiles, automotive, etc.). ▪ Growing market demand, driven by the increasing demand for sustainable and biodegradable materials across various industries	▪ Improvements in PHA production processes, reductions in costs, and exploration of new applications in different industries offer room for innovation. ▪ PHAs can be produced from many different waste sources.
WEAKNESSES	**THREATS**
▪ Production cost, which can be higher than conventional plastics, impacts their widespread adoption. ▪ The downstream processing still usually involves harsh chemicals.	▪ PHAs face competition from traditional plastics and other biodegradable materials, which could threaten their market share and adoption. ▪ Changes in plastic-related regulations and environmental policies could impact the demand and adoption of PHAs in various industries.

2.1.8. Lysine

Product Description and Market Value

Lysine is an essential amino acid crucial for various human bodily functions, but it is also a crucial component in the biobased industry, particularly in the production of various chemicals and materials. Its unique chemical structure and sustainability make it an attractive raw material for industrial applications. According to the latest market research reports, the global lysine market is expected to reach significant market value in the coming years. It was valued at USD 1,754.9 million in 2021 and is projected to grow at a CAGR of 7.5% from 2022 to 2030[48].

Biomass

The biomass feedstocks commonly used to produce lysine include:

- **Sugars**: Raw materials for microbial fermentation processes derived from lignocellulosic biomass require pretreatment and hydrolysis to release fermentable sugars, converted to lysine by engineered microbial strains. Lignocellulosic biomass commonly used to produce lysine includes corn stubble and wheat straw.
- **Starches**: Starch from food crops is another common feedstock for lysine production. However, there is a growing interest in replacing food-crop starch with lignocellulosic materials to avoid competition with food supply.
- **Hemicellulose**: Hemicellulose, a component of lignocellulosic biomass, can be hydrolysed into fermentable sugars. These sugars can be utilized by certain strains capable of fermenting pentose sugars, which are derived from hemicellulose, for lysine production.
- **Molasses** is indeed used in the production of lysine. It serves as a carbon source in the fermentation process for lysine production, offering a sustainable alternative to traditional glucose sources. Research has shown that molasses can effectively replace glucose in lysine production, reducing production costs and using this by-product from the sugar industry[49].

Technologies and Production Process

The technologies used to produce lysine from biomass include microbial fermentation, a key method for producing lysine from renewable sources like lignocellulose, starches, and/or hemicellulose. This process involves using microorganisms to convert biomass-derived sugars into lysine through fermentation[50]. The key steps involve:

- **Pretreatment and hydrolysis** of the biomass to break down the complex structure and release fermentable sugars like glucose and xylose.
- **Fermentation** of the biomass-derived sugars using engineered microorganisms to convert them into lysine.
- **Downstream processing** to purify and recover the produced lysine from the fermentation broth. The conversion of xylose, a pentose sugar present in lignocellulose, remains a challenge in lysine production from biomass. Ongoing research focuses on improving lysine-producing strains' ability to efficiently utilise hexose and pentose sugars derived from lignocellulosic feedstocks[50].

Applications

Lysine has numerous industrial applications:

- **Animal Feed Industry**: Lysine is a major additive to animal feed (NACE: 10.9). It is a limiting amino acid that promotes growth. Adding lysine allows using lower-cost plant proteins while maintaining high growth rates. The global lysine market for animal feed was valued at $8.6 billion in 2023 and is expected to grow at a CAGR of 7.2% from 2024 to 2033.

- **Food and Beverages Industry**: L-lysine is a nutritional supplement for mayonnaise, milk, instant noodles, potatoes, rice, flour, and canned foods. It can also enhance flavour. Lysine is also used in nutritional and sports drinks (NACE: 10, 11).
- **Pharmaceutical Industry**: Lysine is used in the production of various medicines NACE: 21).
- **Cosmetics and Personal Care Industry**: Lysine is used in cosmetics and personal care products, such as baby products, bath products, cleansers, eye makeup, shaving preparations, and hair and skin care (NACE: 20.4). It helps with skin elasticity and firmness due to its role in collagen synthesis[51,52].

In summary, lysine has a wide range of industrial applications. The largest demand comes from the animal feed sector, followed by food, pharmaceuticals, and cosmetics. Ongoing research aims to improve the efficiency of lysine production and expand its use as a versatile industrial compound.

Table 8 *Lysine SWOT Analysis*

STRENGTHS	OPPORTUNITIES
Lysine is an essential amino acid with many applications in different industries. Its market value is expected to grow strongly.	Ongoing research aims to improve the efficiency of lysine production and expand its use as a versatile industrial compound.
WEAKNESSES	**THREATS**
▪ There is a risk of oversupply if production capacity increases too rapidly without corresponding demand growth. ▪ Lysine production requires complex fermentation processes which can be costly and energy intensive[51].	▪ Fluctuations in raw material prices and energy costs can impact profit margins for lysine producers. ▪ Increasing competition from alternative amino acids or protein sources could limit growth in certain applications. ▪ Regulatory changes or consumer preferences shifting away from certain applications like animal feed could pose risks.

2.1.9. Glutamic Acid

Product Description and Market Value

Glutamic acid is a non-essential amino acid, meaning the human body can synthesize it internally and does not solely rely on dietary sources. Glutamic acid is a significant component in the biobased industry, particularly in producing biobased chemicals. The global glutamic acid market is expected to accumulate a market value of US$10,160.6 million in 2023 and reach US$15,787.8 million by 2033, registering a CAGR of 4.7% from 2023 to 2033, driven by increasing demand from end-use industries such as food, pharmaceuticals, and cosmetics[53].

Biomass

The most promising biomass used to produce biobased glutamic acid are:

- **Lignocellulosic biomass** (i.e., rice straw, wheat straw, corn stover and syrup) is the most widely generated agricultural biomass that can produce biobased glutamic acid.
- **Sugarcane molasses and bagasse** are abundant, low-cost agricultural byproducts that can be used as feedstocks to produce biobased glutamic acid through fermentation with engineered bacteria.

- **Soybean meal and soy processing wastes** are abundant, protein-rich biomass that can be enzymatically hydrolysed or fermented to produce biobased glutamic acid and glutamine peptides[54].

Technologies and Production Process

The production of glutamic acid involves various technologies, primarily focusing on fermentation processes using microorganisms like *Corynebacterium glutamicum*[55].

Applications

The industry applications of glutamic acid are diverse and span across various sectors:

- **Food and Beverage Industry**: Glutamic acid is extensively used in the food and beverage industry, serving as a taste enhancer and food preservative (NACE: 10, 11). For instance, monosodium glutamate, a form of glutamic acid, is commonly used to enhance the flavour of food products like canned vegetables, broths, snacks, salad dressings, processed meats, and dairy products. This industry dominates the glutamic acid market, contributing to over 83% of the revenue 2021[56].
- **Pharmaceutical Industry**: Glutamic acid is utilised in the pharmaceutical sector for specific applications, including manufacturing medications (NACE: 21).
- **Animal Feed Industry**: Glutamic acid is also used in the animal feed industry to promote reproduction, animal development, antioxidative response health, and immune system function (NACE: 10.9). The increasing awareness among consumers regarding the nutritional needs of animals, coupled with the demand for high-quality feed production, is expected to drive the use of glutamic acid in animal feed applications.
- **Agricultural Industry**: Applications as an exogenous amino acid widely used to enhance the yield and quality of crops, improve plant growth parameters, and increase resistance to environmental stresses in agricultural plants (NACE: 20.1, 20.2).
- **Other Industries:** Glutamic acid has applications beyond food, pharmaceuticals, and animal feed. For example, gamma poly glutamic acid (γ-PGA), a derivative of glutamic acid, is widely used in the food industry as a supplement and osteoporosis prevention agent[57].

***Table 9** Glutamic Acid SWOT Analysis*

STRENGTHS	**OPPORTUNITIES**
▪ It enables various applications (food additives, feed supplements, therapeutic agents, and agricultural chemicals). ▪ It can be produced by fermentation from residual biomass, preferred to chemical synthesis. ▪ Production usually relies on cheap carbon substrates, including waste, available in large quantities.	▪ Amino acids ‘market doubles every decade. ▪ Microbial proteins (MPs) are promising alternatives to animal- and plant-based ones for food safety and environmental impact.
WEAKNESSES	**THREATS**
▪ Bacteria make production highly sensitive to pH, temperature, and other factors[4]. ▪ Downstream high-purity separation and purification are significant obstacles to cost-effective production[4].	Increasing awareness of Monosodium Glutamate (the main final product of glutamic acid synthesis) harms human health

2.1.10. 1,3-Propanediol

Product Description and Market Value

1,3-Propanediol is an organic compound and a versatile chemical used in polymers, solvents, and other applications, produced through chemical and biological processes. Its main uses are as a building block for polymers like polytrimethylene terephthalate and as a solvent, antifreeze, and component in wood paint. The global 1,3-propanediol market size was valued at USD 789.17 million in 2023 and is expected to grow at a compound annual growth rate (CAGR) of 10.1% from 2024 to 2030[58].

Biomass

The biomass feedstocks commonly used to produce 1,3-propanediol (1,3-PDO) include:

- **Glycerol**: a prominent biomass resource obtained as a by-product in large quantities during various industrial processes, such as biodiesel production and soap manufacture. Also, crude glycerol, a by-product of biodiesel production, could be utilised as a raw material for 1,3-PDO production.
- **Glucose** derived from different types of biomasses, such as corn (corn stover and corn steep liquor), crops straw (i.e., wheat and rice) and Sugarcane Bagasse.

These biomass feedstocks are commonly employed in producing 1,3-propanediol through various green and sustainable processes[59–61].

Technologies and Production Process

The technologies used to produce 1,3-propanediol (1,3-PDO) from corn steep liquor and crude glycerol include fermentation processes and metabolic engineering. Specifically, using two-waste culture medium, which combines crude glycerol and corn steep liquor, has been proposed for 1,3-PDO production by microorganisms such as *Clostridium butyricum*[62].

Applications

1,3-Propanediol (1,3-PDO) has a wide range of applications in various industries:

- **Cosmetics and Personal Care Industry**: multipurpose ingredient in cosmetics and personal care products, serving as an emollient, humectant, booster, solvent, viscosity enhancer, and active carrier. It is a high-purity ingredient derived from renewable sources and is GMO-free, making it ideal for Ecocert/Cosmos-certified products (NACE: 20.4)[63].
- **Polymer and Chemical Industry**: 1,3-PDO is an important chemical widely used in the polymer industry, especially for synthesising polyesters and polyurethanes. It can be formulated for use in composites, adhesives, laminates, mouldings, coatings, copolyesters, solvents, or aliphatic polyesters (NACE: 19.2, etc.)[64].

Table 10 *1,3-Propanediol SWOT Analysis*

STRENGTH	OPPORTUNITY
Versatile chemicals with many applications in cosmetics, pharmaceuticals, polymers, lubricants, and more.	▪ Emerging technology to derive 1,3-PDO from renewable sources allows for a smaller ecological footprint and safer manufacturing than traditional petrochemical routes. ▪ Developing more efficient microbial cell factories and new bioprocesses to reduce production costs further.

	Applying metabolic engineering and synthetic biology strategies to improve biological production from glycerol, sugars, and other cheap feedstocks.
WEAKNESS Low product concentration and long-term sterility challenges associated with its biological production[65].	**THREATS** Competition from traditional petrochemical-derived 1,3-PDO and other glycols like propylene glycol, butylene glycol, and glycerine

2.3.11 Furfural

Product Description and Market Value

Furfural is an organic compound and an important industrial chemical derived from renewable plant sources that are used in various chemical industries. The global furfural market is expected to reach around $767 million to $1012.6 million by 2028-2033, growing at a CAGR of 2.9% to 5.8% from 2023. In 2022, the market was valued at $595.15 million. In summary, the furfural market is projected to experience significant growth in the coming years, driven by increasing demand for its derivatives and applications in various industries, making it a promising biobased product[66,67].

Biomass

The main type of biomass and biobased elements commonly used to produce furfural is the lignocellulosic biomass. This includes forestry residues, agricultural waste, and municipal solid waste (MSW), and it is an ideal alternative for furfural production. Agricultural wastes such as rice husks, wood, wheat and barley straw, corn stalks and cobs, and maize cobs are commonly used to produce furfural[68,69].

Technologies and Production Process

The technologies used to produce furfural from lignocellulosic biomass include various processes such as biomass pretreatment, acid hydrolysis, and dehydration, with a specific emphasis on various technologies and methodologies used. Some of the key approaches and techniques mentioned in the search results are:

- **Acid Hydrolysis**: Furfural can be created by depolymerizing pentosans with acid to create xylose, which is further dehydrated to produce furfural. This preparation procedure can be carried out in a single step.
- **Catalytic Systems**: Various catalytic systems are used to synthesise furfural from biomass, and the search results emphasise the importance of catalyst selection, reaction conditions, and process optimisation methodologies.
- **Solvent-Thermal Conversion**: This method discussed in the search results involves using solvents and thermal processes for furfural production.

These technologies are part of the process for producing furfural from lignocellulosic biomass, which is a promising renewable platform molecule derived from biomass[70].

Applications

Furfural is an organic compound, and its derivatives have various applications in the biobased industry, including the production of resins, plastics, polymers, pharmaceuticals, and agrochemicals (NACE: 19.2, 20.1, 20.2, 21, 22, etc.). Furfural is a versatile platform chemical with a bright future in many industries.

The use of furfural in the biobased industry aligns with the growing interest in sustainable and renewable alternatives to traditional petrochemical-based products[71].

Table 11 *Furfural SWOT Analysis*

STRENGTH	OPPORTUNITY
▪ Furfural is derived from renewable plant materials, making it an environmentally friendly option. ▪ It finds applications in various industries, showcasing its versatility and demand across sectors. ▪ The global furfural market is projected to experience steady growth.	▪ Increasing demand for sustainable chemicals and eco-friendly products. ▪ The integration of cutting-edge technologies can enhance product quality and drive innovation in furfural-based products, opening new opportunities in the market.
WEAKNESS	**THREATS**
▪ Furfural production can be influenced by fluctuations in raw material prices, which may impact production costs and profitability.	▪ The availability of crude oil-based alternatives poses a threat to the furfural market, especially if these alternatives are more cost-effective or readily available.

2.3.12 Sorbitol

Product Description and Market Value

Sorbitol is a type of carbohydrate known as a sugar alcohol or polyol. It is found naturally in various fruits like apples and blackberries and is also commercially produced for use in the production of biobased products. It is one of the top 12 high-value-added building block intermediate chemicals that can be produced from renewable biomass resources[72]. The global sorbitol market is significant and is projected to grow at a compound annual growth rate (CAGR) of around 5.54% to 6.7% during the forecast period, reaching a value of approximately USD 1.93 billion to USD 2.80 billion by 2026 to 2030. The global market for bio-based sorbitol is experiencing significant growth due to increasing demand for low-calorie food and beverages, as well as the rising awareness about the harmful effects of synthetic ingredients, driving the adoption of bio-based alternatives[73].

Biomass

The main biomass sources used to produce sorbitol are:

- **Switchgrass**: Switchgrass can produce sorbitol through an integrated fermentation and catalytic synthesis process. switchgrass biomass could yield 157.6 kt/yr of sorbitol[74].
- **Glucose** derived from corn or wheat: Sorbitol can be synthetically produced by hydrogenating glucose, typically derived from corn or wheat, in the presence of a catalyst like nickel or platinum, under specific temperature and pressure conditions[75].
- **Empty Fruit Bunch** (EFB): Sorbitol is found naturally in fruits such as apples, apricots, avocados, blackberries, cherries, peaches, plums, and raspberries[76].
- **Cellulosic materials**: Research has shown that waste cellulosic materials (i.e., eucalyptus, rice straw, Sugarcane Bagasse and Oat, etc.) can be converted into sugar alcohols, including sorbitol, using

specific catalysts and processes. In addition, a study found that cotton wool, cotton textile, tissue paper and printing paper are potential waste cellulosic materials that can be directly converted into sorbitol using a Ru/CNT catalyst in the presence of hydrogen and water as the solvent without any acids[77].

- **Sorbitol derivatives**: Different sorbitol derivatives (i.e., 1-(2-butenyl) sorbitol, 1-butyl sorbitol, 1-(2-methyl allyl) sorbitol, 1-isobutyl sorbitol, 1-vinyl sorbitol, 1-ethyl sorbitol) can be used as intermediates or starting materials for the production of sorbitol through various chemical reactions or enzymatic processes. The specific methods for converting these derivatives typically involve catalytic hydrogenation or other chemical reactions[78].

Technologies and Production Process

The technologies used to produce sorbitol include:

- **Catalytic Hydrogenation**: Corn starch is enzymatically hydrolysed to produce glucose, which is then converted into sorbitol through catalytic hydrogenation in a catalyst like nickel or platinum under specific temperature and pressure conditions[72].
- **Microbial Fermentation**: Certain microorganisms like *Zymomonas mobilis* and *Escherichia coli* can ferment glucose into sorbitol. This process involves genetically modified microorganisms efficiently metabolising glucose to produce sorbitol as a metabolic byproduct[79].

Applications

Sorbitol has a wide range of applications in various industries:

- **Food Industry**: It is a sweetener, moisture stabilizer, and texturizer in confectionery like bread, cakes, jellies, and creams. Compared to sugar, it provides a lower glycaemic response. To harmonize flavours, it is also used as a cryoprotectant additive in surimi (refined fish paste) and beverages (NACE: 10, 11)[76].
- **Cosmetic Industry**: Used as a humectant and thickener in cosmetic creams and lotions, providing a refreshing feeling when applied to skin, and used in transparent gels and toothpaste (NACE: 20.4).
- **Pharmaceutical Industry**: Used in preparing synthetic vitamin C, as a stabilizer in pharmaceutical products, as a sweetening agent in oral care products, and as a thickening agent in liquid medicines (NACE: 21).
- Other Industries: used as a plasticizer in plastics, as a precursor in polyether synthesis, and as a sizing agent in textiles, and used to improve quality in paper manufacturing (NACE: 13, 22, etc.) [80].

Table 12 *Sorbitol SWOT Analysis*

STRENGTH	OPPORTUNITIES
▪ Sorbitol has versatile applications and is used in various industries like food and beverage, pharmaceuticals, cosmetics, and personal care due to its properties.	▪ Increasing health awareness and rising diabetes cases present opportunities for sorbitol as a low-calorie sweetener and alternative to sugar in various products.

▪ Growing market value due to the health-conscious consumers and demand for processed	▪ Potential for product diversification and innovation in the sorbitol market, evolving consumer preferences and industry demands.
WEAKNESSES	**THREATS**
▪ The sorbitol market faces competition from other sweeteners and sugar alcohols, which may impact market share and pricing strategies.	▪ Regulatory Changes: Changes in regulations regarding sweeteners and food additives could impact the sorbitol market and its usage in different industries

3. Data Collection Guidelines

The data collection is based on the compilation of an Excel template composed of the following elements.

- **Objectives**: outlines the objectives of the project and WP1. as well as the methodological approach for creating Regional Data Hubs.
- **Glossary**: Contains the definition of key terms used in the model, their definitions and study boundaries.
- **Regional data collection sheets**: 12 sheets for each pilot region (Lombardy_Italy, Piedmont_Italy, FriuliVeneziaGiulia_Italy, EmiliaRomagna_Italy, Veneto_Italy, Carinthia_Austria, Slovenia, Croatia, Andalusia_Spain, BrusselsCapital_Belgium, Wallonia_Belgium, Franders_Belgium) functional to data collection.

For an overview of the model, refer to **Annex 1**.

3.1.Data Collection Template

Each specific Regional Data Collection sheets consists of 3 main columns that must be completed with the following information:

PRODUCT column

12 promising products of biobased interest that represent significant or growing demand from bioeconomy stakeholders, according to specific characteristics such as price, characteristic, and accessibility (see Chapter 2.2), were selected. This column need not be completed.

BIOMASS column

The most promising biomasses were identified for each product, representing the organic raw material used for producing the 12 promising products identified. For each specific biomass (Biomass Type), it is necessary to indicate the availability (Biomass Availability) of the biomass in the region by choosing between a YES or NO option. If the YES option is chosen, it is necessary to proceed with filling in the Primary Biomass column first and then the Secondary Biomass column.

- Primary Biomass column: Primary biomass refers to the initial plant materials directly harvested from nature, such as crops. An example of primary biomass is corn, barley, or soybean. Relating on the primary biomass at least one of the following two values must be indicated: Cultivated Area, which is the total land area - measured in hectares - used for growing primary biomass crops, or Production Volume, which indicates the total quantity of primary biomass crops harvested - measured in tons. The Yield value (Tonnes / Hectare) can be calculated if the two previous values are available (or it can be used to find one of the two previous values, if available). The yield value of primary biomass is a measure of the amount of primary biomass produced per unit area of land. For each value included into the table, it is mandatory to provide the relevant reference with the relative year, which must be included in the appropriate columns (Reference, Year).
- Secondary Biomass column: Secondary biomass consists of the by-products or residues left over after the primary biomass has been processed or harvested (secondary biomass coincides with 'Biomass Type'). For instance, when corn is harvested, these residues, such as corn stover or corn straw, are considered secondary biomass. Similarly, barley extract or straw are by-products of

barley, or soybean oil and meal are considered a secondary biomass. Relating on the secondary biomass the following information is required, if available: Production Volume, which indicates the total quantity of residual or by-product biomass generated from the primary biomass - measured in tons - and the Yield value, calculated from the ratio of Production Volume related to secondary biomass and Cultivated Area related to primary biomass (Tonnes / Hectare). The yield value of secondary biomass is a measure of the amount of secondary biomass produced per unit area of land, typically expressed in tonnes per hectare. For each value included into the table, it is mandatory to provide the relevant reference with the relative year, which must be included in the appropriate columns (Reference, Year).

Finally, the Notes column was included to include any additional information or calculations made during data collection and relevant to the study.

TECHNOLOGY column

Mature and already validated industrial technology that allows the conversion of the secondary biomass (Biomass Type) into the final product (Product Type). It is mandatory to choose one of the three following options:

- YES: the presence at the industrial level of facilities using the technology to transform the secondary biomass (Biomass Type) into the final product (Product Type)
- NO: the absence at the industrial level of facilities using the technology to transform the secondary biomass (Biomass Type) into the final product (Product Type)
- ADAPTABLE: the existence of industrial plants using the technology to obtain the product (Product Type) from a biomass different from the secondary biomass (Biomass Type) or the existence of industrial plants using the technology to obtain the product (Product Type) as a reaction intermediate from a biomass, which can be either the secondary biomass (Biomass Type) or a different one. This third option is based on the principle that - the industrial system could theoretically be readapted to transform the secondary biomass (Biomass Type) into the final product (Product Type). For the ADAPTABLE option, it is essential to indicate, whenever available, all variations from the process initially considered (alternative biomass and by which process the product is extracted as an intermediate element) in the Notes column.

Note that, if the YES or ADAPTABLE option is chosen, a descriptive sheet (Company Column) should be produced for each industrial entity that owns the technology.

Finally, if available, indicate the amount of product (Product Type) that is obtained through the specific technology (Production Volume (Tonnes)).

COMPANY column

Name and basic information (City, Address, Number) of the company that owns the technology indicated in the technology column. For each company is mandatory to indicate the NACE code relating the company's activities and provide a brief description of the fields, activities, and applications of the company (maximum of 250 words). In addition, is required to clarify the maturity level of the technology possessed by the company, choosing from one of three options: Applied Research (TRL 4-5), Pilot Small Demo (TRL 6-7) or Full Scale (TRL 8-9).

Finally, the Notes column was included to include any additional information or calculations made during data collection and relevant to the study.

4. Data Collection

4.1. Methodology

In pursuing sustainable development and resource optimisation, the SYMBIO project in WP1 is taking on the challenge of evaluating data to discover the biomass abundance in all 12 pilot regions, to be further scaled up in the next WPs of the project. Under the leadership of LGCA, all SYMBIO partners have collected data to complete the mapping, which includes the definition of classification criteria for INPUT (biomass, plants, technologies), PROCESSES and OUTPUT (applications, finished products, markets) of bio-based products, adapted to industrial sectors characterised by the NACE classification system.

The methodology created to map the availability of primary and secondary biomass and technologies necessary for producing the 12 selected products is based on a three-step process: Collection, Calculation and Analysis. This process ensures accuracy and reliability in mapping out the abundance of various biomass types. The methodology pathways have been designed using customised strategies for each region to ensure that the methodology is suited to their specific contexts and needs while adhering to the general guidelines for data collection. The organisation of monthly meetings allowed a continuous exchange of opinions and ideas between all regions involved, creating an adaptable and reliable methodology for different needs. For detailed insights into the specific methodology carried out by each pilot region, please refer to **Annex 2**.

Step 1: Collection of Primary and Secondary Biomass Data

The foundation of the inventory lies in the collection of primary data regarding the regional availability of primary biomass resources (Soy, Barley, Rice, Canola, Maim, Wheat, Alfalfa/Switchgrass, Felling losses in forest, Industrial roundwood, pulp wood). This process is initiated by conducting desktop research and literature reviews to gather information on general biomasses prevalent in the 12 pilot regions. The methodology agreed upon between the partners to systematise data collection on production and manufacturing is to predominantly use existing EU and national statistical datasets (e.g., EUROSTAT[81], ISTAT[82], and Statistični Urad SI). The data that would be collected are Cultivated Area (Hectare), Production Volume (Tonnes) and Yield (Tonnes / Hectare) concerning the primary biomasses. In some cases, Production Volumes were found in other units (quintals or m3) and were then converted into hectares. In this way, it would be possible to establish a strong foundation to proceed in the next collection phases.

As previously mentioned, some regions have slightly adapted the methodology as needed. In the Andalusia region, information about regional biomass availability has been collected directly from publications by regional ministries (the Regional Ministry of Agriculture, Fisheries, Water and Rural Development of the Andalusian Regional Government). In Slovenia, the data collected via the statistical office has been integrated with the organisation's internal knowledge of the industries/crops covered in Slovenia due to its small territory.

At the regional level, other various sources, such as data hubs of funded projects, studies (e.g., scientific publications or results), and existing EU platforms (e.g., ECoP's H4C), have also been used.

This preliminary data scouting, using primary biomass data, serves as a cornerstone for reliable further analysis and provides insights into the types and quantities of biomass available within the regions.

Data on secondary biomass have been searched in previous databases or specific market studies and analyses. If they have not been found, step 2 serves as a support.

Step 2: Data Calculation

For a detailed picture of the local biobased supply chains, it is fundamental to include secondary raw materials. With the primary data, the focus shifts to calculating the secondary biomass metrics in each specific region. The team adopts a systematic approach to calculate secondary biomass figures based on the methodologies suggested by LGCA and agreed upon during monthly meetings. By utilizing percentage values and conversion factors derived from literature and provided by local bioeconomy clusters, the team endeavours to accurately quantify secondary biomass resources (e.g. Barley Extract, Soybean Meal, Alfalfa Fiber, Soya Fiber) starting from primary biomass data.

Step 3: Data Collection on Production Technology

Complementing the primary biomass data collection and the secondary biomass calculation efforts is the mapping of the existing technologies employed in the production of the 12 specific products from biomasses within the project regions. Through desktop research and cross-referencing with regional business directories, the analysis aims to identify relevant companies operating in the chemical/ biochemical field.

Subsequent prioritization and selection of companies are conducted collaboratively by all project partners, ensuring the inclusion of key stakeholders in the research process. When necessary, a survey is crafted to gather insights into these companies' technologies in biomass production. The engagement with listed companies progresses through a series of steps, including initial contact via telephone, followed by the dissemination of written information and online survey links. Persistent follow-ups via reminder emails and calls ensure maximal participation and data collection. In cases where data from companies is not forthcoming, potential expert interviews are considered to supplement the research efforts.

In addition, to gain a comprehensive understanding of the workflow adopted by each partner within the SYMBIO consortium, LGCA has asked each project partner to provide their workflow for calculating secondary biomass data (see **Annex 2**). This systematic approach ensures consistency and reliability in the calculated metrics across all 12 pilot regions. Simultaneously, in collaboration with WP1 partners, LGCA actively participates in cross-validation activities to ensure the collected data's accuracy and comprehensiveness. This collaborative approach significantly boosts the reliability of the dataset, effectively minimising potential discrepancies and establishing a sturdy foundation for subsequent project analyses.

Step 4: Data Collection on Company

After identifying the existence of technologies, the focus is on gathering data on companies that possess them. The methodology involves several key approaches:

- Direct Contact: Engaging with companies directly through initial phone calls or emails to establish contact and introduce the project. This step ensures that the companies are aware of the project and its objectives, fostering a cooperative relationship for data sharing.
- Online Research: Conducting thorough internet searches to identify companies that are not immediately accessible through direct contact. This includes exploring company websites and professional networks.

- Database Utilization: Leveraging databases to access detailed profiles and contact information of relevant companies. These databases are valuable resources for identifying and targeting companies that might not be easily found through other means.

This systematic approach ensures a comprehensive and accurate collection of data on companies possessing relevant technologies, forming a critical component of the overall project analysis.

4.2. Limitations

Collecting data often comes with limitations and challenges in the methodology employed. The study is no exception, and several factors must be considered when interpreting the results.

Primarily, insufficient datasets on the secondary biomass resource pose a significant challenge. In some instances, data for certain regions may be scarce, difficult to obtain or entirely unavailable and must be supplemented. For this reason, although the template initially required data collection of only secondary biomass, a second section related to primary biomass was added. Indeed, the secondary biomass information can be obtained through specific calculations starting from the primary biomass values, as seen in the previous section.

However, it’s necessary to remember that while these calculations are based on established methodologies and rigorous analysis, they inevitably introduce a degree of uncertainty. Different partners may utilise slightly different approaches or assumptions, leading to variations in the derived values. This variability can affect the overall accuracy and reliability of the data, particularly when attempting to compare results across different regions or periods. A method proposed is to conduct additional expert interviews with regional authorities and major enterprises identified in activity of the Task 1.3, to obtain the approximate conversion rates/coefficients, or harvest indices (see HI). Harvest indices were the main factor to use in the calculation of what is the amount of (left/ by-product) biomass such as straws.

Furthermore, the lack of regional data, forced the use of national-level data as substitutes. However, this approach inherently assumes homogeneity within the national context, overlooking potential regional variations. Consequently, the extrapolation of national-level data to represent specific regions can introduce considerable uncertainties and inaccuracies in the analysis. Moreover, even when regional data are available, discrepancies in data collection methods, reporting standards, and quality assurance practices can complicate the integration and interpretation of the data. Variations in sampling techniques, measurement protocols, and data processing procedures may result in inconsistencies that undermine the reliability and validity of the findings.

Challenges have been found even regarding the mapping of the mature and already validated industrial technology that allows the conversion of the secondary biomass (Biomass Type) into the final product (Product Type). In many cases and regions analysed, there aren’t industrial plants that already process the secondary biomass to obtain the final products. For this reason, although initially the Template only provided for choosing between the presence and absence of technology (YES/NO option) was thought to be useful to also considered the existence of ADAPTABLE industrial plants, i.e. plants that use the technology to obtain the final product (Product Type) starting from different biomass than the ones requested, or the existence of industrial plants obtaining the final product (Product Type) as a reaction intermediate, starting from the secondary biomass (Biomass Type) or a different one. This option is based on the principle that the industrial plant could theoretically be readapted to transform the specific secondary biomass (Biomass Type) into the desired final product (Product Type). For the ADAPTABLE option, it would be essential to indicate further all variations that must be implemented from the initial process.

Additionally, it's essential to acknowledge the dynamic nature of the systems under investigation. Environmental conditions, land-use patterns, economic activities, and other factors are subject to change over time, potentially influencing the accuracy and relevance of the data. As such, our analysis may be limited by the temporal scope of the available data, failing to capture emerging trends or shifts in the underlying dynamics.

In summary, while our methodology offers valuable insights into the subject matter, it has limitations and challenges. The reliance on calculated data, the substitution of national-level data for regional analysis, issues related to data quality and consistency, and the dynamic nature of the systems being studied all contribute to the complexity of the analysis. As researchers, we must remain vigilant in acknowledging these limitations and exercising caution in interpreting the results, ensuring that our findings are presented with appropriate caveats and considerations.

5. Harmonization of the collected data

5.1. Methodology

Data harmonisation is critical to ensure uniformity, consistency, and comparability across datasets, facilitating accurate analysis and interpretation. The harmonisation takes a multifaceted approach, guided by established principles and methodologies endorsed by all project partners during monthly meetings. One fundamental aspect of the process involves adhering to guidelines designed to maintain the uniformity of the data. These guidelines serve as a framework for standardising data collection, organisation, and presentation, ensuring coherence and consistency throughout the harmonisation endeavour and helping mitigate discrepancies from disparate data sources.

LGCA has provided the following guidelines for data collection in WP1:

Primary Biomasses Data Collection:

Begin by gathering information on the general biomasses present in each region. Utilise verified websites such as Eurostat and national statistical organizations. If data is unavailable, cross-reference with Eurostat's databases or national statistical organizations like ISTAT for Italy. Eurostat links provided: Eurostat Biomass Data - 1[83] and Eurostat Biomass Data - 2[84].

Secondary Biomasses Data collection:

Once the primary biomass data is gathered, proceed to calculate, or insert specific biomass data if found. If specific data is unavailable, consider calculating it based on percentages and correlations found in literature or provided by local clusters, universities, and sector experts. Ensure the calculation method for transparency and harmonisation purposes and provide it to the other partners.

Technology Method of Production:

If possible, explore information regarding the technology method of production for each biomass. Reach out to relevant organizations and clusters in your region for insights. If you find the technology information obtained for each product useful, use the Notes column in the template to record it.

Equally essential is achieving the appropriate equivalences and conversions of measurement units and data. In this regard, meticulous attention is paid to harmonising units of measurement to ensure consistency and comparability across datasets. This entails converting data from one unit to another using robust methodologies and validated conversion factors. By employing reliable conversion techniques, the harmonisation process minimises errors and possible inaccuracies.

When data for key variables such as Cultivated Area, Production Volume, and Yield are unavailable for the same year, specialised methodologies are employed to ensure data consistency and completeness. For instance, when production volume and yield data are missing while cultivated area information is available, the latest available cultivated area number is utilised to maintain data coherence. In cases where yield information is also absent, yield is calculated by dividing the cultivated area by the production volume, ensuring the harmonised datasets' integrity and completeness.

Furthermore, the human element introduces an additional layer of complexity to the harmonisation process. The involvement of multiple stakeholders with varying priorities, perspectives, and expertise necessitates effective communication and collaboration to overcome challenges and achieve consensus. Coordinating disparate teams and aligning their efforts requires strong leadership, clear communication, and a collaborative mindset to navigate organisational cultures, bureaucratic hurdles, and competing interests effectively. In conclusion, data harmonisation is a multifaceted effort that demands a systematic and rigorous approach to ensure uniformity, consistency, and comparability across different datasets from each region. By adhering to established guidelines, leveraging reliable data sources, and employing specialised methodologies, the harmonisation process facilitates accurate further analysis and interpretation, thereby enhancing the value and utility of the harmonised datasets for informed decision-making and policy formulation in the next WPs of the project.

5.2. Limitations

The process of harmonizing data, though essential for ensuring comparability and facilitating analysis, has various limitations and difficulties. For instance, when data is gathered from different sources such as datasets, interviews, and national administrative records, it becomes imperative to harmonize them to ensure compatibility and enable cohesive analysis. However, the path to achieving this harmony is often obstructed by many hurdles stemming from divergent data formats, variable definitions, or inconsistent codifications. Furthermore, the complexities of harmonization are compounded by discrepancies in data collection methods, reporting standards, and quality assurance practices, particularly when dealing with regional data.

A critical consideration in data harmonization is the reliance on calculated values to determine secondary biomasses. Even though these calculations are supported by established methodologies and rigorous analyses, they still result in some uncertainty in the dataset. Different approaches or assumptions may be used by each partner involved in the harmonization process, resulting in discrepancies in the values derived. The resulting variability can significantly impact the data's overall accuracy and reliability, particularly when attempting to compare results across different regions or periods. The integrity of the harmonized dataset is compromised by this variability, which also complicates the interpretation of findings and could potentially distort conclusions drawn from the analysis.

Additionally, the temporal dimension introduces another layer of complexity to the harmonization process. As datasets evolve, incorporating new observations and revisions, and maintaining consistency and coherence becomes increasingly challenging. Changes in data collection methodologies, or updates to reporting standards can all contribute to inconsistencies within the dataset, necessitating ongoing efforts to harmonize and validate the data. Failure to adapt to these temporal dynamics can compromise the integrity of the harmonized dataset, rendering it obsolete or unreliable for subsequent analyses.

Furthermore, the human element adds another dimension to the harmonization process. Collaborative efforts are essential for successful data harmonization, but coordinating disparate teams and aligning their efforts can be a daunting task.

In conclusion, while data harmonization is indispensable for ensuring comparability and facilitating analysis, it is beset by numerous limitations and difficulties. From reconciling disparate datasets to addressing inconsistencies in data collection methods and overcoming the challenges of unit conversion, the journey towards harmonization is fraught with complexities. However, despite these challenges, the pursuit of harmonization remains paramount for SYMBIO, as it enables researchers, policymakers, and practitioners to unlock valuable insights and drive informed decision-making.

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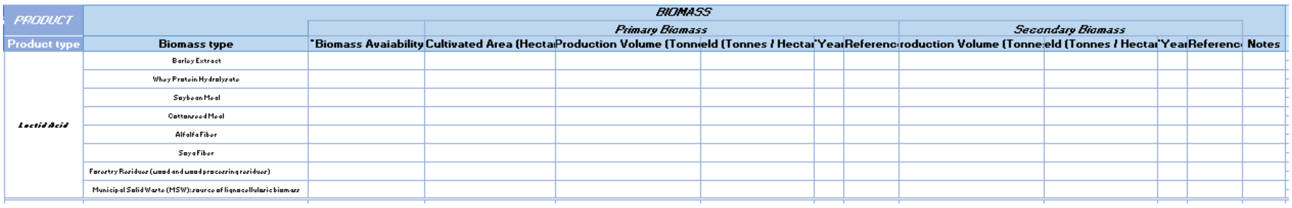
Annex 1 - Data Collection Model

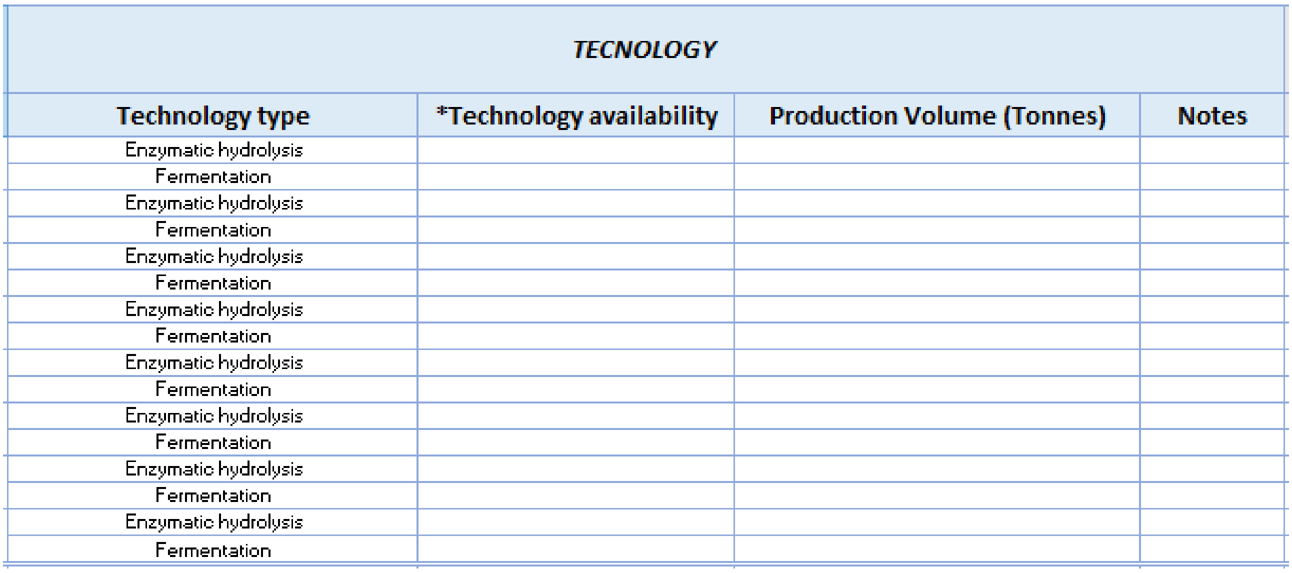
The complete Data Collection Model can be found on the last page of the deliverable. In Annex 1, enlargements are given for each column (see section 3.1) using lactic acid as a reference. The template is repeated for all 12 selected products, with their respective biomasses and technologies.

PRODUCT column and BIOMASS column



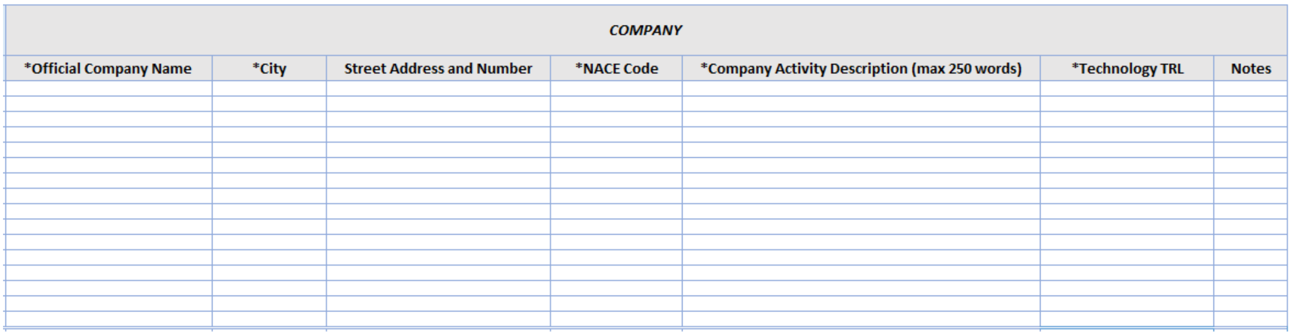
PRODUCT	*BIOMASS*											
			Primary Biomass					*Secondary Biomass*				
Product type	**Biomass type**	***Biomass Avaiability**	**Cultivated Area (Hecta**	**Production Volume (Tonn**	**eld (Tonnes / Hecta**	***Yea**	**Referenc**	**roduction Volume (Tonne**	**eld (Tonnes / Hecta**	***Yea**	**Referenc**	**Notes**
Lactid Acid	Barley Extract											
	Whey Protein Hydrolysate											
	Soybean Meal											
	Cottonseed Meal											
	Alfalfa Fiber											
	Soya Fiber											
	Forestry Residues (wood and wood processing residues)											
	Municipal Solid Waste (MSW): source of lignocellularic biomass											

TECHNOLOGY column



TECNOLOGY			
Technology type	***Technology availability**	**Production Volume (Tonnes)**	**Notes**
Enzymatic hydrolysis			
Fermentation			
Enzymatic hydrolysis			
Fermentation			
Enzymatic hydrolysis			
Fermentation			
Enzymatic hydrolysis			
Fermentation			
Enzymatic hydrolysis			
Fermentation			
Enzymatic hydrolysis			
Fermentation			
Enzymatic hydrolysis			
Fermentation			
Enzymatic hydrolysis			
Fermentation			

COMPANY column



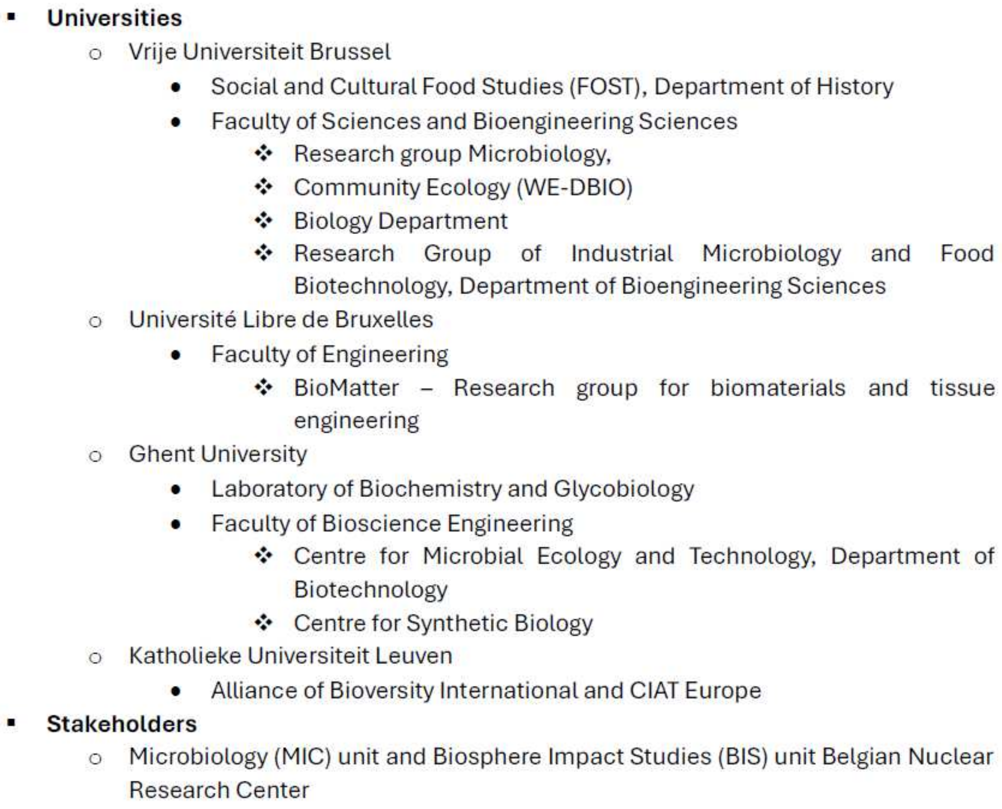
COMPANY						
***Official Company Name**	***City**	**Street Address and Number**	***NACE Code**	***Company Activity Description (max 250 words)**	***Technology TRL**	**Notes**

Annex 2 – Data Collection methodology per pilot region

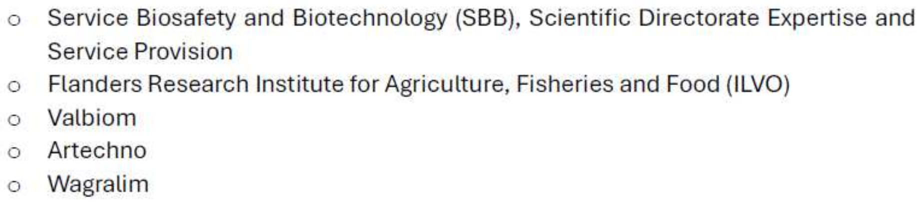
SERN - Belgium

SERN is responsible for three of the twelve pilot regions of the SYMBIO project and has been collecting data on available biomass types since February. The initial tasks involved Research, Mapping, and Data Collection of Regional Biomass information in Brussels, Flanders, and Wallonia.

The inventory relies on data from various sources, including data hubs, studies, and EU platforms. Initially, SERN focused on national-level research to locate relevant information. This revealed that collecting public data on biomass would be challenging. Research extended to national universities and other stakeholders.



- **Universities**
    - Vrije Universiteit Brussel
        - Social and Cultural Food Studies (FOST), Department of History
        - Faculty of Sciences and Bioengineering Sciences
            - Research group Microbiology,
            - Community Ecology (WE-DBIO)
            - Biology Department
            - Research Group of Industrial Microbiology and Food Biotechnology, Department of Bioengineering Sciences
    - Université Libre de Bruxelles
        - Faculty of Engineering
            - BioMatter – Research group for biomaterials and tissue engineering
    - Ghent University
        - Laboratory of Biochemistry and Glycobiology
        - Faculty of Bioscience Engineering
            - Centre for Microbial Ecology and Technology, Department of Biotechnology
            - Centre for Synthetic Biology
    - Katholieke Universiteit Leuven
        - Alliance of Bioversity International and CIAT Europe
- **Stakeholders**
    - Microbiology (MIC) unit and Biosphere Impact Studies (BIS) unit Belgian Nuclear Research Center



- Service Biosafety and Biotechnology (SBB), Scientific Directorate Expertise and Service Provision
- Flanders Research Institute for Agriculture, Fisheries and Food (ILVO)
- Valbiom
- Artechno
- Wagralim

EUROSTAT was recognized as a primary source for gathering data on Belgium's three regions. However, while the platform provides some data, it is insufficient for comprehensive mapping. Specifically, EUROSTAT lacks information on production yield (tonne/ha). Nonetheless, it offers comprehensive data regarding the area (cultivation, harvest, and production).

Brussels

Most universities identified as stakeholders are based in or originally from Brussels. However, limited responses from researchers impeded mapping. Existing studies provided some data, such as "La Biomasse et la Bioénergie (ER 12)."

Flanders

For the Flanders region, our research has focused, so far, on the literature found online and published by scientific organisations/entities/centres that work on these matters. Those studies map the Flemish bioeconomy by collecting information on how strongly a certain sector (and/or its biobased share) in Flanders is growing and data on the import, export, and production of different biomasses.

Wallonia

Contact with Université de Liège and Valbiom indicated ongoing inventories of organic materials. Despite multiple contacts, the information provided was insufficient to complete the template. Future efforts will involve direct contact via LinkedIn and interviews. Wallonia is advanced in biomass utilization, but public information remains scarce, complicating the completion of the template.

Conclusion

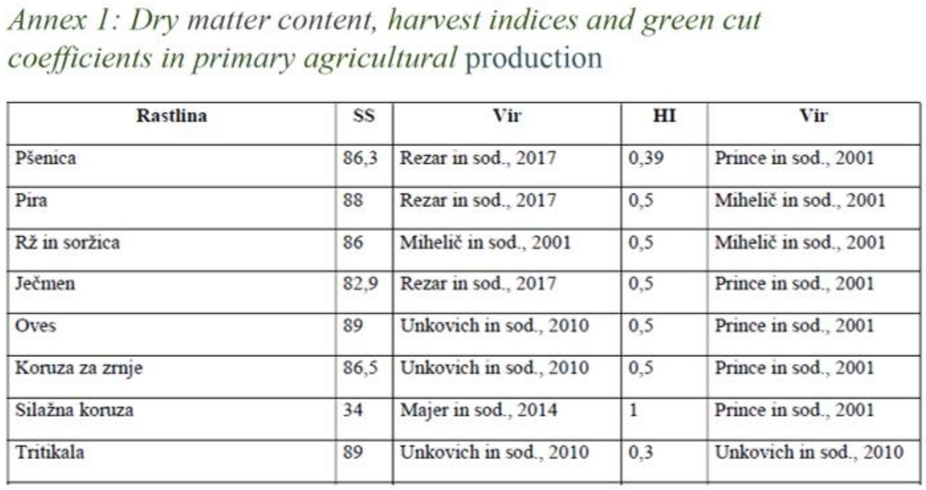
In the second wave of contacts, SERN focused on Valbiom and ILVO Vlaanderen experts in Wallonia and Flanders. Research on biomass quantities in the three regions will continue through open sources and stakeholder identification, with strategy adjustments based on recent findings.

Slovenia

The task considered the collection of the biomass produced in Slovenia annually. The first step was to check the availability of the specific feedstock. The data has been collected mainly through the statistical office of Slovenia (Statistični Urad SI), which is a national statistics platform with gathered data on production and manufacturing per selected sectors, as well as through internal knowledge of the industries/ crops covered in Slovenia due to its small territory. For example, it is known that soybeans are not common for Slovenian agriculture, yet the information was double-checked, and the statistical office showed small amounts produced, which we therefore considered as biomass available, regardless of low quantities produced (5804 tons a year).

In some cases, statistics for the cultivated area (CA), production volume (PV), and yield was not available for the same year. Where the production volume and yield were missing (with cultivated area information available), we used the cultivated area number from the latest available year. If information on the yield was missing, too, we calculated it by dividing CA and PV.

The main difficulty occurred with the case where the corn/wheat production was available, but the biomass, such as "corn stover" and "wheat straw", was questionable. In this case, we have contacted the professor from the Biotechnical University of Ljubljana, who gave us the approximate conversion rates/coefficients or harvest indices (see HI). Harvest indices were the main factor used to calculate the amount of (left/ by-product) biomass such as straws.



Annex 1: Dry matter content, harvest indices and green cut coefficients in primary agricultural production

Rastlina	SS	Vir	HI	Vir
Pšenica	86,3	Rezar in sod., 2017	0,39	Prince in sod., 2001
Pira	88	Rezar in sod., 2017	0,5	Mihelič in sod., 2001
Rž in soržica	86	Mihelič in sod., 2001	0,5	Mihelič in sod., 2001
Ječmen	82,9	Rezar in sod., 2017	0,5	Prince in sod., 2001
Oves	89	Unkovich in sod., 2010	0,5	Prince in sod., 2001
Koruza za zrnje	86,5	Unkovich in sod., 2010	0,5	Prince in sod., 2001
Silažna koruza	34	Majer in sod., 2014	1	Prince in sod., 2001
Tritikala	89	Unkovich in sod., 2010	0,3	Unkovich in sod., 2010

Example: 138000 is the wheat production. With HI of 0,39, it means that 0,61 is the wheat left-over (straw). Multiplying 138000 by 0,61 means 84180 tons of wheat straw harvested.

The conversion rates were not there for the case of a corn stover. The rest of the data required has mostly been covered.

Andalusia

SYMBIO Methodology – Research Approach in ANDALUSIA for WP1

Step 1: Data collection of primary data of available biomass

The methodology used in this work is based on a literature review of the main information sources for quantifying the biomass resources produced in the agricultural and industrial phases.

Most of the information collected in WP1 to evaluate the regional biomass data has been obtained from a publication by the Regional Ministry of Agriculture, Fisheries, Water and Rural Development of the Andalusian Regional Government. They periodically publish the main statistical information on Andalusia's agricultural and fisheries sectors through their website. The aim is to provide society with data that may be of interest to them about agricultural, livestock and fishing activity in the Andalusian Community,

The latest of these publications, entitled 'Caracterización del Sector Agrícola y Pesquero de Andalucía' (Characterization of the Agricultural and Fishing Sector in Andalusia), compiles most of these statistics and their evolution updated to the year 2022.

Step 2: Data calculation

The proposed methodology will be followed when available from the literature review.

Step 3: Research on used technology for production

Desktop research of relevant companies in the manufacturing and process industry sector in the region of Andalusia.

Austria

For WP1, the following 3-steps-approach by the Austrian partners (ANRI and BABEG) was applied:

- Data collection of biomasses
- Data calculation for specific biomass
- Data research on used technology of production

Step 1: Data collection of primary data of available biomass

collection of information about general biomasses in the region of Carinthia

- Desktop and literature research by BABEG.
- Cross-validation by ANRI to ensure accuracy and completeness.

The research started with regional biomass for the secondary resource streams described by leading partner LGCA (e.g. soy for soy straw). Since there is often no explicit data on the quantities of secondary resource flows (e.g. soy straw), data on general biomasses are used. In a further step, statistical ratios can be applied to estimate the potential quantities required.

Main sources used for biomass data:

- International level
- Eurostat
  https://ec.europa.eu/eurostat/databrowser/view/apro_cpnh1__custom_10912843/default/table?lang=en and
  https://ec.europa.eu/eurostat/databrowser/view/apro_cpnhr/default/table?lang=en&category=agr.apro.apro_crop.apro_cp.apro_cpnh
- National level: National statistic organization: Statistics Austria, Ministries and further official reports by Federal environmental agency

Step 2: Data calculation

- Calculation of specific biomasses data (e.g. wheat straw, rice straw, barley extract) for the region of Carinthia:
  First calculation of specific biomasses and research of potential calculation methods regarding conversion factors and estimation ratios
  Calculation of specific biomasses based on methodology suggested by the lead partner on the WP1 meeting on the 19th of April (Methodology: starting from the general biomasses and calculating using percentage and conversion factors found for each region in literature and given by local clusters)

Future steps:

- Coordination meetings with other pilot region work groups to align on calculation methods. These meetings serve as a platform to discuss and harmonize approaches across different groups within the project.
- Discussion on methodologies for calculating specific biomasses and secondary products, such as corn steep liquor and crude glycerol, based on the available primary data and researched conversion factors.

Step 3: Data collection on used technology of production

- Desktop research of relevant companies in the chemical field in the region of Carinthia (*Source: regional list of chambers of commerce* https://firmen.wko.at/SearchSimple.aspx)
- Cross-check of companies and prioritisation by both Austrian partners for a final list of contacts in the region
- Creation of a survey for interviews regarding the used technologies within the companies based on the given data table by BABEG.
- Cross-check of a survey by ANRI

Ongoing:

- Contact of listed companies: first step by telephone, second step by sending written information and a link to an online survey, third step reminder emails/calls
- Evaluation of survey/approach based on first companies and potential adaptation of approach.
- Potential expert interview if data wasn't providable by the companies.
- Analysis of final results for the decision of specific biomass flows processable in the pilot region Carinthia.

*** Mandatory field**

PILOT REGION	PRODUCT	BIOMASS												TECNOLOGY				COMPANY						
				Primary Biomass					Secondary Biomass															
Name	Product type	Biomass type	*Biomass Avaiability	(*)Cultivated Area (Hectare)	(*)Production Volume (Tonnes)	Yield (Tonnes / Hectare)	*Year	*Reference	Production Volume (Tonnes)	Yield (Tonnes / Hectare)	*Year	*Reference	Notes	Technology type	*Technology availability	Production Volume (Tonnes)	Notes	*Official Company Name	*City	Street Address and Number	*NACE Code	*Company Activity Description (max 250 words)	*Technology TRL	Notes
LOMBARDY (ITALY)	Lactid Acid	Barley Extract	YES											Enzymatic hydrolysis	YES									
														Fermentation	YES									
		Whey Protein Hydrolysate	YES											Enzymatic hydrolysis	YES									
														Fermentation	YES									
		Soybean Meal	YES											Enzymatic hydrolysis	YES									
														Fermentation	YES									
		Cottonseed Meal	YES											Enzymatic hydrolysis	YES									
														Fermentation	YES									
		Alfalfa Fiber	YES											Enzymatic hydrolysis	YES									
														Fermentation	YES									
		Soya Fiber	YES											Enzymatic hydrolysis	YES									
														Fermentation	YES									
		Forestry Residues (wood and wood processing residues)	YES											Enzymatic hydrolysis	YES									
														Fermentation	YES									
		Municipal Solid Waste (MSW): source of lignocellulosic biomass	YES											Enzymatic hydrolysis	YES									
														Fermentation	YES									
	Glycerol	Oil crops: Canola	YES											Enzymatic Hydrolysis	YES									
														Saponification	YES									
														Transesterification	YES									
		Oil crops: Rapeseed	YES											Enzymatic Hydrolysis	YES									
														Saponification	YES									
														Transesterification	YES									
		Oil crops: Palm	YES											Enzymatic Hydrolysis	YES									
														Saponification	YES									
														Transesterification	YES									
		Oil crops: Soybean	YES											Enzymatic Hydrolysis	YES									
														Saponification	YES									
														Transesterification	YES									
		Animal fats	YES											Enzymatic Hydrolysis	YES									
														Saponification	YES									
		Waste cooking oil (WCO)	YES											Enzymatic Hydrolysis	YES									
														Saponification	YES									
		Sugarcane	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Sugarbeet	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Corn	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Molasses	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
	Succinic Acid	Corn Stover and Straw	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Sugarcane Bagasse (SCB)	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Wheat Straw	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Rice Straw	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Barley Straw	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Miscanthus	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Municipal Solid Waste (MSW): source of lignocellulosic biomass	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Forestry Residues (wood and wood processing residues)	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
	Acetic Acid	Corn Stover and Cop	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Wheat Straw	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Sugarcane Bagasse (SCB)	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Poplar Sawdust	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Barley Straw	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Forestry Residues (wood and wood processing residues)	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
	Adipic acid	Oil crops: Rapeseed	YES											Enzymatic Hydrolysis	YES									
														Transesterification	YES									
														Direct fermentation	YES									
														Fermentation + Chemical Hydrogenation	YES									
		Oil crops: Canola	YES											Enzymatic Hydrolysis	YES									
														Transesterification	YES									
														Direct fermentation	YES									
														Fermentation + Chemical Hydrogenation	YES									
		Oil crops: Palm	YES											Enzymatic Hydrolysis	YES									
														Transesterification	YES									
														Direct fermentation	YES									
														Fermentation + Chemical Hydrogenation	YES									
		Oil crops: Coconut	YES											Enzymatic Hydrolysis	YES									
														Transesterification	YES									
														Direct fermentation	YES									
														Fermentation + Chemical Hydrogenation	YES									
		Forestry Residues (wood and wood processing residues)	YES											Direct fermentation	YES									
														Fermentation + Chemical Hydrogenation	YES									
		Corn Stover	YES											Direct fermentation	YES									
														Fermentation + Chemical Hydrogenation	YES									
		Rice Straw	YES											Direct fermentation	YES									
														Fermentation + Chemical Hydrogenation	YES									
		Sugarcane Bagasse (SCB)	YES											Direct fermentation	YES									
														Fermentation + Chemical Hydrogenation	YES									
	PLA	Corn	YES											Fermentation	YES									
														Condensation	YES									
														Polymerization	YES									
		Sucarcane	YES											Fermentation	YES									
														Condensation	YES									
														Polymerization	YES									
		Sugarbeet	YES											Fermentation	YES									
														Condensation	YES									
														Polymerization	YES									
		Wheat	YES											Fermentation	YES									
														Condensation	YES									
														Polymerization	YES									
		Cassava	YES											Fermentation	YES									
														Condensation	YES									
														Polymerization	YES									
	PHAs	Sugarcane waste	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Sugarcane Bagasse (SCB)	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Corn Stover	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Wheat Straw	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Forestry Residues (wood and wood processing residues)	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Municipal Solid Waste (MSW): source of lignocellulosic biomass	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Waste cooking oil (WCO)	YES											Fermentation	YES									
		Oil crops: Canola	YES											Fermentation	YES									
		Oil crops: Palm	YES											Fermentation	YES									
		Oil crops: Soybean	YES											Fermentation	YES									
	Lysine	Corn Stover	YES											Fermentation	YES									
		Wheat Straw	YES											Fermentation	YES									
		Molasses	YES											Fermentation	YES									
	Glutammic acid	Corn Stover and Syrup	YES											Fermentation	YES									
		Wheat Straw	YES											Fermentation	YES									
		Rice Straw	YES											Fermentation	YES									
		Sugarcane Bagasse	YES											Fermentation	YES									
		Soybean Meal	YES											Fermentation	YES									
		Molasses	YES											Fermentation	YES									
	1,3-Propanediol	Corn steep liquor	YES											Fermentation	YES									
		Crude glycerol	YES											Fermentation	YES									
		Corn Stover	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Wheat Straw	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Rise Straw	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Sugarcane Bagasse	YES											Enzymatic Hydrolysis	YES									
														Fermentation	YES									
	Furfural	Forestry Residues (wood and wood processing residues)	YES											Acid Hydrolysis	YES									
														Catalytic Systems	YES									
														Solvent-Thermal Conversion	YES									
		Municipal Solid Waste (MSW): source of lignocellulosic biomass	YES											Acid Hydrolysis	YES									
														Catalytic Systems	YES									
														Solvent-Thermal Conversion	YES									
		Maize Cobs	YES											Acid Hydrolysis	YES									
														Catalytic Systems	YES									
														Solvent-Thermal Conversion	YES									
		Corn Stalks and Cobs	YES											Acid Hydrolysis	YES									
														Catalytic Systems	YES									
														Solvent-Thermal Conversion	YES									
		Sugarcane Bagasse	YES											Acid Hydrolysis	YES									
														Catalytic Systems	YES									
														Solvent-Thermal Conversion	YES									
		Rice Husks	YES											Acid Hydrolysis	YES									
														Catalytic Systems	YES									
														Solvent-Thermal Conversion	YES									
		Wheat Straw	YES											Acid Hydrolysis	YES									
														Catalytic Systems	YES									
														Solvent-Thermal Conversion	YES									
		Barley straw	YES											Acid Hydrolysis	YES									
														Catalytic Systems	YES									
														Solvent-Thermal Conversion	YES									
	Sorbitol	Switchgrass	YES											Catalytic Transfer Hydrogenation (CTH)	YES									
														Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Wheat	YES											Catalytic Transfer Hydrogenation (CTH)	YES									
														Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Corn	YES											Catalytic Transfer Hydrogenation (CTH)	YES									
														Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Rice Straw	YES											Catalytic Transfer Hydrogenation (CTH)	YES									
														Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Eucalyptus	YES											Catalytic Transfer Hydrogenation (CTH)	YES									
														Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Empty Fruit Bunch (EFB)	YES											Catalytic Transfer Hydrogenation (CTH)	YES									
														Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Sugarcane Bagasse and Oat	YES											Catalytic Transfer Hydrogenation (CTH)	YES									
														Enzymatic Hydrolysis	YES									
														Fermentation	YES									
		Cotton wool and textile	YES											Catalytic Transfer Hydrogenation (CTH)	YES									
		Tissue and Printing Paper	YES											Catalytic Transfer Hydrogenation (CTH)	YES									
		Sorbitol Derivatives	YES											Catalytic Transfer Hydrogenation (CTH)	YES									