Biological Resources Certifications Schemes

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☐	**R**	Document report
X	**DEM**	Demonstrator, pilot, prototype
☐	**DEC**	Websites, patent fillings, videos, etc.
☐	**OTHER**	

Dissemination Level

X	**PU**	Public, fully open, e.g. web
☐	**SEN**	Sensitive, limited under the conditions of the Grant Agreement
☐	**CI**	Classified, information as referred to in Commission Decision 1001/844/EC

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Publishable executive summary

BioReCer aims to ensure the environmental performance and traceability of biological feedstock used by the bio-based industries. This will be executed through the deployment of guidelines to strengthen current certification schemes by including new criteria that align with EU taxonomy and EU corporate due diligence regulations. Within this approach, the added value, the use, as well as the social acceptance of bioproducts will be increased. BioReCer is structured in three main technological pillars:

- Development of a multidimensional assessment framework and a digital BioReCer ICT-tool (BIT) for the aggregated and collaborative analysis of biological feedstocks and their associated supply chains.
- Creation of a BioReCer Innovation Ecosystem Living-Lab (BRIE-LL) following a multi-agent approach and the testing of this framework in four bio-based supply chain case studies.
- Using all generated knowledge to complement current certification schemes by including new sustainability and traceability criteria and ensure their applicability at EU and global scale.

Therefore, D6.1 aims to carry out a Demonstration and Validation of BioReCer tools and methodologies. A framework will be implemented with all relevant stakeholders to develop and streamline the management of the demonstration studies. In this demonstration, the representation of key actors will be included: producers, processors, end-users, consumers, investors, NGOs, governmental bodies for consultation, through the development of value chains

To develop these value chains, 4 case studies were selected in different countries in which different biomasses are included:

- Fishery/sewage sludge demo case (case study 1- Spain): ANFACO-CEC.
- Urban biowaste demo case (case study 2- Italy): UNIVPM.
- Agro sector demo case (case study 3- Greece): CERTH.
- Forestry demo case (case study 4- Sweden): RISE.

1 Introduction

1.1 Definition of WP6 and most important aspects of the case studies

WP6 will demonstrate the adequacy of the assessment methodologies (through BIT) and the adapted certification scheme developed in previous WPs through a cluster reproducibility assessment integrated in the BioReCer tool. To this purpose, 4 different case studies in an industrial representative environment in four EU countries will be established based on regional data. CERTH, RISE, UNIVPM and ANFACO-CECOPESCA will lead the case studies in collaboration with CETAQUA, SPRING and CAP. The case studies have been selected considering their geographical distribution, type and source of feedstock and the bio-based value chain. This approach will be extended to analyse the suitability of the model for the assessment of other relevant biological feedstock flows in Europe. The main outcome of WP6 will be the validation of the developed methodology in an agile way and the demonstration of its suitability to be used as a framework for certifying the sustainability, traceability, and origin of a wide range of biomasses.

The 4 selected case studies are:

- Fishery/sewage sludge demo case (Spain): ANFACO-CECOPESCA and CETAQUA. BioReCer methodologies and tools will be validated in a Galician case-study, involving the most relevant bio-based feedstocks of the region: Fishery/cannery waste and urban/industrial sewage sludge.
- Urban biowaste demo case (Italy): UNIVPM. BioReCer products will be validated in the Lombardy region, which will include wastes treated in biorefineries managed by CAP HOLDING SPA (water and waste utility) i.e., sewage sludge, OFMSW, agro-waste and non-hazardous organic liquid waste.
- Agro sector demo case (Greece): CERTH. Greek case study will be focus on agricultural wastes and related by-product streams, such as tree prunings, straw, crops residues and others.
- Forestry demo case (Sweden): RISE. The Swedish study will be focus on forestry wastes as Sawdust, Bark, GROT and other waste products.

In the mid-report, preliminary data from the demonstration of the developed methodologies of BioReCer on the 4 case studies will be collected. A theoretical framework of the origin, destination, characterisation and potential interest of the identified biomasses have been defined and the valuable feedback from the case studies from the bio-based value chains of stakeholder's will be evaluated in order to feed the ICT-Tool and to ensure the quality of the certification schemes.

1.2 Impact of case studies value chains on the actual economy

To develop this work package, as indicated above, a different number of case studies were selected based on the importance of the biomasses in each of the countries. These are economic activities with a high impact within these communities, which means that their introduction into the market improves the economic development of these areas.

1.2.1 Case study 1

The case study of Galicia, Spain, is based on two basic pillars, fisheries and urban and industrial sewage sludge. These two sectors were chosen because of their importance in the economic development of the region, as both historically and today fisheries and water are critical and generates a very important source of income. Regarding the fishery sector, in Galicia, it stands as a vital pillar within the community of Galicia playing a significant role in the region's economic landscape and contributing significantly to its Gross Domestic Product (GDP) (According to recent data, the fishing sector contributes approximately 5% to Galicia's GDP (*Industrias Pesqueras*, 2022), highlighting its importance as a key driver of economic activity). With its extensive coastline and rich marine resources, Galicia has long been recognized as one of Europe's leading fishing regions, harnessing the bounty of the sea to fuel economic growth and sustain livelihoods.

In addition, the sector provides indirect employment opportunities through its extensive supply chain, supporting a network of businesses that cater to the needs of the fishing industry, from equipment suppliers to transportation services.

Also, as one of the most important and consolidated biomasses from the sea in the economic development of this region and the rest of Spain, are macroalgae. The value of macroalgae increased from €6.2 billion in 2007 to €13.27 billion in 2017. The data shows a sustainable increase in market value similar to that of production. In 2018, and according to the report by the market research company "Markets and Markets" the growth forecast for the global seaweed market estimates a compound annual growth rate of 8.4% until 2023, to reach around €16.2 billion. In Spain, macroalgae production accounted for 1.25% of the European total in 2017 (*FAO*, 2020). This production has been growing at an annual rate of 25% in recent years, from 134 t in 2007 to 4921 t in 2018. (*García & Peteiro*, 2015.)

On the other hand, urban and industrial sewage sludge management plays a crucial role in Galicia, Spain, contributing to environmental sustainability, agricultural productivity, and resource conservation. With increasing urbanization and industrialization, the effective treatment and utilization of sewage sludge has become paramount in addressing waste management challenges while harnessing the potential of organic resources to benefit various sectors of the economy.

One of the main destinations for sewage sludge in Galicia is agriculture. Treated sewage sludge, when applied to agricultural land, serves as a nutrient-rich organic fertilizer that restores soil fertility and increase crop yields. By recycling organic matter and essential nutrients, such nitrogen, phosphorus, and potassium, sewage sludge helps to improve soil structure, water retention, and nutrient cycling, promoting sustainable agricultural practices and reducing reliance on chemical fertilizers.

In addition to its role in agriculture and land restoration, sewage sludge can be utilized to generate renewable energy. Through processes such as anaerobic digestion and thermal conversion, sewage sludge can be converted into biogas, biofuels, and thermal energy, providing a sustainable alternative to fossil fuels and reducing greenhouse gas emissions. By harnessing the energy potential of sewage sludge, Galicia can mitigate the effects of climate change, increase energy security, and promote the transition to a low-carbon economy.

1.2.2 Case study 2

The second case study is located in the region of Lombardy, Italy and, similar to case study 1 involves secondary biological raw materials from urban and industrial activities. In this particular case, it is based on the organic fraction of municipal solid waste (OFMSW), the sewage sludge, including the ones originated by co-treatment of municipal wastewater, the agro-industrial waste, and the water-based non-hazardous organic waste (e.g., sludge from septic tanks). All these wastes, treated in the main Wastewater Treatment Plants (WWTPs) of the territory and managed by CAP Holding Spa, are intended to be processed for Volatile Fatty Acids (VFA), biopolymers, and biofertilizer recovery at the biorefinery of Sesto San Giovanni WWTP (Lombardia).

Sewage sludge production is well controlled and easily traceable as it is mainly generated in WWTPs, and their appropriate management is mandatory by legislation. Agro-industrial waste production can also be easily traceable in large farms, although this kind of waste is characterized by large spatial distribution and disperse pollution from small farmers that could be hard to trace. OFMSW is a highly dispersed waste, which is hard to trace.

The traditional treatment of these wastes consists of aerobically and/or anaerobically degrading the organic matter up to a certain degree of stabilization to avoid environmental issues such as instability of organic matter, high pathogen concentrations, odour, eutrophication, or pollution of groundwater. The seasonal production, characteristics variability and the high costs of agro-industrial waste treatment hinder their management, which entails that they are sometimes treated by non-environmentally friendly practices. The circular economy principles developed in the biorefinery schemes managed by CAP HOLDING SPA allow not only avoiding the aforementioned environmental issues, but also producing valuable products.

The overall turnover of the Italian bioeconomy in 2017 was €330B, and it employed 2 million workers. Turnover and employment in the Italian bioeconomy increased by about 1.25 % per year from 2011 to 2017, and by about 2% from 2017 to 2018. Moreover, waste treated in biorefineries plays a significant role in the local economy (Faba *et al.*, 2021). Specifically, biorefineries create jobs, stimulate investment, and contribute to economic diversification in regions where they are located.

1.2.3 Case study 3

Case study 3 (Greece) is based on bio-waste from agriculture. As an agrarian nation, Greece possesses fertile soils, favourable climate conditions, and abundant water resources that support a diverse range of agricultural activities, from olive and grape cultivation to dairy farming and fisheries. By harnessing its natural resources and agroecological diversity, Greece can produce a wide variety of high-quality food products for domestic consumption and export markets, reducing dependency on imported goods and enhancing food self-sufficiency. In 2022, agriculture contributed around 3.76 percent to the GDP of Greece (O´Neill, 2024).

This activity generates a huge variety of bio-wastes such as tree pruning, straw or crops. By incorporating these agricultural by-products into value-added products and processes, Greek companies can diversify their product portfolios, reduce production costs, and improve overall efficiency. For instance, tree pruning residues can be converted into biomass pellets or biochar, serving as renewable sources of energy or soil amendments in agriculture. Similarly, straw and cultivation residues can be utilized in the production of biofuels, bio-based materials, and biochemicals, offering alternatives to fossil fuels and conventional plastics.

1.2.4 Case study 4

Finally, case study 4 focuses on the use of waste from the wood industry.

The forestry sector in Sweden has a very important role in their economy. Sweden is the World's 4th largest exporter of pulp, paper and sawn timber, and, in 2022, export value was 186 billion (SEK) and a little over 15.8 billion (SEK) was invested. The forest industry is one of the largest in Sweden and represents approximately 10-12 % of the Swedish industry in terms of employment and sales. Today, the forest industry employs 115,000 people in total (Skogsindustrierna, 2021). About half of the forests are owned by private owners, one quarter by private companies and the remaining part by the state.

Considering the secondary raw materials from the forest processing industry, the largest volumes of potential resources for biobased products comes from GROT (branches, roots, tips), saw dust, bark, and fibre sludge. These are all produced in amounts of a few hundred thousand up to a million tons on an annual basis. Other interesting residual streams that can be valorised are warm water, carbon dioxide, and various sludges. Among the cluster members of RISE, five of the largest forest industries in Sweden are represented and in 2020 RISE performed an inventory of the available residual streams and the quality and characteristics of these materials for the purpose of using these as raw materials in the development of circular biobased value chains. RISE has experience in utilizing a large range of residual streams in various projects such as bio-sludge, wastewater sludge and chemical sludge, Lignin, Bark, Fibersludge and fiber reject, talloil, Terpentine, extractives, Green Lye sludge, GROT, Saw dust, Ash, Methanol, Lye. These resources can be used in the production of both green chemicals and materials capable of replacing the oil-based alternatives.

Sawdust, bark, and other waste products from the wood industry represent valuable resources that can be repurposed into various high-value products and applications. One of the primary avenues for valorisation is bioenergy production. Sawdust and wood chips can be converted into biomass pellets, briquettes, or chips for use in district heating systems, industrial boilers, and power plants. This renewable energy source not only reduces reliance on fossil fuels but also contributes to Sweden's ambitious climate goals by mitigating greenhouse gas emissions and enhancing energy security. Furthermore, wood residues can be utilized in the production of bio-based materials and chemicals, thereby reducing dependence on petrochemicals and fostering a more sustainable industrial ecosystem. Sawdust, for example, can be processed into lignin, cellulose, and hemicellulose, which serve as feedstocks for the production of bioplastics, biochemicals, and advanced materials. By tapping into the potential of wood residues, Sweden can stimulate innovation, create new market opportunities, and strengthen its position as a global leader in sustainable manufacturing.

In conclusion, the use of these biomasses in these sectors is key, not only because of their importance for the economic development of the different regions, but also because of their potential to be revalued and increase the potential of these sectors, while mitigating the carbon footprint of the processes by giving them greater added value.

1.3 Expected contribution of WP6 to the project

Work Package 6 will make several contributions to the BioReCer project.

First, the development of the value chains will be established (in cooperation with other work packages). These value chains will be based on the development of production systems for different biomasses, based on information that has been obtained from companies. The implementation of each phase will be carried out in a way that match with their production process, with the objective of subsequently implementing quantitative data from bibliographic data, reports, laboratory data, etc. and finally, implementing real data from the different industries. These data and models will be used by WP5 to train the tool and establish an automated data entry system.

On the other hand, since the beginning of WP6 continued work will be carried out together with stakeholders, companies or institutions that will be involved in the platform and with which different collaborations have been established, such as those mentioned above. Another contribution will be done in cooperation with work package 4 to obtain an adequate number of stakeholders to validate this working methodology. These companies will be the ones with whom we will work together on the certification of value chains, certification of raw materials and the acquisition of data, work in which WP6 will play a leading role.

1.4 General progress and current status of the work package

The work package started in M8 and is planned to continue until M36, i.e., until the end of the project. Subsequently, the work carried out in each of the case studies that make up the work package will be specified in more detail, but, in general terms this is the progress up to this point:

- Analysis of the raw materials and biomasses of interest, their composition, evolution and importance within the production systems of each of the study cases.
- Development of the value chains of each of the biomasses, including the material flow diagrams, inputs and outputs and specification of each of the phases of the production systems.
- Introduction of secondary data flows from reports, scientific articles, government articles and other bibliography. Introduction of primary data from organizations.

Recruitment of stakeholders for the project (currently 92) with whom we work to obtain data, ask questionnaires and make interviews.

2 Current status and development of each of the case studies

2.1 Case study 1

2.1.1 Fishery

-Origin of biomasses

According to the European Commission, in the context of external trade statistics, fishery products include: edible fishery products (fresh, chilled, frozen, salted, smoked and dried fish, canned products, molluscs, etc), products, (meals, oils, fats, etc.) and algae (*Glossary: Fishery products*, 2023). More than 70% of the total fish caught is subjected to further processing before being placed on the market resulting in large quantities of fish waste. This production remains constant throughout the year (Coppola *et al.,* 2021).

This process begins at sea, where ships catch large quantities of fish that arrive in port. Once in port, they are selected by the different processing companies that send them to their production facilities, mainly for human consumption. In these places, the large quantities of waste mentioned above are generated and need to be managed. This is where the processing companies come in. These companies introduce them into their production chains, where they have different destinations depending on the sector they are destined for, as we can see in Figure 1.

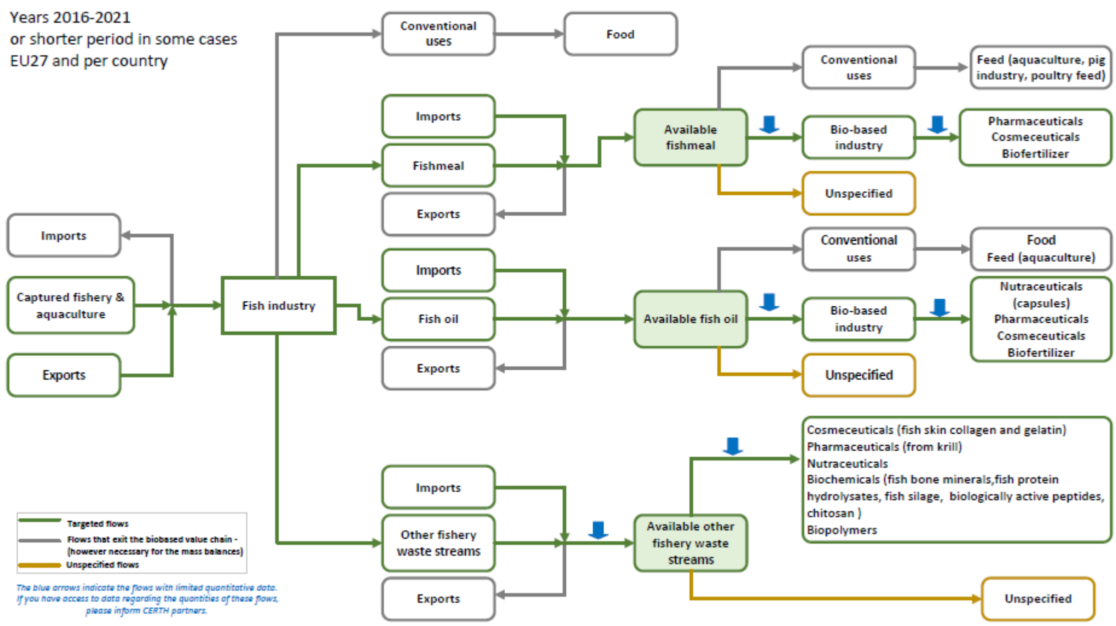


Figure 1. Fish industry flows.

-Value of the products and possible destinations.

One of the most common destinations for these discards is the production of fish oils and fishmeal. This is an industry that collects large quantities of waste and transforms it into products that can be used in various sectors The proportion of the world's fisheries used to produce fishmeal and fish oil has declined over the past 20 years. From 2001 to 2010, the average annual fishmeal production was above 5.5 million tonnes, while from 2011 to 2020 it was around 5 million tonnes. The production of fish oil in 2018 was nearly 1.3 million tonnes a year, the highest level in the past 20 years. (European commission, 2023)

Fish oils go through a series of centrifugation, bleaching and purification steps are followed to obtain products suitable for marketing. In these stages, less pure oils are obtained, but they can be easily used in various sectors.

On the other hand, these by-products are used to obtain collagen. This involves hydrolysis, centrifugation and filtration stages in the processing. This process produces, collagen products are obtained that are not destined for the traditional industry but can be introduced into various industries.

Finally, there is another source of biomass from the sea, algae. The production of algae is constantly increasing due to the use of the large quantities of biomass that reach the coasts from the sea. Macroalgae production still depends on harvesting from wild stocks (68% of the macroalgae production units), but macroalgae aquaculture (land-based and at sea) is developing in several European countries and currently represents 32% of the macroalgae production units (Araújo *et al.,* 2021).

These algae are a very interesting source of nutrients and are used, among other uses, in the production of polysaccharides. This is a multi-stage process in which the biomasses are separated (to obtain only the algae part), filtered and centrifuged to obtain polysaccharides with a very good nutritional profile and physic-chemical qualities.

In this context, the valorization strategies for fish discards, fish by-products and algae could contribute to the economic growth. Likewise, new uses for fish waste could minimize the costs associated to the landing obligation, and reduce the enormous environmental problems associated with the large amount of waste (Coppola *et al.,* 2021).

-Characterization (composition).

In this case, in our three value chains, we obtain three biomasses: fish oils, collagen and polysaccharides. Each of them can provide different nutrients that can be used in different sectors, so the characterisations were carried out according to the potential value of each one of them.

Table 1. Crude Fish oil characterization. ANFACO.

Parameter	Value
Omega 3	40.6 %
Omega 6	4.84 %
Saturated fatty acids	30.81 %
Monounsaturated FA	22.64 %
Polyunsaturates FA	46.55 %

Table 2. *Hydrolyzed Collagen characterization. ANFACO.*

Parameter	Value
Humidity	87 %
Total protein	12.5 %
Total fats	0.32 %
Ash	1 %

Table 3. Seaweed characterization. ANFACO.

Parameter	Value
Protein	11.5 %
Carbohydrate	46.99 %
Lipid	1.43 %
Ash	30.18 %

-Value of the products and possible destinations.

Discards from fish processing plants are processed into fish oils on the one hand and collagen. In the case of fish oils, they are treated in a stepwise process to remove all impurities. This is done through a chain of processes to purify it and obtain a pure product. This product can be used as a biofertilizer, pharmaceutical product, or in the cosmetic industry due to its high concentration of essential fatty acids. In addition, it can also be processed directly into omega 3.

In the case of partially hydrolysed collagen, it can be used in different sectors such as cosmetics, biochemistry, or the production of biopolymers. Depending on its degree of hydrolysis, it can be used in one sector or another.

In the algae sector, the processing of polysaccharides produces products that can be used in the food industry, as additives, in the pharmaceutical industry due to their immunostimulant and prebiotic activity, or in the textile industry.

-Possible companies and their importance in the chain

In our region, the fish industry and the seaweed processing industry are very important, accounting for more than 5% of the GDP of the region. For this reason, several companies related to this industry are interested in the valorisation of seaweed by-products and in opening new markets with them. This is the case of companies marketing additives for various industries, such as cosmetics, pharmaceuticals, and foodstuffs.

As examples of companies involved in the project in our case study, there are companies which representing each step of the value chain: fish and algae producers, processors, food developers and companies developing ingredients for several industries. Their names are protected by a NDA.

-Updated value chains

These chains have been modelled, representing the process to obtain the different bioproducts (fish oil, collagen, and polysaccharides), as well as the inputs and outputs to the system using, where available, real information shared by the stakeholders of the project. The chains are under development, inputting data and modelling against the values that are of interest.

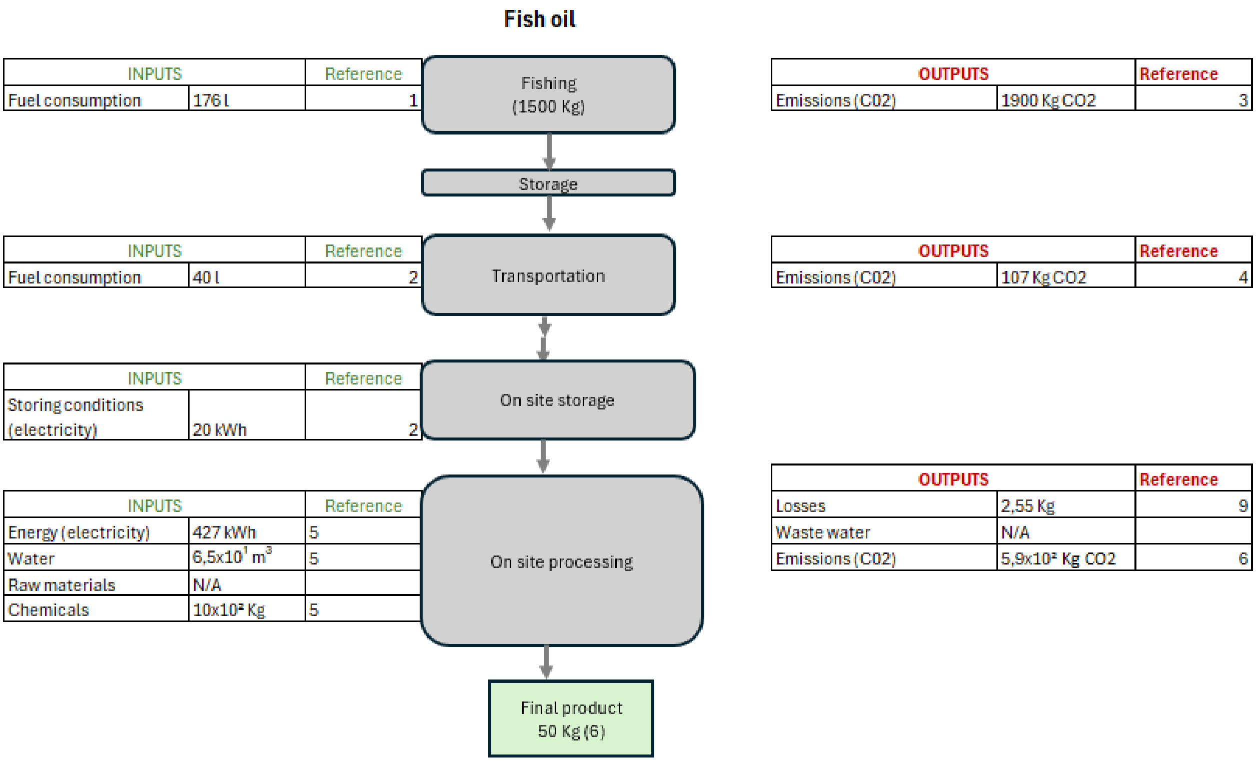


Figure 2. Inputs and outputs for fish oil. The data have been extracted from bibliography and have been converted to produce 50 Kg of Fish oil starting from 1500 Kg of biomass. [1][2][3][4][5][6]

[1] Vázquez-Rowe, I., Villanueva-Rey, P., Moreira, M. T., & Feijoo, G. (2014). Edible protein energy return on investment ratio (ep-EROI) for Spanish seafood products. Ambio, 43, 381-394. l

[2]https://www.researchgate.net/publication/348744569_Energy_Consumption_Analysis_in_Katsuwonus_Pelamis_sp_Freezing_and_Storaging_Process.

[3] Sala, A., Damalas, D., Labanchi, L. et al. Energy audit and carbon footprint in trawl fisheries. Sci Data 9, 428 (2022). https://doi.org/10.1038/s41597-022-01478-0.

[4] Chutia, S., Gohain, L., Kakoty, N. M., & Deka, D. (2022). Robotic algae harvester: A novel method for efficient algae collection. Aquacultural Engineering, 98, 102266.

[5] Hilmarsdóttir, G. S., Ögmundarson, Ó., Arason, S., & Gudjónsdóttir, M. (2022). Identification of environmental hotspots in fishmeal and fish oil production towards the optimization of energy-related processes. Journal of Cleaner Production, 343, 130880.

[6] EUMOFA-Monthly-Highlights-April-2019-Fishmeal-and-Fish-Oil

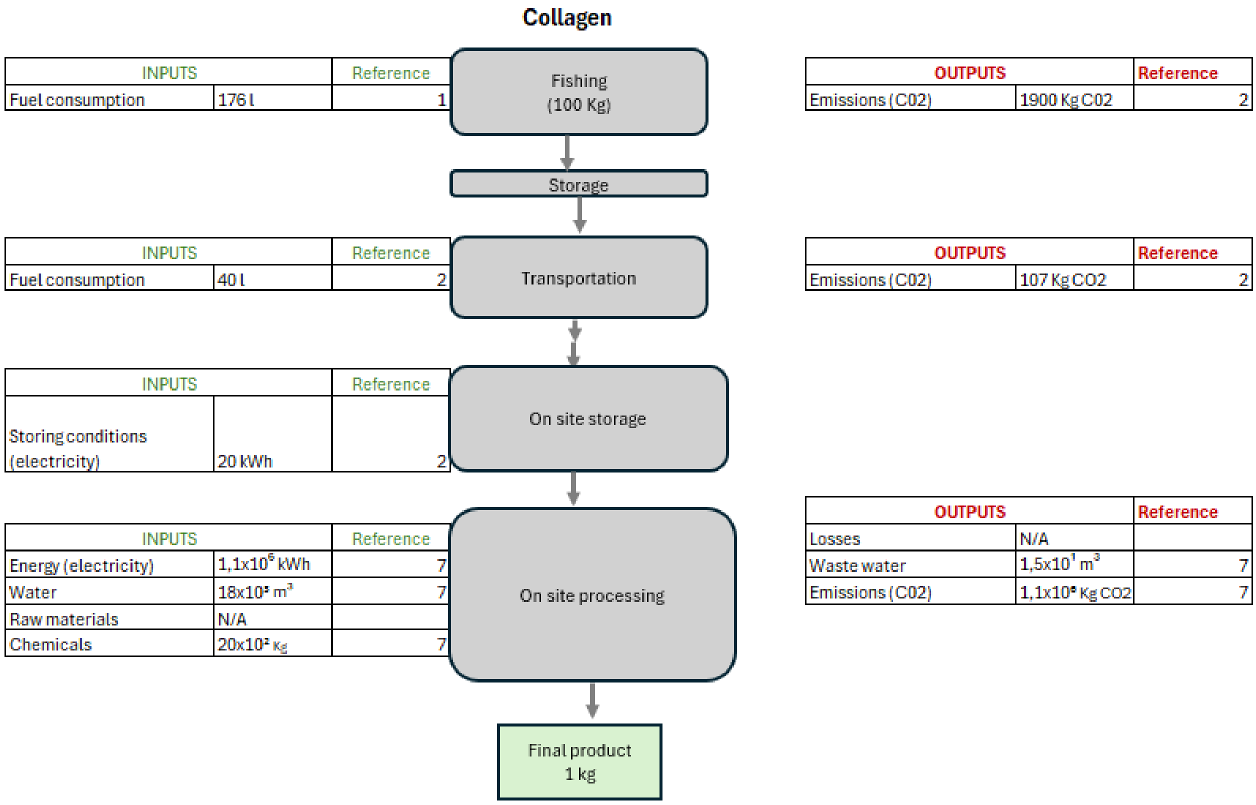


Figure 3. Inputs and outputs for collagen. The data have been extracted from bibliography and have been converted to produce 1 Kg of collagen starting from 100 Kg of biomass. [7]

[7] Wojdalski, J., Krajnik, M., Borowski, P. F., Dróżdż, B., & Kupczyk, A. (2020). Energy and water efficiency in the gelatine production plant. AIMS Geosci, 6(4), 491-503.

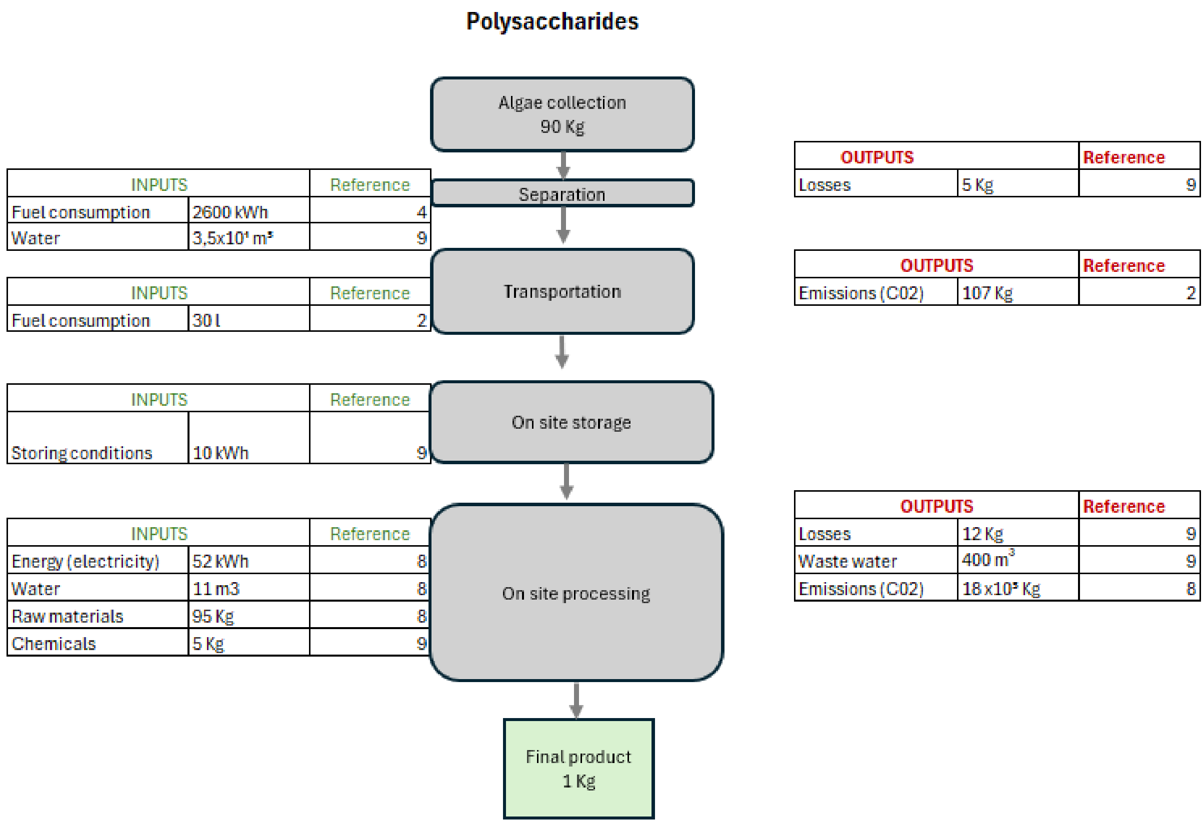


Figure 4. Inputs and outputs for polysaccharides. The data have been extracted from bibliography and have been converted to produce 1 Kg of polysaccharides starting from 90 Kg of biomass. [8][9]

-Flow diagrams explaining the points where biomass products of interest are produced.

In this case, flow diagrams (figure 5, 6, 7) of the bioproducts production processes have been developed, in which tables have also been introduced to obtain quantitative data.

These diagrams show the production process of the different bioproducts. In the case of fish oil, this is a process in different phases where different types of oils are obtained with different degrees of refinement. In each of the phases, losses and some wastes are generated, as well as the introduction of raw materials, chemicals or water. The energy consumption of the process is also quantified.

In the case of the collagen flow diagram, what is finally obtained are partially hydrolysed peptides. For this, as shown in figure 6, a process is carried out in which other substances are

[8] Data from algae company Saadia, K. (2017). The carbon footprint of polysaccharide production from red microalgae. (chrome - extension://efaidnbmnnnibpcajpcglclefindmkaj/https://repositorio.unican.es/xmlui/bitstream/10902/12153/1/400121.pdf)

[9] Data from algae company

eliminated from the initial sample, as well as a final process in which bioproducts of the required size are obtained.

In the last diagram, in the case of polysaccharides, the production process consists of several stages in which a ground and dried polysaccharide product is finally obtained as a result of this production process. The costs of energy, water and materials are quantifiable and are shown in the diagram.

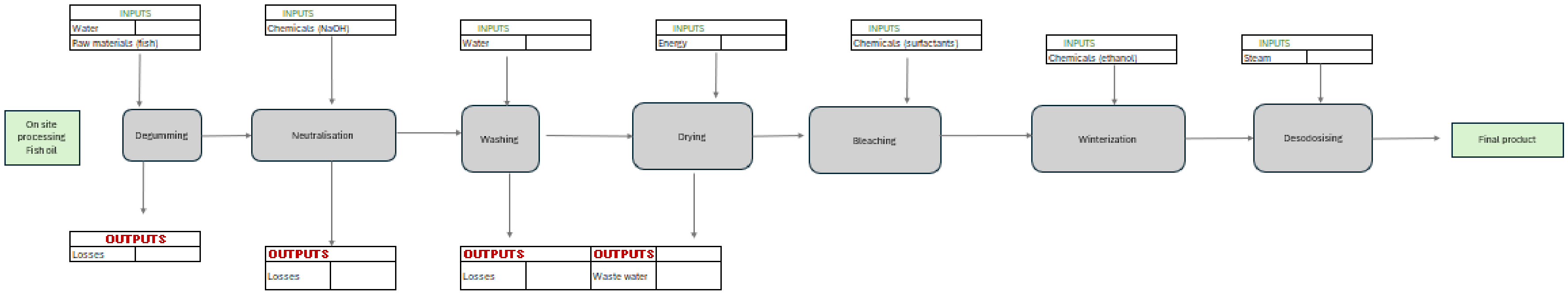


Figure 5. Fish oil flowchart with inputs and outputs.

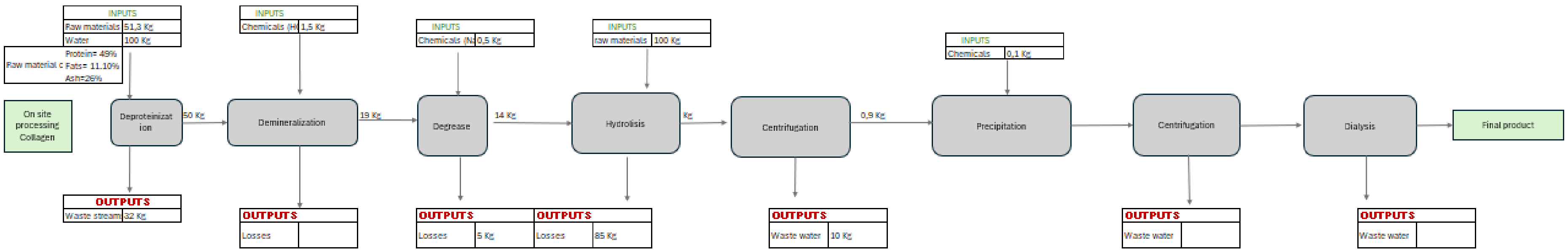


Figure 6. Collagen flowchart with inputs and outputs. The preliminary data has been extracted from tests and studies carried out at ANFACO-CECOPESCA facilities.

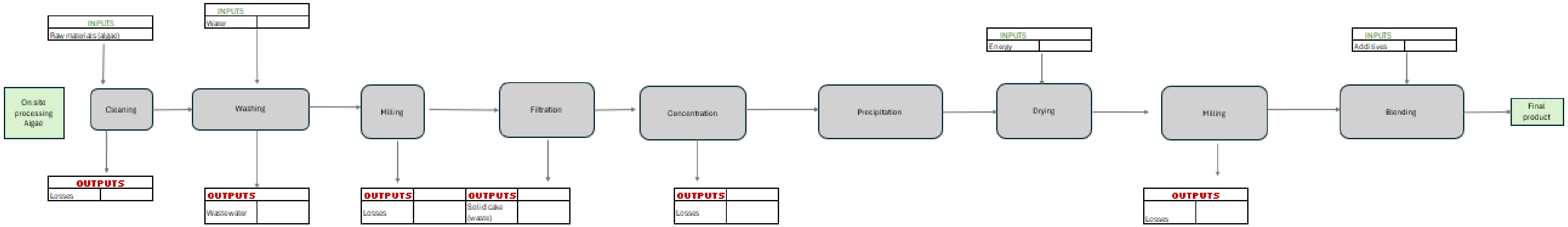


Figure 7. Algae flowchart with inputs and outputs.

-Explain how this certification will improve your production system.

Currently, companies that produce by-products that they want to revalorise do not have the capacity to introduce them into a large number of sectors because there is a lack of market confidence in the origin and composition of these products, there is no single regulation that standardizes these processes and that is why these companies must introduce these products into sectors with low added value or manage them for their elimination.

This certification system will improve the production systems because, on the one hand, it will give security to customers or companies interested in purchasing this type of products, since they will be able to know and have greater reliability about the sustainability of the process. The biomass value chains with which we work with must certify the origin, quantities, energy and water consumption, etc. of each of their phases and their characterization. This will improve both their better acceptance by interested parties and facilitate their introduction to the market.

On the other hand, it will help the introduction of other biomasses using the same certification systems, thus expanding the existing market.

Cooperation will be necessary between all interested parties so that these certification processes are carried out in the best way, that is, certifying entities, governments and companies.

2.1.2 Sewage sludge

-Origin of biomasses.

According to the National Water Quality Plan (2007-2015), there are more than 2,500 wastewater treatment plants (WWTP) in Spain that purify more than 3,375 Hm^3 of wastewater per year.

The most common technology for municipal wastewater treatment is the activated sludge process, a biological process that generates large quantities of organic sludge. These are commonly known as sewage sludge.

In this process, the organic matter in wastewater is oxidised and transformed into microbial biomass, by a wide range of organisms. The process is generally carried out in a large aerated tank, where the wastewater and microorganisms remain in contact for a few hours. The mixture then flows to a settling tank where the microbial clots fall to the bottom and the treated wastewater flows down the drain. The clots accumulated at the bottom of the tank are then removed in the form of sludge: some is recycled to the aeration tank, to maintain the process, while the excess sludge, produced by microbial growth, must be eliminated.

In most cases, the process is preceded by primary decantation, which also generates organic sludge, although of a slightly different nature. This primary sludge must be eliminated together with the excess secondary sludge (Figure 8). Primary settling produces sludge that is pumped to a thickener, where it is concentrated up to 7 %. On the other hand, secondary decantation with the addition of the polyelectrolyte allows the flocs of organic matter to be separated from the inorganic matter by conveying the sludge to the thickener, which is concentrated at approximately 4.8 %.

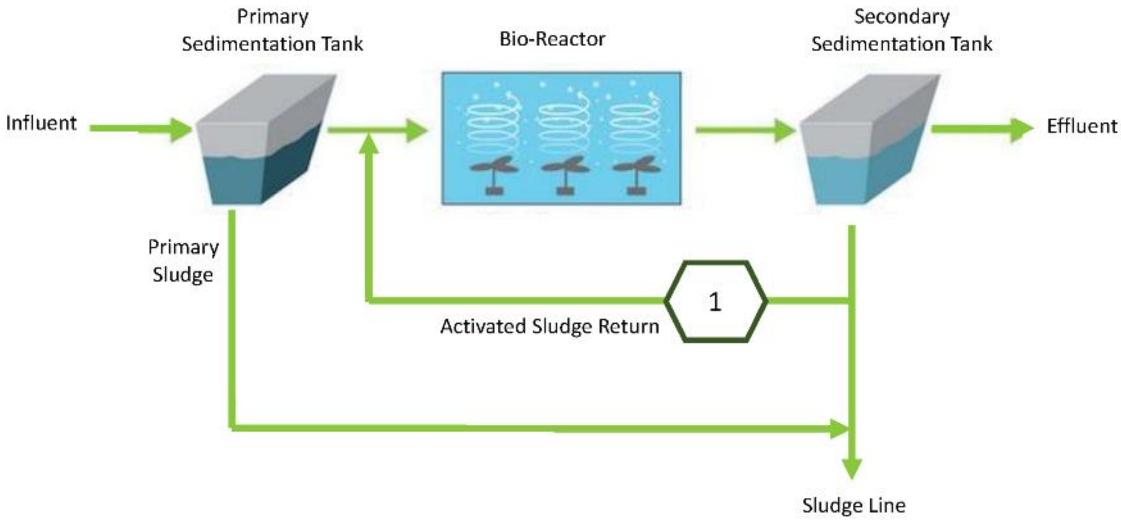


Figure 8. Sludge line in a typical WWTP.

The sludge separated from the treated water in the last stage of the process contains more than 90 % water and is highly biodegradable. To facilitate the handling and disposal of the sludge, desiccation processes are usually applied. Dehydration is usually carried out with mechanical processes using: vacuum filtration, a jacket centrifuge, a basket centrifuge, belt filters, press filters or variable volume plate filter presses. The solids concentration achieved by dehydration is approximately 30 %. In the secondary settling treatment, all sludge undergoes biological purification.

Another important factor is that the quality of the sludge is not constant, it varies according to the design characteristics of each plant, the type of wastewater treated, the industries that produce it, the time of year, the weather, the location of the plant and so on.

-Characterization (composition).

Depending on the type of sludge we are referring to, for example, primary sludge, biological sludge, or mixed sludge, the latter being understood as being derived from the mixture of the previous two, the characterization is very different. Taking into account that the type of sludge proposed as a substrate for this case study is the dehydrated sludge from a WWTP, used to generate high added value products such as volatile fatty acids, Table 4 would show a typical composition.

Table 4. Typical composition of dehydrated sewage sludge in a WWTP.

Parameter	Value
pH	6.1
Total COD (g O2/L)	315.8
Soluble COD (g O2/L)	9.6
Total solids (g/L)	310.5
Volatile solids (g/L)	155.2

-Value of the products and possible destinations.

These sewage sludges obtained in WWTPs can be subjected to a fermentation process to give rise to VFA (acetic, propionic, butyric and valeric and their branched acids), which have a high and growing market demand and business volume. These compounds can be used as antimicrobial agents and/or chemical reagents with versatile applications in industries such as chemistry and cosmetics (Sauer et al., 2008; Kelm et al., 2017). Within the food sector, propionic and butyric acid are used as food preservatives (especially bread doughs and other baked products) and animal feed (Ayan et al., 2020). Apart from direct use, VFA can be transformed into higher value products. The elongation of VFA chains allows the production of fatty acids from medium chain ones such as caprylic acid (octanoic acid). Furthermore, from the polymerization of VFAs, polyhydroxyalkanoates (PHA) can be obtained, which give rise to a type of bioplastic with multiple applications (Fradinho et al., 2014).

VFA production is traditionally obtained from non-renewable petrochemical sources, such as oil refining, with a consequent negative effect on health and the environment. An alternative for the production of these acids with less associated environmental impact are bioprocesses and the use of renewable raw materials such as, for example, organic waste and in particular sewage sludge. VFA can be obtained as intermediate products of the fermentative processes that are part of anaerobic digestion (AD). Recent studies have shown that AD processes can be designed and/or adapted for the simultaneous production of different resources with high added value (Khan et al., 2016), which would facilitate their implementation and technological adaptation to obtain VFA.

Table 5. Market price of the main VFA (Chemanalyst, 2024).

VFA	Market value (€/t)
Acetic acid	1.090
Propionic acid	1.580
Butyric acid	1.800

Although the purity of the bioproducts generated is analogous to the VFA produced from the petrochemical route, the fact that they come from waste acts as a limiting barrier to their potential use in certain sectors such as cosmetics or human food. That is why a first approach has been carried out with end users who are testing the suitability of these VFA produced from renewable substrates in order to incorporate them into their value chain. Three main destinations have been assessed: sale to companies in the petrochemical industry to replace the marketing of conventional pure VFA, lower purity VFA to be used as a food additive in the animal industry, and production of biobased green disinfectants from these products.

-Possible companies and their importance in the chain (names, if possible, or if you have an NDA or other protection figure, you can comment in a more generic way about their sector and why it is important in your region).

*No information other than names can be provided.

- Energy companies: REPSOL.
- Animal food companies: NUDESA.
- Cleaning agents company: DISICLIN, J.R.SABATER.

-Updated value chains (until now or, if you anticipate that in the following days you will have more updates, wait until this moment to send it).

The sludge generated in the WWTP is subjected to the dehydration process, giving rise to the substrate whose composition has been shown in Table 4. It undergoes the fermentation process in which VFA are produced. These VFA are diluted in the fermenter effluent, but need to be subsequently treated through a concentration and purification process (variable dependent on the end use), and separated from each other if desired. Once the adaptability tests of the bioproducts generated to the requirements of the end users have been carried out, they would have a potential to reach the market, either to energy companies, to companies that manufacture animal food additives or to others that produce cleaning agents and disinfectants of surfaces. The entire value chain is shown in Figure 9.

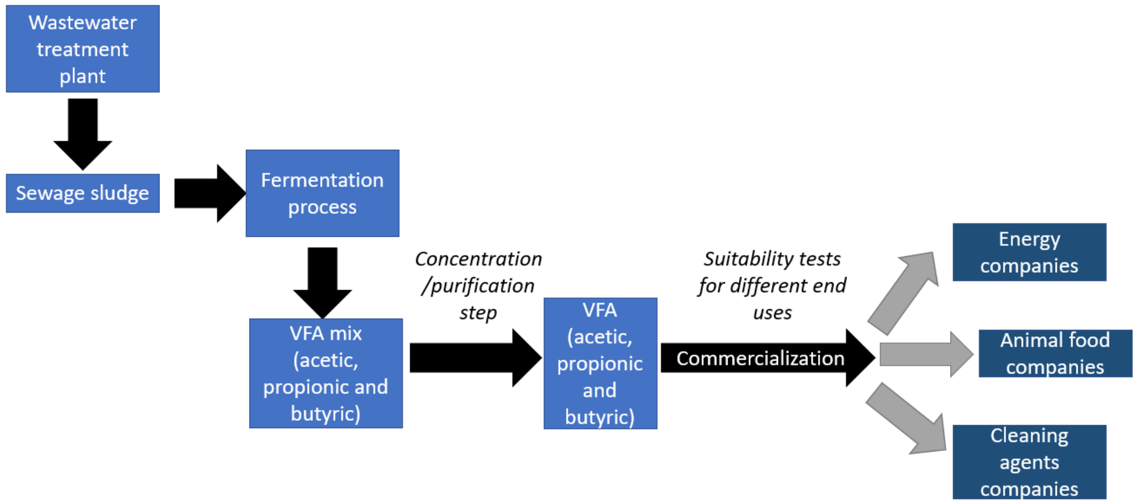


Figure 9. Value chain of the VFA from biological processes.

-Flow diagrams explaining the points where biomass products of interest are produced.

In Case Study 1, the use of sewage sludge as a substrate to produce VFA was proposed. Specifically, it would be proposed to use the generation of sludge from a WWTP treating the pollution of around 250,000 equivalent inhabitants, therefore the input to the system would be a sludge flow of 58 t/d (at 30% dryness) as Figure 10 shows. After being subjected to the fermentation process to give rise to the VFA, the solid fraction (cake with high dryness) must be separated from the supernatant, which contains the VFA. This stream will be subjected to a membrane train and subsequently to a liquid-liquid extraction + distillation to obtain annually: 339 m^3 of acetic acid, 81 m^3 of propionic and 71 m^3 of butyric acid.

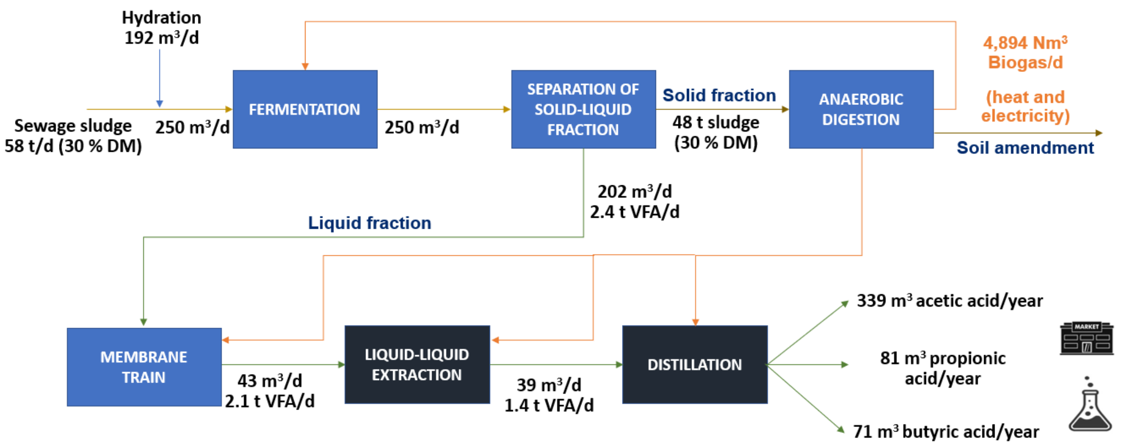


Figure 10. Flow diagram of the proposed process to produce bio-based VFA.

-Explain how this certification will improve your production system.

One of the challenges of this type of biorefineries to produce VFA from organic waste streams is the acceptance of the final product by users, as well as its quality certification. A change is necessary in the legal framework that allows the use of products obtained from waste and this requires the involvement of public authorities and the general public to work towards its acceptance. Furthermore, this change is not viable without compliance with quality standards and health regulations that can only be guaranteed through technical and scientific progress.

The main barriers that the management of sewage sludge must face in order to achieve the commercialization of these bioproducts are the following:

A) Technical criteria for the use of VFA from sludge. It is necessary to specify whether the current criteria that apply to VFA from the petrochemical industry would also apply to those from waste. Furthermore, it must be verified that these VFA of biological origin meet these criteria and are competitive from both a technical and economic point of view.

B) Lack of uniformity in legislative development. Although European directives regulate waste management systems, each Member State requires different requirements, which complicates the operation of companies at an international level, therefore conditioning the creation of scale in the market. In Spain, where each Autonomous Community has its specific legislation, this phenomenon is even more complicated.

Therefore, these certifications will help improve the VFA production system by giving solidity and security to the process, as well as standardising in some way the origin of these products, strengthening their organic origin compared to those derived from fossil sources.

2.2 Case study 2

In the EU, OFMSW is defined as the mixture of the wastes derived from parks, gardens, kitchen, and restaurants. However, its definition is different depending on the region and the nation. The OFMSW is characterised by high moisture and biodegradability, and it represents one of the main reasons of adverse environmental impacts and risks in traditional landfilling, due to odours, groundwater contamination by leachate etc. (Alibardi et al., 2015).

Sewage sludge results from municipal wastewater treatment (Bonfiglioli et al., 2014). Wastewater from households, some industries (after pre-treatment), rainfall, and urban runoff is received by wastewater treatment plants (WWTPs) aiming to eliminate contaminants and safely returning treated water to the environment. Wastewater undergoes physical, chemical, and biological operations, achieving the removal of settleable solids, organic forms of carbon, nitrogen, and phosphorus. The resulting products generated during these treatment processes are recovered water and wastewater sludge, which is composed of solids and biosolids, typically in a liquid or semi-solid form (Metcalf & Eddy, 2003).

The water-based non-hazardous organic waste includes digestate from anaerobic treatments of municipal waste, sludge from septic tanks and sewage cleaning.

Agro-industrial wastes are inedible materials produced as a result of various agricultural and agro-industrial operations. They include wastes from slaughterhouses and meat processing, animal dung or manure, field crop wastes, crop residues, harvest wastes, and wastes from food consumption and processing (C. C. Ogbu and S. N. Okechukwu, 2022).

Lombardia is the first region in Italy in the agro-industrial sector and more than one-sixth of the population of the whole Italy lives in this region. In 2021 6,133 companies active in the food and beverages industry were observed. Concerning the food industry and referring to active companies, most of them fall into the category of bakery and flour products, with 3,798 units (65.4% of the total). They are dispersed throughout all the territory, but they are mostly concentrated in city areas. The remaining companies in the food industry represent 34.6% of the total. Therefore, almost two thirds of the total food companies are carrying out activities relating to artisanal bread-making and pastry-making, the remaining third is made up of all other activities. Among these, a good number of food companies in Lombardia are found in meat processing activities, which account for 10.7% of the total, in the activities of so-called other food products (10.5% of the total) and the ones of dairy products (6%). Alongside these, it is also worth mentioning the processing activities due to the number of companies in grains and starch production (2.3%), fruit and vegetable processing (2.1%) and animal feed products (1.8%). Within the beverage industry, the greatest number of companies is found in the production of beer (34.5% of the total) and in the production of wines from grapes (29.2% of the total). Therefore, 63.7% of beverage companies focus on these two activities. Two other activities worth highlighting are the distillation of alcohol, which accounts for 19.3% of beverage companies, and the soft drink and mineral water industry (14.6% of the total)[10].

OFMSW, sewage sludge, water-based non-hazardous organic waste and agro-industrial wastes can be processed in biorefineries to obtain renewable products such as struvite (slow-release fertilizer) and volatile fatty acids (VFA). The latest can be converted into biopolymers (e.g., PHA - Polyhydroxyalkanoates). All these secondary raw materials can be used by different industries producing fertilisers (from struvite), chemicals (from VFA) and bioplastic (from PHA) (Morgan-Sagastume et al., 2013; Conca et al., 2020).

This study considered these kinds of waste, more specifically the ones that are nowadays treated and/or authorized to be treated in seven of the wastewater treatment plants (WWTPs) managed

[10] https://www.regione.lombardia.it/wps/portal/istituzionale/HP/DettaglioRedazionale/servizi-e-informazioni/Imprese/Imprese-agricole/ricerca-e-statistiche-in-agricoltura/rapporto-agroalimentare-2022/rapporto-agroalimentare-2022

by CAP HOLDING SPA: Robecco sul Naviglio, San Giuliano Milanese Ovest, Sesto San Giovanni, Canegrate, Pero, Rozzano and Bareggio. In general, the wastes can be categorized based on the EER code, according to the European List of Waste[11]. In this sense, all types of waste are fully defined by the six-digit code and the respective two-digit and four-digit chapter headings, also in terms of the origin of the waste. Table 6 lists the wastes considered in this study identifying them with the respective codes. Moreover, the provenience of each waste is specified by the subchapter.

[11] 2014/955/EU: Commission Decision of 18 December 2014 amending Decision 2000/532/EC on the list of waste pursuant to Directive 2008/98/EC of the European Parliament and of the Council Text with EEA relevance (http://data.europa.eu/eli/dec/2014/955/oj)

Table 6. List of the wastes considered in the study according to the European List of Waste.

Type of waste	EER code	Definition	Sub-chapter	Chapter
AGRO-INDUSTRIAL WASTE	020201	sludge from washing and cleaning	02 02: wastes from the preparation and processing of meat, fish and other foods of animal origin	02: WASTES FROM AGRICULTURE, HORTICULTURE, AQUACULTURE, FORESTRY, HUNTING AND FISHING, FOOD PREPARATION AND PROCESSING
	020204	sludges from on-site effluent treatment	02 02: wastes from the preparation and processing of meat, fish and other foods of animal origin	
	020301	sludges from washing, cleaning, peeling, centrifuging and separation	02 03: wastes from fruit, vegetables, cereals, edible oils, cocoa, coffee, tea and tobacco preparation and processing; conserve production; yeast and yeast extract production, molasses preparation and fermentation	
	020304	materials unsuitable for consumption or processing	02 03: wastes from fruit, vegetables, cereals, edible oils, cocoa, coffee, tea and tobacco preparation and processing; conserve production; yeast and yeast extract production, molasses preparation and fermentation	

Type of waste	EER code	Definition	Sub-chapter	Chapter
	020305	sludges from on-site effluent treatment	02 03: wastes from fruit, vegetables, cereals, edible oils, cocoa, coffee, tea and tobacco preparation and processing; conserve production; yeast and yeast extract production, molasses preparation and fermentation	
	020399	wastes not otherwise specified	02 03: wastes from fruit, vegetables, cereals, edible oils, cocoa, coffee, tea and tobacco preparation and processing; conserve production; yeast and yeast extract production, molasses preparation and fermentation	
	020403	sludges from on-site effluent treatment	02 04: wastes from sugar processing	
	020501	materials unsuitable for consumption or processing	02 05: wastes from the dairy products industry	
	020502	sludges from on-site effluent treatment	02 05: wastes from the dairy products industry	

Type of waste	EER code	Definition	Sub-chapter	Chapter
	020599	wastes not otherwise specified	02 05: wastes from the dairy products industry	
	020601	materials unsuitable for consumption or processing	02 06: wastes from the baking and confectionery industry	
	020603	sludges from on-site effluent treatment	02 06: wastes from the baking and confectionery industry	
	020699	wastes not otherwise specified	02 06: wastes from the baking and confectionery industry	
	020701	wastes from washing, cleaning and mechanical reduction of raw materials	02 07: wastes from the production of alcoholic and nonalcoholic beverages (except coffee, tea and cocoa)	
	020704	materials unsuitable for consumption or processing	02 07: wastes from the production of alcoholic and nonalcoholic beverages (except coffee, tea and cocoa)	
	020705	sludges from on-site effluent treatment	02 07: wastes from the production of alcoholic and nonalcoholic beverages (except coffee, tea and cocoa)	

Type of waste	EER code	Definition	Sub-chapter	Chapter
	020799	wastes not otherwise specified	02 07: wastes from the production of alcoholic and nonalcoholic beverages (except coffee, tea and cocoa)	
OFMSW	200108	biodegradable kitchen and canteen waste	20 01: separately collected fractions (except 15 01)	20: MUNICIPAL WASTES (HOUSEHOLD WASTE AND SIMILAR COMMERCIAL, INDUSTRIAL AND INSTITUTIONAL WASTES) INCLUDING SEPARATELY COLLECTED FRACTIONS
	200201	biodegradable waste	20 02: garden and park wastes (including cemetery waste)	
	200302	waste from markets	20 03: other municipal wastes	
WATER-BASED ORGANIC WASTE	190604	digestate from anaerobic treatment of municipal waste	19 06: wastes from anaerobic treatment of waste	19: WASTES FROM WASTE MANAGEMENT FACILITIES, OFF-SITE WASTEWATER TREATMENT PLANTS AND THE PREPARATION OF WATER INTENDED FOR HUMAN CONSUMPTION AND WATER FOR INDUSTRIAL USE
	200304	septic tank sludge	20 03: other municipal wastes	20: MUNICIPAL WASTES (HOUSEHOLD WASTE AND SIMILAR COMMERCIAL, INDUSTRIAL AND INSTITUTIONAL WASTES) INCLUDING SEPARATELY COLLECTED FRACTIONS
	200306	waste from sewage cleaning	20 03: other municipal wastes	

Type of waste	EER code	Definition	Sub-chapter	Chapter
SEWAGE SLUDGE	190805	sludges from treatment of urban wastewater	19 08: wastes from wastewater treatment plants not otherwise specified	19: WASTES FROM WASTE MANAGEMENT FACILITIES, OFF-SITE WASTEWATER TREATMENT PLANTS AND THE PREPARATION OF WATER INTENDED FOR HUMAN CONSUMPTION AND WATER FOR INDUSTRIAL USE

The characterization of the wastes, when available, was obtained from laboratory analysis (Table 7 and Table 8).

Table 7. Characterization of some of the EER (agro-industrial waste, water-based non-hazardous organic waste, and sewage sludge) authorized to be treated in CAP HOLDING SPA (laboratory analysis).

EER	COD [mgO2/L]	BOD5 [mgO2/L]	N [mg/L]	P [mg/L]	TVS/TS	TS%	density [kg/m3]
02 03 01	4800.00	1927.50	95.67	48.00	0.13	0.98	
02 02 04	17725.00	10870.00	1227.72	126.00	0.47	4.85	
02 03 05	82124.00	55546.67	465.03	58.50	0.62	3.70	1043.33
02 06 03	65562.00		546.00		0.74	3.53	1010.00
02 03 04	50572.06		519.14		0.88	7.04	992.50
02 02 01	15130.81	4697.40	99.67	17.40	0.95	3.68	
02 07 01	3765.00		173.00		0.67	1.50	
02 06 01	71134.00	19533.33	167.60	61.40	0.88	3.50	
02 05 02	50903.50	5300.00	4122.75			1.93	
19 06 03	31063.00	11015.00	3923.00	1629.00	0.59	5.40	
20 03 04	20800.00	9900.00	1153.00		0.80	1.50	
20 03 06	10060.00	4790.00	849.92		0.65	2.00	
19 08 05					0.69	21.10	

Table 8. Composition of the EER 20 01 08 (OFMSW) authorized to be treated in CAP HOLDING SPA (laboratory analysis).

EER 20 01 08	UdM	VALUES (average of n.15 samples)
TOTAL MONITORED WASTE	kg	126.90
COMPOSTABLE MATERIAL	%	85.48
NON-COMPOSTABLE MATERIAL	%	8.14
ORGANIC WASTE	% of the total	86.46
COMPOSTABLE BAG	% of the total	2.06
INTERNAL BIOPLASTIC	% of the total	0.90
HERBACEOUS WASTE	% of the total	0.36
LIGNOCELLULOSIC WASTE	% of the total	0.00
PAPER AND CARDBOARD	% of the total	2.07
WOODEN PACKAGING	% of the total	0.02
PLASTIC BAGS	% of the total	1.27
PLASTIC	% of the total	1.97
GLASS	% of the total	0.33
METALS	% of the total	0.26
INERT MATERIAL	% of the total	0.22
NATURAL STONES LITTER	% of the total	0.68
DIAPERS	% of the total	1.00
OTHER	% of the total	2.40

In addition, a typical characterization of sewage sludge (Table 9) and OFMSW (Table 10) was considered from the scientific literature.

Table 9. Typical chemical composition of primary and secondary sludge (Metcalf & Eddy, 2003; IWA Publishing, 2022).

Parameter	Primary sludge range (typical)	Secondary sludge range (typical)
Total solids (TS), %	1-9 (3)	0.4-1.2 (0.8)
Volatile solids (VS), % of TS	60-85 (75)	59-85 (70)

Parameter	Primary sludge range (typical)	Secondary sludge range (typical)
pH	5-8 (6)	6.5-8.0 (7.1)
Alkalinity (mg/L as $CaCO_3$)	500-1500 (600)	580-1100 (790)
Organic acids (mg/L as Hac)	200-2000 (600)	1100-1700 (1350)
Energy content (kJ/kg VSS)	23,000-29,000 (25,000)	19,000-23,000 (20,000)
Structural compounds		
Cellulose (% of TS)	8.0-15 (10)	7.0-9.7 (-)
Protein (% of TS)	20-30 (25)	32-41 (36)
Grease and fats (% of TS)	5.0-35 (6)	5.0-12 (8.0)
Nutrients, minerals and metals		
Nitrogen, % of TS	1.5-4 (2.5)	2.4-5.0 (3.8)
Phosphorus (P_2O_5), % of TS	0.8-2.8 (1.6)	0.5-11.0 (5.5)
Potassium (K_2O), % of TS	0.0-1.0 (0.4)	0.5-0.7 (0.6)
Iron (not as sulfide), % of TS	2-4 (2.5)	-
Silica (SiO_2), % of TS	15-20 (-)	-

Table 10. Typical characteristics of OFMSW (Cabbai et al, 2013; Stylianou et al., 2020).

Parameter	Range (average)
Moisture (%wt)^{ar}	22.5-70.5 (53.9)
pH	4.9-7.3 (6.5)
TS (%wt)^{ar}	22.5-40 (34.4)
VS (%wt)^{ar}	60.4-85.6 (74.7)
Ash (%wt)^{db}	6.0-8.3 (6.9)
Fat and waxes (%wt)^{db}	15.6-31.9 (23.8)
Pectin (%wt)^{db}	13.0-18.8 (17.1)
Lignin (%wt)^{db}	6.8-10.1 (8.7)
Glucan (%wt)^{db}	34.2-45.0 (39.7)
Xylan (%wt)^{db}	0.2-2.4 (1.1)
Protein (%wt)^{db}	8.3-10.4 (9.5)
Starch (%wt)^{db}	3.2-6.2 (5.0)
Elemental analyses	
Carbon (%wt)^{db}	38.5-49.4 (45.7)
Oxygen (%wt)^{db}	29.5-36.6 (32.0)
Hydrogen (%wt)^{db}	5.3-7.5 (6.1)
Nitrogen (%wt)^{db}	1.8-3.0 (2.3)
Sulfur (%wt)^{db}	0.2-0.3 (0.2)
C/N (%wt)^{db}	15.4-24.2 (19.5)
Nutrients	
TKN (g/kg)^{db}	23.5-25.8 (24.7)
TP (g/kg)^{db}	2.7-3.5 (3.1)
TK (g/kg)^{db}	9.8-10.2 (10.0)

^{ar} as received, ^{db} dry basis

-Value chain, flow diagram and the importance of the certification

The biorefinery considered for the specific case study (Figure 11) is composed of different units:

- Thickener unit
- Fermenter reactor
- Dewatering unit
- Phosphorus recovery unit (struvite)
- Volatile Fatty Acids (VFA) storage
- Biomass selection and nitritation unit
- PHA accumulation unit
- Anaerobic digestion unit
- Dewatering unit

The wastes entering in the biorefinery may undergo specific pre-treatments such as mechanical, chemical, or physical. For example, the OFMSW is sent to a bag breaker and deprived of the metal content. The solid part of the wastes is then separated from the liquid one, fermented, and again thickened. From here, the liquid part goes first to a crystallizer unit for recovering the phosphorus as struvite, then to a VFA storage. From here it is sent first to a biomass selection and nitritation unit and then to a PHA accumulation section, from where a PHA-rich sludge is generated. The solid part after the fermentation unit goes to anaerobic digestion for biogas production. After the anaerobic digestion, there is a solid/liquid separation from where the liquid part is sent to the biomass selection and nitritation unit. The valuable products of interest in this biorefinery are the VFA, the struvite, and the PHA-rich sludge. The VFA can have internal use in the WWTP as a nutrient source and/or may be applied for some chemical production. The struvite can be applied by fertilizer industries for fertilizer production. The PHA-rich sludge, after specific extraction and/or purification processes, can be utilized by bio-plastic industries for bio-plastic production.

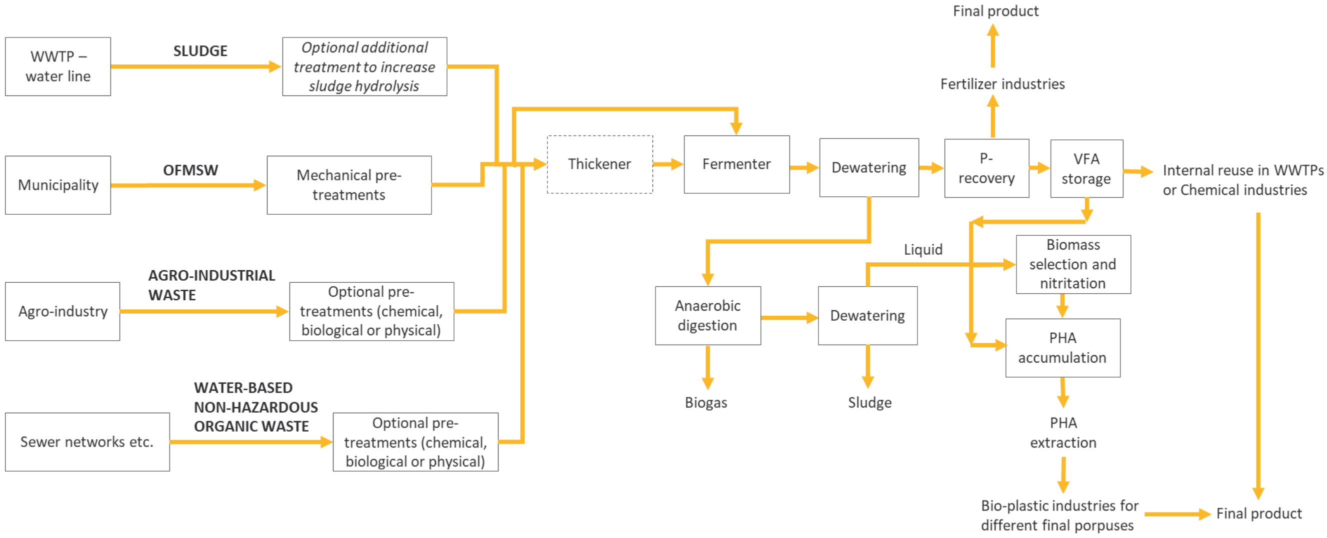


Figure 11. Schematic representation of the biorefinery of the Italian Case Study.

To ensure that the products obtained in this biorefinery are fully circular, all the steps of the production process, including the collection and the transportation of the feedstocks, must be carried out in a sustainable and circular manner. In this respect, all possible steps of the value chain prior to the production process would be relevant to assess the circularity and sustainability of the by-products.

The elements of the supply chain were defined and analysed according to the ISCC supply chain system (ISCC EU System Document 203 "Traceability and Chain of Custody")[12]. In this sense, the feedstock sourcing includes the point of origin and collection, while the processing and distribution is composed of the processing unit, the trader/storage, and the raw products. Additionally, a final product refinement includes the refinement unit (eventually) and the final stage. A schematic representation of the value chain of the Italian Case Study is given in Figure 12.

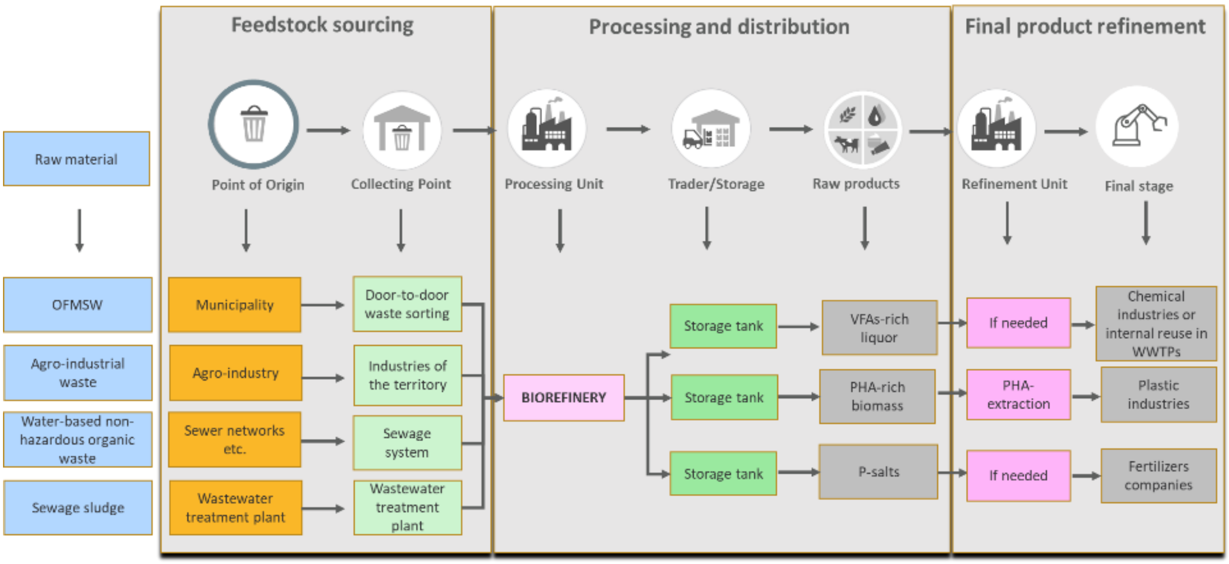


Figure 12. Supply chain of the Italian Case Study.

Starting from the value chain, it was created a more detailed flow diagram of the case study, considering both the actual treated wastes (Figure 13) and the maximum authorized wastes (Figure 14).

These flow diagrams illustrate the origin of the wastes (identified with the relative EER codes), eventual inputs of water, energy, and/or reagents in the different sections of the supply chain, where transportation occurs, and the different sections of the biorefinery.

[12] https://www.iscc-system.org/wp-content/uploads/2022/05/ISCC_EU_203_Traceability_and_Chain-of-Custody-v4.0.pdf

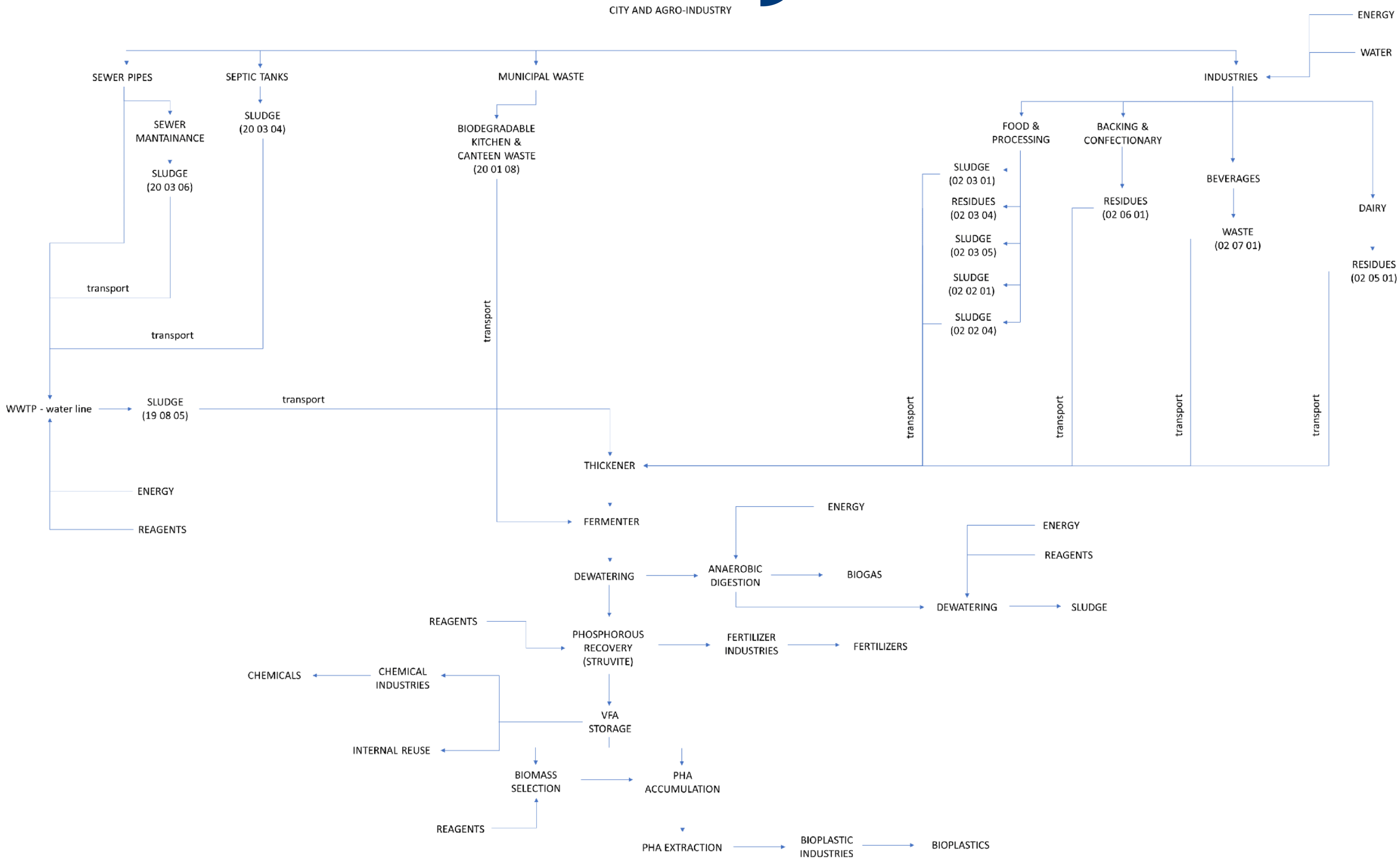


Figure 13. Flow diagram of the Italian case study (treated wastes).

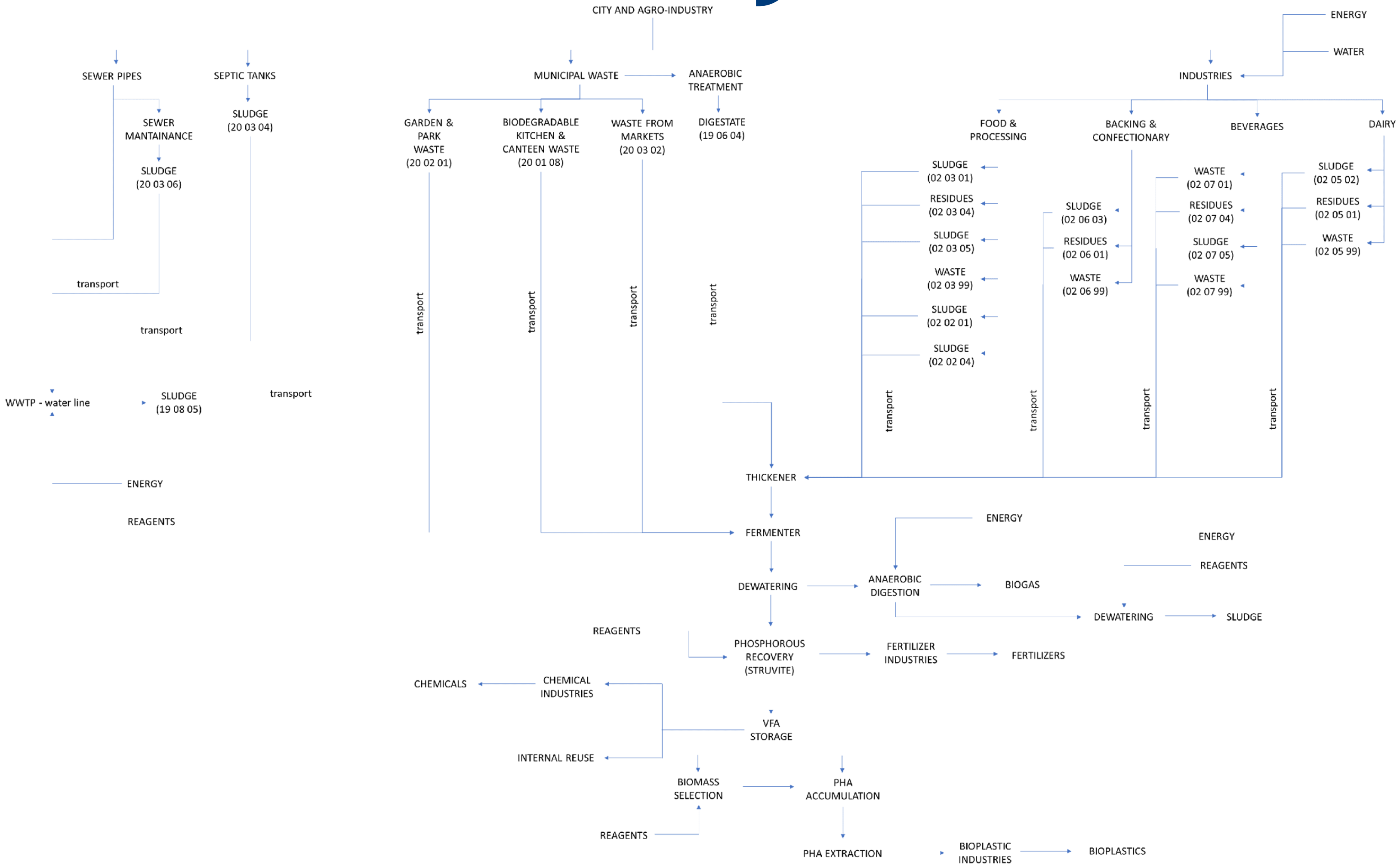


Figure 14. Flow diagram of the Italian case study (authorized wastes).

The type and the quantity of the wastes treated in CAP HOLDING SPA facilities is given in Table 11, while the authorized amounts are given in Table 12.

Table 11. Quantity and type of waste treated in the facilities of CAP HOLDING SPA.

WWTP	Type of feedstock	EER	Quantity [t/y]	Years considered
Sesto San Giovanni	Sludge	190805	55088	2016-2021
Sesto San Giovanni	Agro-industrial waste	020304	5	2020-2021
Sesto San Giovanni	Agro-industrial waste	020501	196	2019-2021
Sesto San Giovanni	OFMSW	200108	121	2022
Robecco sul Naviglio	Sludge	190805	72161	2016-2022
Robecco sul Naviglio	Agro-industrial waste	020304	42	2021-2022
Robecco sul Naviglio	Agro-industrial waste	020701	8	2021-2022
Robecco sul Naviglio	Water-based organic waste	200304	3994	2017-2022
Robecco sul Naviglio	Water-based organic waste	200306	4752	2017-2022
San Giuliano Milanese Ovest	Sludge	190805	44524	2016-2022
San Giuliano Milanese Ovest	Agro-industrial waste	020201	661	2021-2022
San Giuliano Milanese Ovest	Agro-industrial waste	020204	721	2022
San Giuliano Milanese Ovest	Agro-industrial waste	020301	430	2021-2022

WWTP	Type of feedstock	EER	Quantity [t/y]	Years considered
San Giuliano Milanese Ovest	Agro-industrial waste	020304	1	2022
San Giuliano Milanese Ovest	Agro-industrial waste	020305	27	2022
San Giuliano Milanese Ovest	Agro-industrial waste	020601	540	2022
San Giuliano Milanese Ovest	Agro-industrial waste	020701	1277	2021-2022
Canegrate	Sludge	190805	50002	2016-2021
Pero	Sludge	190805	158133	2016-2021
Rozzano	Sludge	190805	50453	2016-2021
Bareggio	Sludge	190805	25072	2016-2021

Table 12. Quantity and type of waste authorized to be treated in the facilities of CAP HOLDING SPA.

WWTP	Type of waste	Quantity [t/y]
Sesto San Giovanni	Agro-industrial waste	15500
Sesto San Giovanni	OFMSW	15500
Sesto San Giovanni	Water-based non-hazardous organic waste	1500
Sesto San Giovanni	Sludge	66500
Robecco sul Naviglio	Agro-industrial waste	3052
Robecco sul Naviglio	Sludge	22500
San Giuliano Milanese Ovest	Agro-industrial waste	2441

WWTP	Type of waste	Quantity [t/y]
San Giuliano Milanese Ovest	Water-based non-hazardous organic waste	75000
San Giuliano Milanese Ovest	Sludge	22500

The definition of the steps of the supply chain represents the preliminary step to develop a certification scheme, based on tracking and traceability (T&T), to ensure that all the steps of the production process are circular. This certification, which aims to increase the reliability and transparency of the whole value chain, is expected to also increase the willingness of users to consume the circular bio-products obtained in this biorefinery.

2.3 Case study 3

-Origin of biomasses

Residual biomass streams from the agro-industrial sector are generated from agricultural practices (agricultural waste) as well as from the agro-industry (agro-industrial waste). The agro-industry establishes links between enterprises and supply chains for developing, transforming and distributing specific inputs and products in the agricultural sector (FAO, 2023).

Agricultural waste corresponds to 7.5-17.5% of the overall waste originating from the Food Supply Chain (Ingrao et al., 2021) and it includes the by-products that are generated in the agricultural production cycle through management and harvesting practices. The main biomasses and their origin, encountered in the Region of Central Macedonia (RCM), are the following:

- Straw and stems are by-products originating from cereals cultivation. Straw is the remaining by-product after grain harvesting and it consists of senesced leaves (sheath and blade) and stems (node and internode). It contains approximately two-thirds stem and one-third leaf (56% internodes, 7–8% nodes, 23% leaf sheaths, 14% leaf blades). The generated straw is discharged from conventional combines and falls to the field ground. Stems constitute the main structural axe of a vascular plant that supports leaves, flowers and fruits, transports water and dissolved substances and produces new living tissue (McCartney et al., 2006). The most important flows of straw and stems are considered the ones which originate from the following crops: wheat, maize, rice, sunflower and cotton. These crops are produced abundantly, are economically important for the region and they present a wide geographical distribution (Hellenic Statistical Authority, 2021).

- Prunings: Tree pruning is a fundamental horticultural practice that assures the healthy maintenance of the orchards and ameliorates the crop production yield (Avitabile et al., 2023, Strnad et al., 2020). During pruning, a considerable amount of biomass is produced which originates from cutting and removing certain parts of a tree (Kougioumtzis et al., 2023). The most important tree cultivations in the region, producing this kind of biomass, are olives, peaches/nectarines, and cherries; vines (although technically not a tree) also produce significant quantities of prunings every year (Hellenic Statistical Authority, 2021).
- Agro-industrial by-products are generated from food processing industries (Koul et al., 2022). More specifically, fruit processing is a major contributor to waste generation. The employed processes necessitate the removal of parts such as the core, peel, pips, and kernel (de Castro et al., 2020). Fruit pulp/pomace is a by-product originating from fruit processing industries, producing juice, compost, jams, wine, etc. (Vorobyova and Skiba, 2021, Vukušić et al., 2021). In the region the most common industries process peaches, apples and grapes (Hellenic Statistical Authority, 2021). Furthermore, a significant amount of waste is produced by the olive-oil industry, consisting of kernels, olive pomace, olive mill wastewater and two-phase olive mill wastewater. Olive oil pomace constitutes the main solid by-product from the olive oil extraction corresponding to 35–40% of the total weight of the olives processed in the mill. This biowaste is composed of crushed olive stones, pulp and skins and variable amounts of water depending on the extraction procedure (Gullón et al., 2020).

-Characterization

Agricultural wastes/residues are mainly lignocellulosic biomass consisting of cellulose, hemicellulose, and lignin, with cellulose being the main component. Small quantities of extractives, such as ash and proteins are also contained (Awogbemi and Kallon, 2022). In Table 13 the indicative composition of various types of straws and stems is depicted showing that there are no substantial differences in cellulose, hemicellulose, and lignin content. Furthermore, certain agricultural wastes/residues have been reported to consist of starch, lipid components and relevant quantities of nutrients such as nitrogen and phosphorus (Srivastava et al., 2023).

Table 13. Indicative composition of straw/stems; range (mean value).

Parameter	Wheat straw	Rice straw	Corn stalks	Sunflower stalks	Ref.
Moisture (% wt)^{ar}	0.0-17 (9.3)	6.6-12 (8.3)	8.02	9.2	(ECN)
Ash (%wt)^{db}	1.3-22 (9.0)	12-22 (18.5)	3.0-7.0 (5.5)	4.6	(ECN)
Cellulose (%wt)^{db}	28-52 (6.3)	28-41 (35.7)	38	35.0-38.5 (36.8)	(ECN)
Hemicellulose (%wt)^{db}	11-39 (5.2)	22-27 (23.7)	26	33.5	(ECN)
Lignin (%wt)^{db}	8.0-30 (5.2)	9.9-21.6 (14.0)	11	17.5	(ECN)
Crude protein (%wt)^{db}	3.6-4.2 (3.9)	2.4-6.8 (4.2)	1.8-11.5 (3.9)	1.8-11.2 (7.3)	(Feedipedia)

Tree prunings are also rich in cellulose, hemicellulose, and lignin. The composition of pruning residues from various trees is summarized in Table 14.

Table 14. Indicative composition of representative prunings; range (mean value).

Parameter	Olive tree	Peach tree	Grape	Cherry tree	Ref.
Moisture (% wt)[ar]	4.6-14 (8.4)	39.4-42.1 (40.5)	43.7[1]	26[2]	(ECN) Grape: (Feedipedia) Peach: (Pari et al., 2018)
Ash (%wt)[db]	13.3	1.6 ± 0.2	2.2-3.0 (2.6)	1.3[2]	(ECN) Peach: (Buratti et al., 2018)
Cellulose (%wt)[db]	30.3	31.3	-	42.0[2]	(ECN) Peach: (Buratti et al., 2018)
Hemicellulose (%wt)[db]	17.9	16.7	-	34.0[2]	(ECN) Peach:(Buratti et al., 2018)
Lignin (%wt)[db]	21 (acid insoluble) 3.1 (acid soluble)	22.8 ± 0.5 (acid insoluble)	10-25 (17.1)[1]	24.0[2]	(ECN) Grape: (Feedipedia) Peach: (Buratti et al., 2018)

[1]Grape branches and leaves, fresh, [2]cherry wood

The agro-industrial waste is also rich in bioactive compounds. Peach pomace is an extraordinary source of multiple beneficial substances, including phenolics, proteins, alkaloids, and sugars (Vorobyova and Skiba, 2021). In Table 15 the indicative composition of by-products derived from the processing of olives and fruits is depicted.

Table 15. Indicative composition of olive cake and apple, peach, grape and orange pomace; range (mean value).

Parameter	Olive cake	Peach pomace	Grape pomace[4]	Ref.
Moisture (% wt)[ar]	6.4	94.1	60.3	(ECN) Peach: (Hu et al., 2015) Grape: (Feedipedia)
Ash (%wt)[db]	10.9	2.1	4.2-9.5	(ECN) Peach: (Rudke et al., 2023)
Carbohydrate (%wt)[db]	-	25.9 *(water soluble)*	1.6 (starch)	Apple: (Vukušić et al., 2021) Peach: (Hu et al., 2015)
Total sugars (%wt)[db]	-	-	3.9-31.8 (18.5)	(Feedipedia)
Nitrogen (%wt)[db]	1.8	-	2.0-2.2 (2.1)	(ECN) Orange peel: (Pathak et al., 2017)
Phosphorus (g/kg)[db]	0.9-1.6 (1.3)[1]	2.2[2]	2-3 (2.5)	(Feedipedia) Peach pulp: (Argun and Dao, 2016)

Parameter	Olive cake	Peach pomace	Grape pomace[4]	Ref.
Potassium (g/kg)[db]	6.7-14.2 (10.5)[1]	0.4[2]	-	(Feedipedia) Peach pulp: (Ashraf et al., 2011)
Total extractable polyphenols (g GAE/kg) [db]	13.9	-	-	Olive Cake: (Niaounakis and Halvadakis, 2006)
Phenolic acids (mg/kg)[db]	-		-	Apple and orange: (Ben-Othman et al., 2020)
Phenolic compounds (mg GAE/g) [db]	-	2.0[3]	30.7-48.8	Peach pomace: (Plazzotta et al., 2021) Grape pomace: (Drescher and Kienberger, 2022)
Flavonoids (mg/kg)[db]	-	320 QE[3]	-	Apple and orange: (Ben-Othman et al., 2020) Peach pomace: (Plazzotta et al., 2021)

[1]Olive oil cake, crude, without stones, [2]pulp, [3]frozen peach pomace, [4]fresh grape pomace.

-Possible destinations and value of the products

Current uses

Generally, the most popular destinations of lignocellulosic secondary biomass are incineration, landfilling, and bio-energy production via anaerobic digestion (AD) (Chatterjee and Mazumder, 2024). Straw is used for soil enhancement activities, such as disposal on field to retain organic carbon, nitrogen and nutrients. Furthermore, it is used for animal feed and bedding and as a fuel. Other uses include the production of supporting materials and pulp and paper. Unfortunately, a significant amount of agricultural residues are still incinerated in situ (Aghaei et al., 2022, Hamelin et al., 2019, Shahryari et al., 2018). Similarly, tree prunings are used for soil-enhancement, incinerated on-field or landfilled (Devi et al., 2017). Concerning olive pomace, the traditional management practices encompass incineration, field disposal for soil-enhancement purposes, discharge into nearby water bodies and storage/evaporation in lagoons (Espadas-Aldana et al., 2021, Gullón et al., 2020). The conventional uses of solid wine by-products are animal feed and fertilizer/compost with or without further processing (Bordiga, 2016). Generally, fruit waste is managed in traditional ways, such as landfilling, compost and animal feed (Zhu et al., 2023).

In Figure 15 the results of D2.1 are depicted, where the available agriculture's secondary biomass for the EU-28 has been quantified and the utilization pathways have been determined.

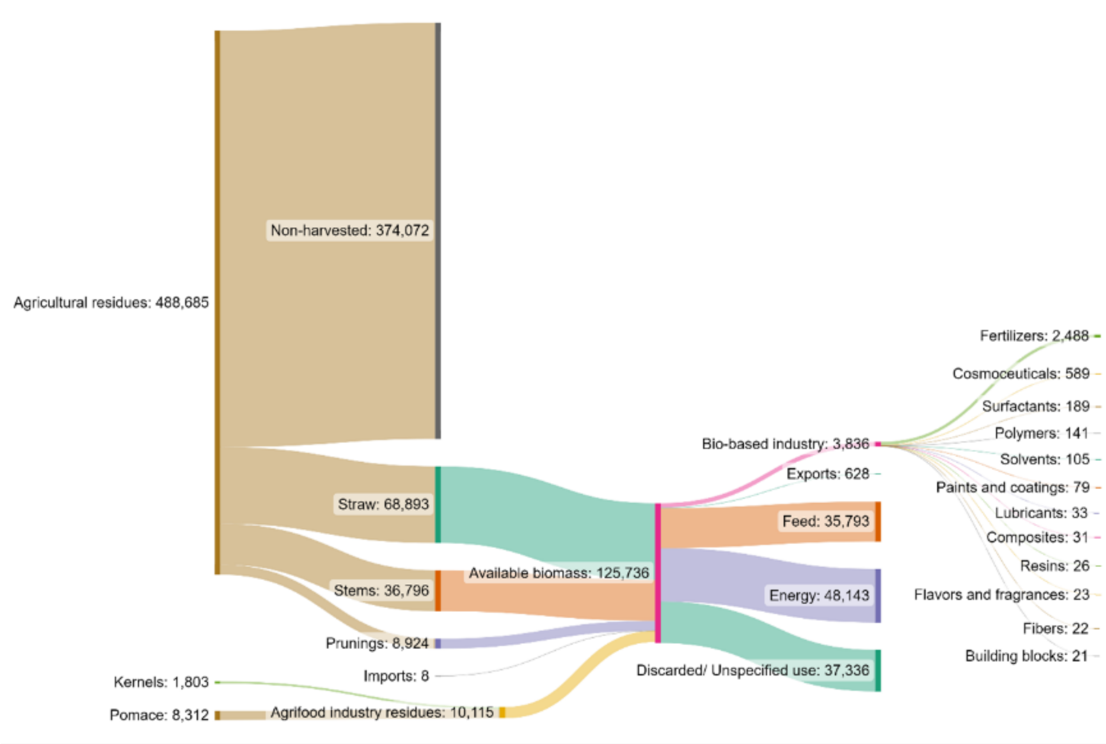


Figure 15. MFA Sankey diagram for agricultural biomass (EU-28); Quantities in kt/yr.

From the developed Sankey diagram for agriculture case study, it can be concluded that a small fraction of agriculture and food processing industry by-products are actually used in the bio-based sector for the production of high-value products. The vast majority of the residual biomass has an established market for feed and energy applications.

Valorization

Agricultural secondary biomass can be considered as suitable and inexpensive candidate to produce value-added compounds without affecting or competing directly with the ever-growing demand of the world's food supply chains (Srivastava et al., 2023).

The lignocellulosic composition of the biomass derived from the agricultural sector enable its valorization into valuable products. The main routes for processing them are the thermochemical (combustion, gasification, pyrolysis/liquefaction) and the biochemical (transesterification and fermentation). The thermochemical biomass processing is leading mainly to the production of energy/heat and fuels (Rahimi et al., 2022). Additionally, the thermochemical degradation of lignin can also lead to the production of extractives, such as tannins, lipids, resins, steroids, terpenes, terpenoids, flavonoids, and phenolic compounds (Mujtaba et al., 2023). Fermentation can lead to the production of chemical building blocks (ethanol, butyrate, propionate and various lactic acid types), VFAs, polymers, enzymes, bio-hydrogen and bio-products – including organic acids, biofuels, enzymes, and bioactive compounds (Chatterjee and Mazumder, 2024, Jesus et al., 2017). The cellulose content can also lead to the production of packaging (Bangar et al., 2023) and cellulose-based functional materials, such as fibers, membranes, gels (He et al., 2023), cellulose-based materials for 3D printing, lignocellulosic materials for biomedical applications (Mujtaba et al., 2023), particleboards (Kougioumtzis et al., 2023) etc. Furthermore, lignocellulosic biomass can be used for the production of bio-fertilizers (Zhou et al., 2024), bio-surfactant (Qamar and Pacifico, 2023) and for environmental remediation (Mujtaba et al., 2023). Agro-industrial waste are rich in bioactive compounds with functional properties, which can be used in the pharmaceutical, cosmetic and food sector (Arias et al., 2023, Pavlić et al., 2023, Sarangi et al., 2023).

-Possible companies and their importance in the chain

The two companies that are included in the agrifood case study cover two significant domains of the regional economy and produce high-value, important commodities and technologies with a large share in the Greek market. Besides, they constitute two very illustrative examples of the implementation of circularity principles within specific regional boundaries. In both cases, residual by-streams and waste derived from primary agricultural practices or secondary processing of agricultural commodities are obtained and processed in order to achieve their valorization and re-integration in the value chain. By that means, valuable residual streams are incorporated in new added-value products, deterring their conventional management as waste. The two value chains that are investigated are the production of compost and bio-based composites. The companies that support BioReCer's endeavors towards the analysis of the bio-based value chains are the following:

- **CHIMAR HELLAS SA** provides a range of binder technologies and services for the adhesive resin and wood panel industries. It is an innovative company active globally in industrial research, development, and licensing of competitive, chemical technology suitable for the industrial production of adhesives and chemicals, as well as for their application in the industrial manufacture of composite wood-based panels, engineered wood and impregnated/lamination papers (products applied in furniture making, building construction, insulation etc). (CHIMAR expertise extends to the development of binder technology for the production of novel bio-composite panels using non-wood biomass materials, agricultural and industrial residues as well as recycled materials.

- **Biosolids SA** is a company that produces compost, organic soil improvers, liquid fertilizers, substrates, beneficial microorganisms and stimulants. More specifically, the company premises include a composting plant in Skydra, in the prefecture of Pella, with a capacity of 22,000 tonnes per year. The company utilizes organic residues for the formulation of the products, achieving a legal, rational, economical, environmentally beneficial and sustainable management of the organic residues.

-Updated value chains

Particle boards value chain

The generation of panels derived from alternative feedstocks other than wood is of particular importance for the Greek market. In particular, Greece, as most of the Mediterranean countries, is a net importer of wood and wood-based products. There are few companies in Greece producing conventional wood-based panels, operating majorly at small capacities (Koulelis et al., 2017). The forest wood supply in Greece is limited mainly attributed to inefficient management practices and policies, ecological factors and Greece's natural landscape that renders the harvest of wood a challenge (Koulelis et al., 2023). Additionally, the demand for panels in the Greek market is high and for most of the years, the consumption surpasses the national production, thus creating a deficit and a need for import, as depicted in Figure 16.

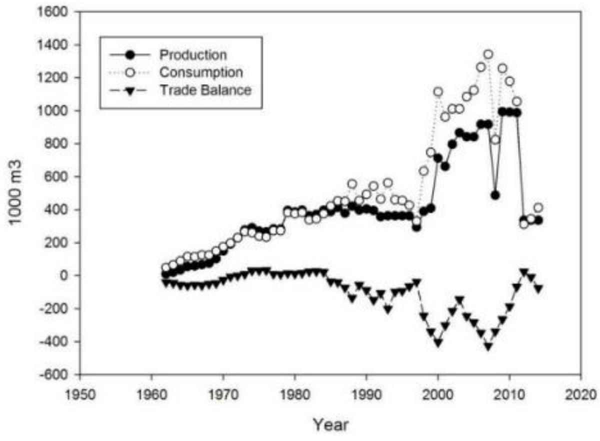


Figure 16. Greek wood-based panels production, consumption and trade balance during the decades (Koulelis et al., 2017).

In total, it is estimated that the production of wood-based panels amounted to 373,309 m^3 in Greece for 2022 while the net imported quantities were equal to 382,188 m^3 (FAO, 2024). Therefore, there is a heightened need for the incorporation of alternative resources in the panel production industry. A viable alternative is the formulation of panels derived from residual lignocellulosic biomass streams, such as agricultural residues which constitute an abundant resource that is easily supplied and conventionally destined to lower value applications such as feed or energy. In this scope, CHIMAR SA develops and provides the technology for the formulation and application of binders that meet the specific requirements and allow the production of panels from lignocellulosic biomass. In a general context, it is highlighted that the development of wood composites themselves is inextricably linked with the advancements in the field of the polymer binders that hold the wood elements together and enable the manufacture of the composites (Pizzi et al., 2020).

CHIMAR SA develops the technology for binder synthesis tailored for binding multiple lignocellulosic feedstocks and provides the expertise that is required for the binder application in the production of bio-based composites. The substitution of wood with agricultural by-products for the production of an added-value commodity is a practice that brings numerous benefits for the regional economy, generating value to the actors of the value chain. In this sense, the farmer manages the residual streams in a sustainable way and gains additional revenue from selling the straws and stems, while the composite-producing company generates a high-value product by utilizing a waste stream with a traditionally lower price and in parallel, the consumption of valuable wood is avoided.

The development of this kind of technology and products is particularly beneficial for the investigated region. According to the Hellenic Statistical Authority, the Region of Central Macedonia is covered by 607,730 ha of agricultural fields (31.7% of the total surface of RCM) and 400,710 ha of forest area (20.9% of the total surface). Therefore, it can be deduced that there is a comparative advantage with the utilization of agricultural residues attributed to their availability and a limitation regarding the potential supply of wood in the area. In addition, the high demand for wood panels in conjunction with the relatively low production volumes at a national as well as at a regional level render the case study of alternative composites a highly important case study that exhibits substantial potential for development.

-Value chain description

In the scope of BioReCer, the whole value chain is assessed. The system boundaries start from the generation of the biological feedstock (in this particular case study referring to wheat straw) through the agricultural practices. More specifically, the cultivation phase of the primary agricultural products is included in the analysis. The feedstocks of interest are generated during the harvesting activities performed with the use of a combine and subsequently a series of pretreatment steps take place in order to collect the by-products and store them on field. In this scope, the tasks of windrowing, baling and stacking are performed. Consequently, straw is in the form of straw bales in order to facilitate its management and transportation. During the transportation phase, the straw bales are loaded on trucks and transferred to the facility in which the main processing will take place.

Within the facility premises, the biological feedstocks are subjected to pretreatment processing tailored to the specific properties and needs of each raw material. It is necessary to process the lignocellulosic biomass in order to comply with specific requirements (e.g. moisture content) and enhance the structure (e.g. retting process for the extraction of the fibers) to enable the effective conversion to the final bio-based product. Subsequently, the main processing steps take place including: cutting in chips, screening, mixing of lignocellulosic material with glue mixture, forming of panel, cold pre-press, hot press and trimming. The production of particle boards constitutes the final output, concluding the bio-based value chain. The schematic representation of the value chain stages is presented on Figure 17.

-Bio-based soil enhancers value chain

Fertilizers/soil-enhancers are indispensable commodities for agricultural production. In particular, Greece's demand for fertilizer is projected to grow by 0.9% each year until 2026, rising from 147,220 metric tons in 2021 to 156,200 metric tons in 2026. Since 2007, the country's demand has increased 4.1% annually. With regard to the production of fertilizer in Greece, it is set to decline by 1.6% annually, from 224,940 metric tons in 2021 to 201,400 metric tons in 2026 (Report Linker, 2024).

Focusing on the area of interest, Region of Central Macedonia (RCM) is a region with substantial agricultural production. More specifically, the primary sector (Agriculture, Forestry and Fishing) of the region contributes to 20.2% of the gross value added at a national level. In this regard, the region occupies a leading role in the production of wheat (34% of national produce), barley (25%), maize (28%), rice (87%), cotton (33%) and sunflower (30%). Additionally, the cultivation of arboreal crops is highly important for the region's prosperity as reflected in the volumes of production of peaches (77% of national produce), cherries (72%), apricots (41%), kiwis (45%), pears (25%) and apples (20%). Therefore, it is evident that the large agricultural production of the area leads to heightened needs for the supply of fertilizers and soil amendments, rendering the bio-based soil enhancers value chain a very important and impactful case study for investigation.

The company that is engaged in BioReCer Project that is related to the production of bio-based soil enhancers is Biosolids SA. The company produces bio-based soil enhancers derived from residual streams such as fruit pomace, sludge and agricultural residues. In parallel, the company constitutes an industrial actor that facilitates the sustainable management of waste streams, while creating upcycled products, acting as a paradigm for industrial symbiosis.

-**Value chain description**

The bio-based soil enhancers value chain starts from the production of the three different biological feedstocks that constitute the basic raw materials for the final bio-based product. The three different feedstocks are the straw from cereal cultivation, prunings derived from arboreal crops and fruit pomace that constitutes the by-product of a fruit processing facility. These feedstocks have three different value chains extending from the basic stage of cultivation to the inflow of the feedstocks to the main processing facility.

The prunings along with the pomace streams derive from the cultivation of arboreal crops. More specifically, the cultivation of tree crops constitutes the first stage of the value chain. The pruning of the trees is an indispensable practice for the growth and productivity of the tree that is performed during the cultivation stage (Strnad et al., 2020). The prunings are collected, stacked and stored on the field and subsequently their transportation to the industrial facility is executed. Based on the company's requirements for materials, the inflow of prunings is subjected to shredding as a pretreatment processing in order to achieve particle reduction.

With regard to the pomace value chain, the starting point is the tree cultivation stage. In this case, the focus is oriented towards the fruits that are collected. Once harvested, the fruits are collected, stored and transported to the fruit-processing industry. A very prevalent domain of agrifood industries in the RCM is the peach-processing industry due to the abundant cultivation of peach trees in the area (Ordoudi et al., 2018). An overview of the fruit processing stages that are executed in the fruit processing facility includes the following stages: Washing, kernel removal, peeling and sorting of peaches, filling, degassing, closing, pasteurization, cooling, drying of extra moisture and storage (Paraskevopoulou et al., 2020). As part of the fruit processing stages, the fruit pomace is a by-product stream that is collected, stored and transferred to the bio-based soil enhancers facility, instead of being conventionally treated as a waste stream. Within the plant, there is no need to apply any pre-treatment processing on the pomace and thus it is directly sent to the main production process. The value chain of the straw is identical to the one described concerning the case of bio-based composites, starting from the cultivation stage and extending up to the inflow to the plant. Straw does not require any pretreatment to be used for the production of the soil enhancers. The main processing steps that take place in Biosolids SA are summarized as follows: Import of waste/ Weighting, Unloading of the waste, first processing/ addition of subsidiary material, composting, maturing, refining, final processing, standardization/labelling, disposal or sorting. The bio-based soil enhancer that is generated constitutes the output of the system and concludes the system boundaries.

-Flow diagrams explaining the points where biomass products of interest are produced

The elucidation of biomass route is critical for the assessment of the value chain and especially from the perspective of certification schemes. The biological feedstocks of interest, namely straw and prunings constitute by-products from the cultivation and harvesting of primary agricultural commodities. The by-products are collected and gathered on the agricultural land and packed in compact forms, such as straw bales. This practice facilitates the biomass storage, handling and transportation. Therefore, the field constitutes the first collection point of the biological feedstock. Subsequently, the biological feedstock streams are transferred to the industrial facility, being the second point of interest for the supply chain. Finally, with regard to the production line two phases can be discerned. Firstly, the pretreatment of the biological feedstock takes place in order to enable the efficient conversion of the treated material to the final product. The final point of the supply chain is the output of the processing facility.

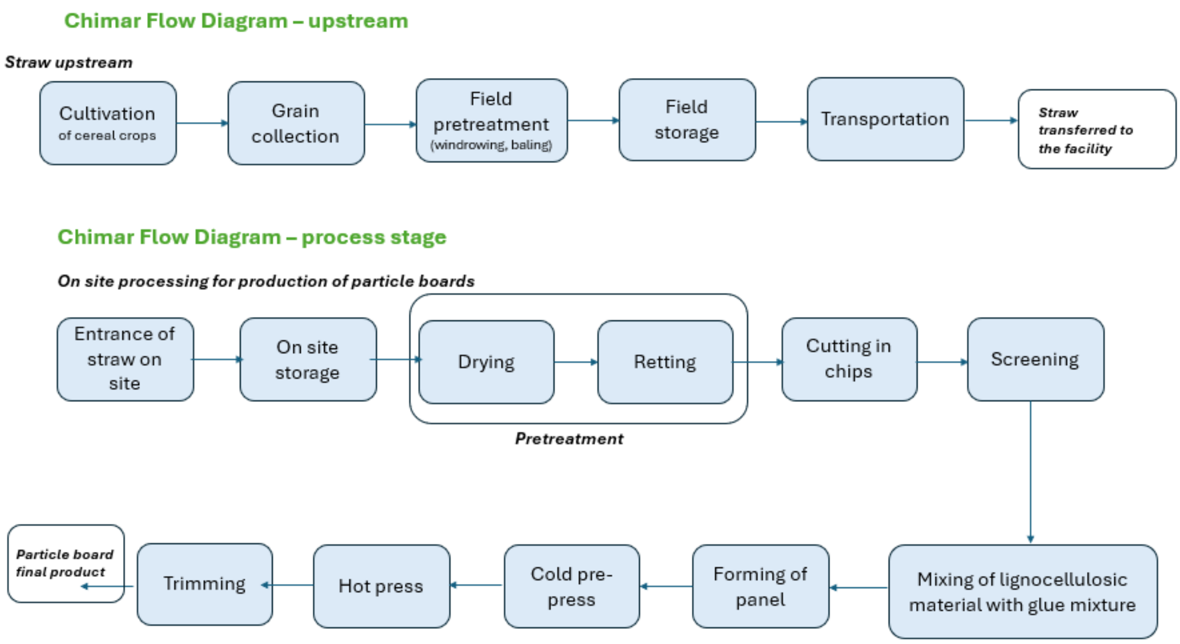


Figure 17. Flow diagrams for Chimar biomass process

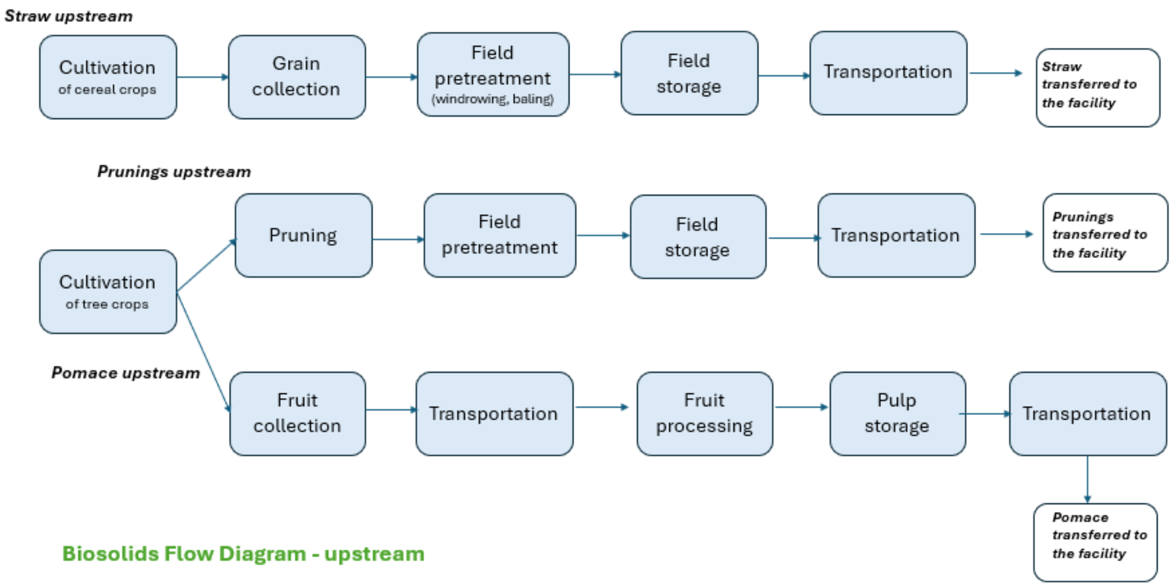


Figure 18. Upstream flow diagram for Biosolids biomass process

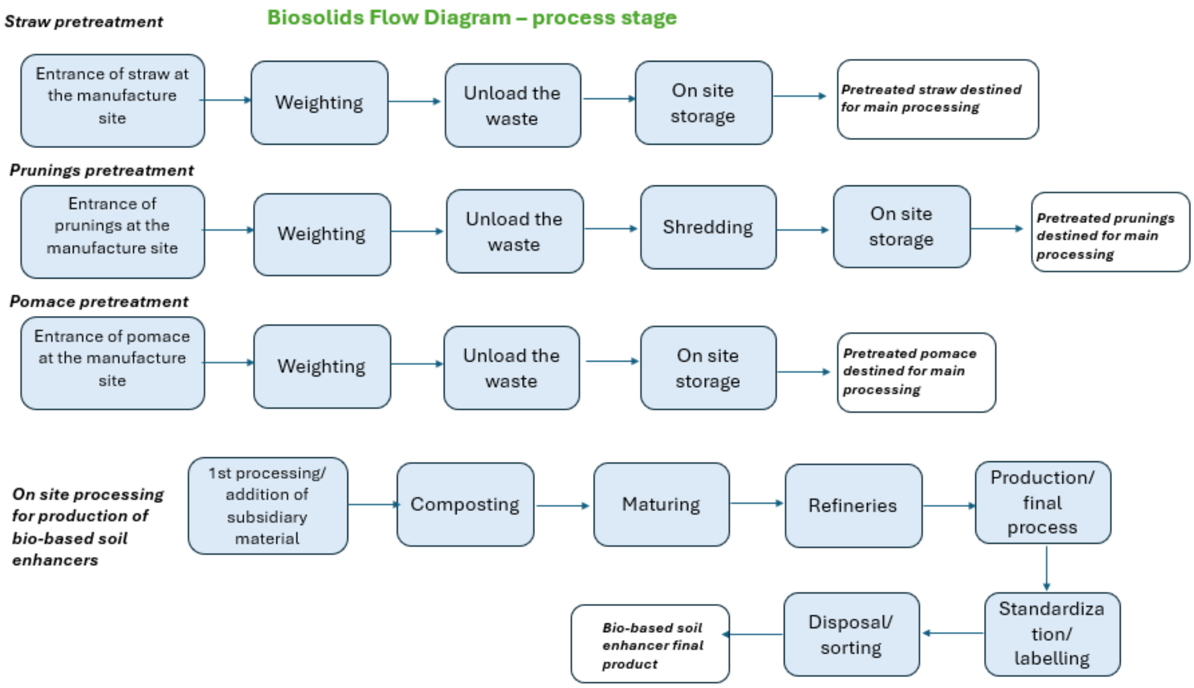


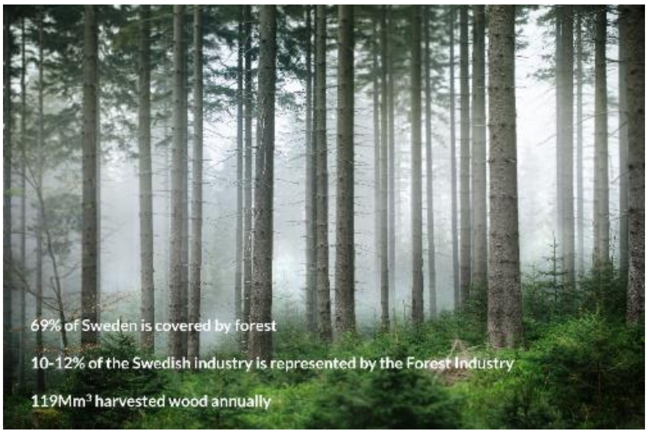
Figure 19. Flow diagram for Biosolids biomass process

-How the certification will improve the production system

The adoption of a certification scheme is a strategy with multiple benefits for a company. Some general benefits, applicable to a wide range of companies include the enhanced market access, selling of the products with a price premium compared to the non-certified counterparts and improved efficiency and management of the system. Undoubtedly, significant environmental benefits are derived from the implementation of certification schemes' principles, coupled with a positive social impact as well (Junior et al., 2016).

Focusing on the companies related to the agrifood case study, special emphasis is placed on the traceability and supply chain of the biological feedstocks. The utilization of secondary streams is not inherently sustainable (Stegman et al., 2020). Therefore, sustainable practices should be adopted throughout the value chain, and more specifically it is critical to ensure the responsible sourcing of biomass residues, establish an efficient supply chain and optimize resource efficiency in the production process. These parameters are regarded as critical aspects from the perspective of certification schemes and thus the appropriate corrective actions should be implemented by the companies.

2.4 Case study 4



Forestry Management in Sweden

Sweden's forests cover roughly 70% of the country's land area, totalling about 28 million hectares. While this area remains stable, the volume of wood within Swedish forests has nearly doubled over the past century. This increase is attributed to both a rise in the number of trees and their larger average size, with thicker trunks being common. Each year, the wood volume in Swedish forests increases by approximately 120 million cubic meters, with around 90 million cubic meters harvested annually through final felling, representing about 1% of the forest land. To maintain sustainability, for every tree harvested, 2-3 new trees are planted[13].

[13] Q&A about the Swedish Forest - Swedish Forest Industries Federation

Sweden boasts approximately 23.5 million hectares of productive forest land, accounting for 58% of the total land area. In 2022, 14.8 million hectares were certified by FSC[14] and/or PEFC[15], with an additional 1.4 million hectares voluntarily taken out of production.

All activities within the forest are strictly regulated by the Forestry Act enforced by Skogsstyrelsen[16]. Forest management is approached with a long-term perspective, spanning 50 to 100 years. Decisions regarding tree species selection, pre-commercial and commercial thinning, harvesting, and reforestation profoundly shape the forest. Balancing various objectives such as productivity, wood quality, biodiversity, and CO_2 absorption guides decision-making. Successful reforestation not only enhances CO_2 absorption but also boosts long-term forest value.

The main stages in forest management are as follows:

Figure 20. The main stages in forest management. Images, from left to right: Forest regeneration. Pre-commercial thinning. Commercial thinning. Final felling.

1. <u>Replanting/Forest Regeneration</u>: Successful reforestation is essential for legal compliance (and certification). Planting is carried out with improved seedlings to maximize productivity.
2. <u>Pre-commercial Thinning:</u> This stage reduces the risk of forest damage and enhances productivity, although future forest shaping depends on specific objectives.
3. <u>Commercial Thinning:</u> Primarily yielding lower diameter pulpwood, commercial thinning increases productivity and the average diameter of trees, making more trees suitable for timber.
4. <u>Final Felling:</u> Forests must mature for at least 45-100 years before final felling (regulated by the Forestry Act). The optimal age for maximizing economic value before final felling typically ranges from 65-130 years. In a typical final felling operation, 10-15% of the area remains unharvested.

The forest industry in Sweden: The forest industry stands as one of Sweden's most pivotal economic sectors, providing widespread employment opportunities across the nation. Benefiting from its rich natural resources and diverse product range, the forest industry plays a vital role in driving Sweden towards a sustainable, biobased future. It comprises a variety of companies that rely on forests as their primary source of raw materials for a wide array of products and services. This encompasses producers of pulp, paper,

[14] *Home | Forest Stewardship Council (fsc.org)*

[15] *Svenska PEFC*

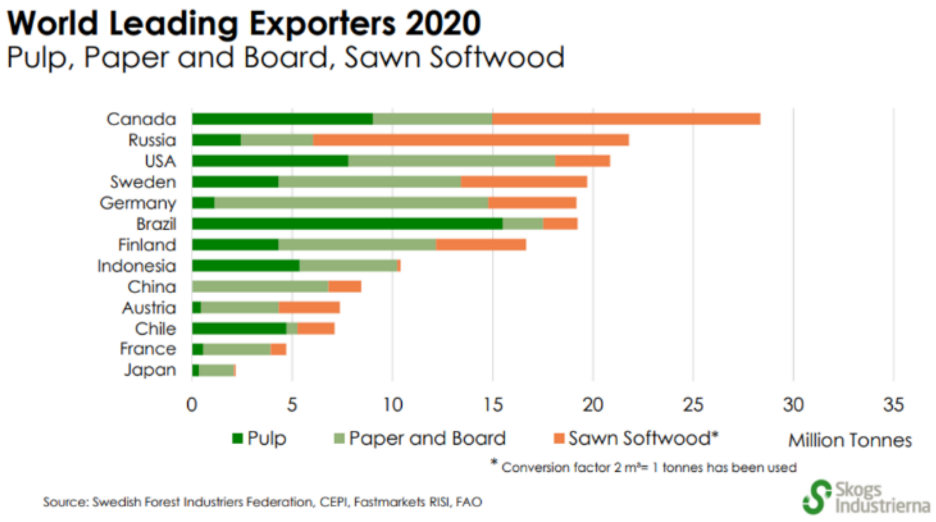
[16] *The Forestry Act - Skogsstyrelsen*

cardboard, packaging, and biofuel, alongside sawmills that manufacture a plethora of boards, planks, roof trusses, and other prefabricated construction elements.

The forest industry wields significant influence within Sweden's economy, making substantial contributions to employment, exports, turnover, and added value. With a strong emphasis on exports, Swedish forest products play a pivotal role in the nation's trade balance, with nearly 90 percent of pulp and paper production and close to 70 percent of sawn timber being exported. This positions the Swedish forest industry among the top exporters globally for these products, reinforcing its stature as a major player in the international market. Employment within the forest sector in Sweden is substantial, with approximately 115,000 individuals employed in various capacities. In several regions, such as certain counties, the forest industry accounts for 20 percent or more of industrial employment, highlighting its crucial role in local economies[17] [18].

[17] *Forest industry significance - Swedish Forest Industries Federation*

[18] Startsida - Skogsindustrierna



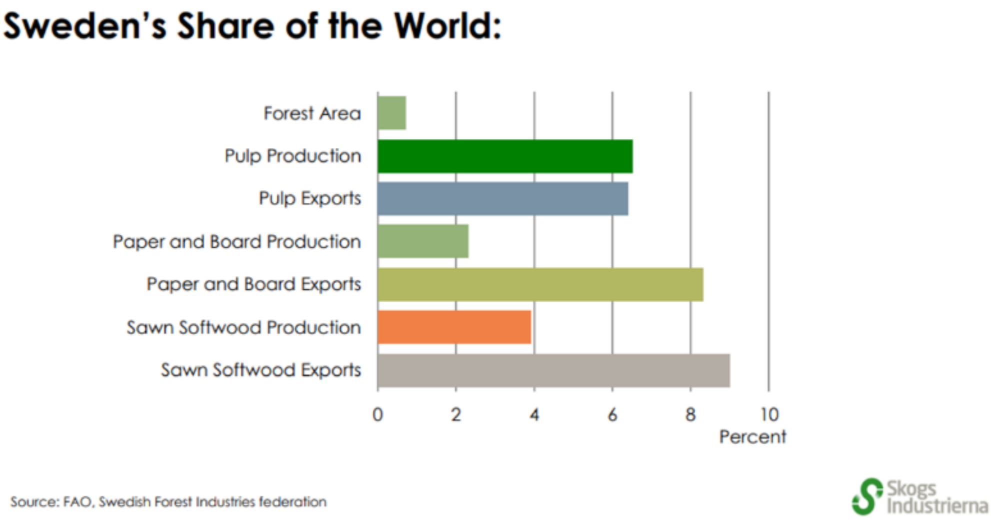


Figure 21. Up: Pulp, paper and board, sawn softwood world leading exporters in 2020. Down: Sweden's forest industry share of the world.

Beyond its economic significance, the forest industry emerges as a crucial component of the climate solution. Forests serve as invaluable carbon sinks, absorbing carbon dioxide during their growth, while wood-based products continue to store carbon dioxide throughout their lifecycle. Transitioning from a fossil-dependent economy to a biobased one is integral to mitigating global warming, and Sweden, along with its forest industry, stands uniquely positioned to lead this transition. Blessed with abundant natural resources, forward-thinking innovators, and a steadfast commitment to investing in a fossil-free society, Sweden's forest industry serves as a driving force towards a bioeconomy.

-General value chain of pulp and paper industry.

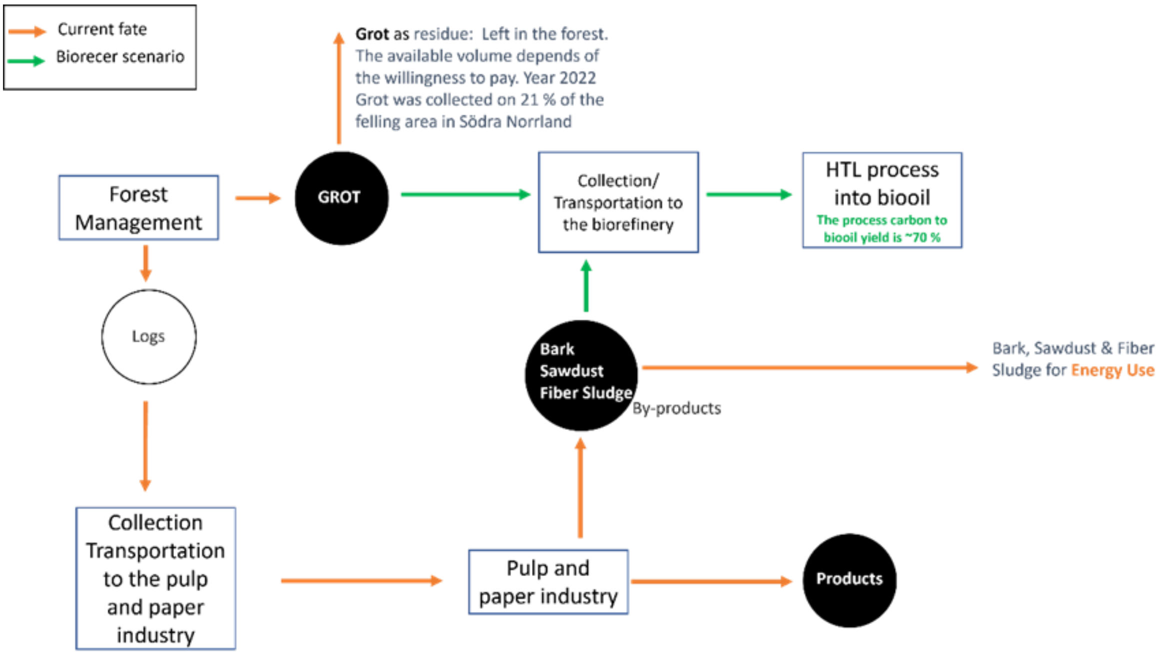


Figure 22. Pulp and paper value chain within the scope of BioReCer Project- CS4

Figure 22 is a simplified representation of the pulp and paper industry value chain within the scope of Study Case 4: Forestry Industry in Västernorrland (CS4). It starts with forest management, followed by the collection and transportation of logs to the paper mill, where they are transformed into products through chemical reactions (Figure 23).

Figure 23. Collection and transportation to the Pulp and Paper Industry

This industry generates a significant variety of by-products, including GROT (branches, roots, tops), sawdust, bark, and fiber sludge. Additionally, there are other streams that hold potential for valorization, even if their availability is limited, such as warm water, carbon, various ashes, and different sludges. Deliverable 2.1 has covered the compositions and general characteristics of GROT, sawdust, bark and fiber sludge. The focus will now shift to the fate of these residual streams in the Västernorrland region (Sweden) and the utilization of these by-products and residues as valuable resources to produce biobased products, including green chemicals and materials that can replace fossil-based alternatives as alternative pathways.

Figure 24.The tree trunk resource utilization of Holmen, one of the Sweden's largest forest owners [19].

Forest Industry Side Streams: Current Status in Västernorrland**:**

- **Bark** is the outer protective layer of a tree, and during industrial processing, it is separated from the wood. Approximately 30-70% of bark is allocated for internal energy use within the industry itself, while the remaining 30-70% is often utilized for district heating or electricity production.

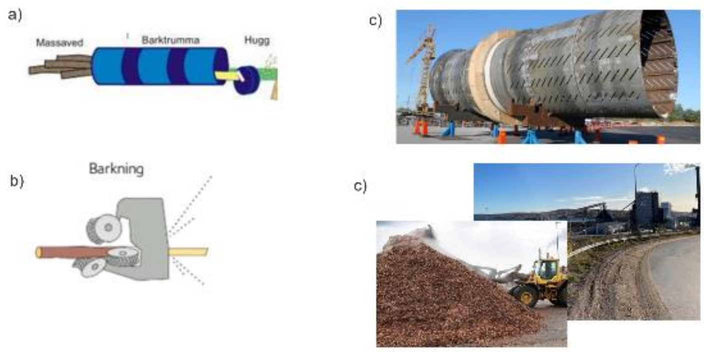


Figure 25. Bark from forest industry. a) Barking technology of wood for pulp production. b) Technology for sawing production. c)Example of a bark dru (weight 350 ton). d) Cogeneration plant as the largest external users of bark.

- **Fiber Sludge** consists of fibers that remain unused in the pulping process. Its quality and volume depend on the specific pulping techniques employed. Typically,

[19] Holmen's value chain

fiber sludge is primarily managed through internal incineration, often at a low heating value.

Figure 26. Right: SCA Pulp Mill, Östrand. Left: Fiber Sluge.

- **Grot** is a timber assortment that is sometimes extracted during final felling. Grot refers to branches and tree tops that are left as residue when the harvester cuts the logs. Spruce dominates higher productivity lands located close to purchasing industries, making them more suitable for GROT collection. However, the margin cost increases with lower productivity lands or longer transportation distances. The availability of Grot depends on the willingness to pay; a low willingness to pay results in Grot being left in the forest. In 2022, Grot was collected from 21% of the felling areas in Södra Norrland (including Gästrikland, Hälsingland, Jämtland, and Västernorrland). For comparison, in Götaland (South of Sweden), Grot was collected from 59% of the felling areas.

Figure 27. Left: A harvester unit is seen in operation, removing branches (grot) from a log. Right: The image depicts a fertile area dominated by spruce trees, resulting in a higher volume of GROT.

- **Sawdust**, a common by-product of wood processing, is created during the cutting or milling of timber. It consists of fine wood particles and is often generated in large quantities in sawmills, carpentry workshops, and other wood-related industries. Bollsta Sawmill[20], located in Kramfors just north of Härnösand in Västernorrland, specializes in processing pine wood and boasts an impressive annual production capacity exceeding 550,000 cubic meters, making it one of SCA's largest sawmills. Among the by-products generated at Bollsta, approximately 90,000 raw tons of sawdust and 45,000 raw tons of bark are produced annually. Regarding sawdust utilization, 20-30% is allocated for internal energy use, while the remaining 70-80% is utilized for wood pellet production. Sawdust from Bollsta Sawmill, as well as other mills in the area, is transported to SCA Bionorr in Härnösand, which has a pellet production capacity of 180,000 tonnes.

[20] *Our units – SCA*

Figure 28. Left: Bollsta Sawmill (Kramfors, Västernorrland). Right: Pellets from sawmill.

BioReCer Scenario: unlocking forest industry side streams through biorefinery processes: The Swedish Forest industry is investing heavily in research and development to utilize side streams from the forest industry as feedstock for biomaterials. Through initiatives like BioInnovation[21][22] , collaborations across industries and disciplines are fostering innovation to maximize the potential of resources such as sawdust, lignin, and tall oil. By optimizing extraction and processing methods, Sweden aims to accelerate the transition towards a sustainable bioeconomy, creating competitive bio-based materials, products, and services. The BioInnovaiton strategic agenda comprises three key areas: 1- Materials, focusing on packaging, textiles and biocomposites; 2- Construction and design, enhancing the value of industrial timber and 3- Chemicals and Energy, developing bio-based chemicals and fuels.

Västernorrland County in Sweden, covering 21,600 square kilometres with around 246,000 residents, is strategically transitioning towards a circular bio-based economy with its regional forest program. Collaboratively developed by stakeholders including governmental bodies, industry, and research institutions, the program emphasizes sustainable forestry management. The forest industry, a major employer in the region, is geographically dispersed with significant coastal operations. Innovative businesses are already contributing to sustainability by offering bio-based products. Legislation since 1993

[21] *Bioinnovation - Swedish Forest Industries Federation*

[22] *Stakeholders - BioInnovation*

promotes a balance between production and environmental goals, emphasizing shared responsibilities between authorities and landowners[23].

Biorefinery technology presents a promising avenue for valorizing side streams from the forest industry. Side streams, such as bark, GROT, sawdust, and fiber sludge, contain valuable components that can be extracted and utilized to produce a range of bio-based products. Biorefineries offer a versatile platform for processing diverse feedstocks, enabling the extraction of valuable compounds and the production of high-quality products while minimizing waste. Through strategic integration of various conversion pathways and optimization of process conditions, biorefineries can unlock the full potential of forest industry side streams, creating economic opportunities and environmental benefits.

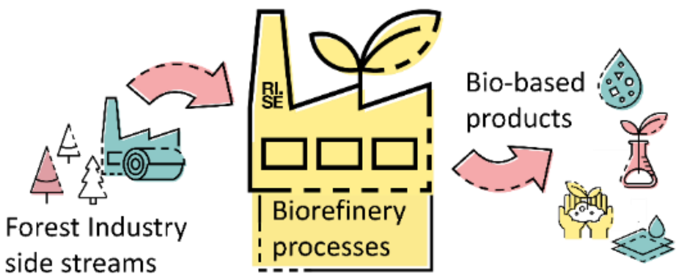


Figure 29. Simplified conceptualization of the value chain for valorizing forestry industry side streams into bio-based products through biorefinery processes.

Sweden's strategic investments in biorefinery technology, exemplified by initiatives like the Bioeconomy Arena[24], underscore the country's commitment to leveraging biomass for sustainable development. **RISE Processum Biorefinery Cluster**, located in Örnsköldsvik (Västernorrland), is at the forefront of research and development in biorefinery products and processes, positioning Sweden as a global leader in biomass utilization. As the leader of **Case Study 4: Forestry Industry in Västernorrland**, RISE Processum Biorefinery Cluster plays a central role in advancing the utilization of forest industry side streams. With substantial state funding and industry interest, these endeavours aim to bridge the gap

[23] Regional Forest Programme 2020-2030 | Provincial government Västernorrland (lansstyrelsen.se)

[24] Bioeconomy Arena will make Sweden a world leader in bioeconomy | RISE

between innovation and commercialization, providing testbeds and infrastructure for companies to efficiently bring their biomass-based innovations to market.

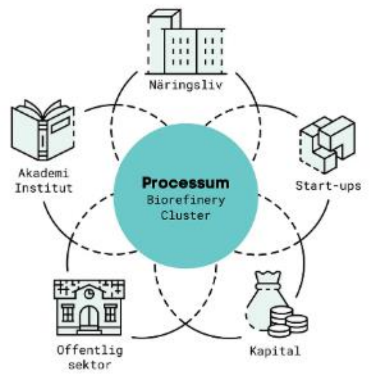
RISE Processum Biorefinery Cluster testbeds and Demonstration facilities

- **Thermochemical pre-treatment:** The test bed Thermochemical pretreatment uses steam explosion for fractionization of lignocellulosic biomass. This treatment makes it possible to access / expose desired structures within the biomass. For example, the test bed can break down wood chips to a slurry, that can easily be further hydrolysed to sugars and then the lignin can be separated. The reactor has a volume of 40 liters and can withstand a pressure of approximately 30 bar, a maximum temperature of 225°C, and a wide pH range
- **Fermentation:** The test environment for fermentation is intended for the cultivation of several types of microorganisms, such as bacteria, yeast and filamentous fungi. Companies and other stakeholders have the opportunity to develop, optimize and scale up their cultures of microorganisms in these bioreactors. Within the framework of the test bed, there are bioreactors on a pilot scale with working volumes of up to 3, 50 and 600 liters.
- **Reactor system for organic chemistry processes:** In an ATEX-classified room at RISE Processum there is a reactor system with pilots that are used to develop processes and products using solvents in a cost-effective manner. The reactor system comprises continuous processes, batch reactors up to 50 liters (Hastelloy, 20 bar), continuous distillation, pilot-scale Soxhlet extraction and it is possible to perform hydrogenation.
- **Hydrothermal carbonisation**: Hydrothermal carbonization (HTC) is a low-temperature thermochemical conversion process to upgrade side streams into hydrochar with interesting properties. Possible areas of use are e.g. soil improvement, environmental remediation, energy storage, and as an energy source. The reactors are from 300-500 ml, to 50 L and 250 L, capable of operating at temperatures up to 300 °C and pressures ranging from 40 to 60 bar.
- **Hydrothermal liquefaction (HTL):** With hydrothermal liquefaction (HTL), biomass is converted into a liquid oil that in many respects resembles fossil crude oil. Oil is the main product in the HTL process, but smaller amounts of gas and solid phase (carbon) are also formed.
  These fractions can then be further processed into various products such as fuels, chemicals, and materials. The process takes place in water and drying the raw materials is thus unnecessary, which contributes to HTL being an energy-efficient process that can convert many different types of biomasses. In just a few minutes, HTL converts biomass into bio-based oil and coal, a similar process that in nature has taken millions of years and formed the fossil variant. RISE Processum has two batch reactors (300 ml) and a continuous pilot for hydrothermal liquefaction under high pressure and high temperatures in a room classified for high-pressure processes. The smaller reactors can be run at 500 ° C and 500 bar temperatures. The larger pilot is specified at 400 ° C and 300 bar and is run as a fully continuous process. The usual procedure is to first test different parameters on a smaller scale

before producing a larger amount in the continuous pilot. At present, about 1 kg of oil/day is produced, but work is underway to increase capacity 10-20 times.

- **Electrochemical biorefinery processes:** This technology uses renewable electricity to create more value from industrial waste streams into bio-fuels and chemicals. We also work with valorisation of CO_2, Carbon Capture and Utilization (CCU), a process where CO_2 is converted into C1-C3 chemicals.

RISE Processum Biorefinery Cluster: Participants of Processum Biorefinery Cluster receive assistance in accelerating towards commercialization, access to unique research infrastructure, support in seeking funding, increasing visibility, and networking with valuable contacts. Offer as a cluster participant:



- Cluster participants get access to unique infrastructure where test and demo facilities linked to biotechnology and chemistry are completely built based on the industry's needs.
- Cluster participants get access to all members of the cluster and the Interest Association, a network that consists of entire value chains where RISE as cluster leader works with matchmaking between the cluster members and the rest of the network.
- Cluster participants get access to guidance and advice in the financing landscape.
- Cluster participants are invited annually to network meetings with the aim of finding synergies and collaborations.
- Cluster participants get the opportunity to participate in events arranged by RISE or where RISE is a partner and have the opportunity to invite speakers.
- Through planned communication efforts, cluster participants are regularly given visibility via RISE digital channels.

Among the potential stakeholders of RISE Processum Biorefinery cluster (hereafter RISE), four of the largest forest industries in Sweden are represented:

- **Holmen**[25] - one of the largest forest owners in Sweden. Their business areas are forest, renewable energy, wood products, paperboard and paper. Holmen's forest cover 1.3 million hectares, of which a little over a million hectares comprise productive forest land. Every part of the tree is used. Products: Wood products (construction (floors, roofs, walls, doors, windows frames, furniture and decking); Paperboad (packaging); Paper (books, packaging and graphical publications); Bioenergy (pellets).

[25] https://www.holmen.com/en/sustainability/our-sustainability-work/reporting/sustainability-report/organisation-and-management/holmens-vardekedja/

- **Metsä Board**[26] - is a modern pulp and paper mill that manufactures and supplies uncoated and coated fine paper as well as bleached sulphate pulps. Every part of the tree is used. Log wood (for wood products (peeled vener products, plywood and sawn timber). Pulpwood is used to produce pulp (which is a raw material for paperboard and printing, tissue and speciality papers). The bark, branches and crowns are in turn used in energy production. They also strive to use production side streams for new bioeconomy products = biochemicals, biogas, bioenergy, solid energy waste such as ash (as fertilizer) and lime (in soil improvement for fields and in the neutralization of wastewater, sell waste to our partners for further processing.
- **Mondi Dynäs**[27] - produces 250,000 tonnes of sack paper and kraft paper. It is one of the world's largest producers of unbleached sack paper and special kraft paper. Avoid waste by keeping materials in circulation: Reusing fibre sludge from the wastewater treatment plant as landfill cover. Alternative use for waste lime mud in production of cement.
- **SCA**[28] – Europe's largest private forest owner and manufactures pulp, paper, sawn wood products and pellets. Bark is used to produce energy to dry the timber; crowns and smaller trees are delivered as pulp wood to our pulp and paper mills. Sawdust is used as raw material for fuel pellets. The entire tree is used as much as possible. SCA produces 11.9TWh of biofuels. They use 10 TWh in our own plants and sell 1 TWh to customers outside the company in form of unrefined biofuels such as branches, crowns and decayed wood, or in the form of refined fuels – pellets.

Other members of the Cluster:

- BRUX[29]: is a service and property company
- C-GREEN[30] converts boisluge into biochar
- Dåva DAC[31] offers disposal of solid waste and sludge
- Domsjö Fabriker[32] is a biorefinery with the main raw materials cellulose, bioethanol and lignin
- Eurocon[33] offers cutting-edge expertise in the process and manufacturing industry, infrastructure and information systems
- IPCO[34] provides advances process solutions
- LabService [35]tailors precise, chemical mixtures for delivery to laboratories

[26] https://www.metsagroup.com/products-and-services/other-bioproducts/

[27] https://www.mondigroup.com/sustainability/reports-and-publications/

[28] https://www.sca.com/en/sustainability/sustainability-platform/fossil-free-world/the-green-cycle/

[29] https://brux.se/

[30] https://www.c-green.se/

[31] https://avfallscenter.se/

[32] https://www.domsjo.adityabirla.com/Sidor/Startsida.aspx

[33] https://www.eurocon.se/

[34] https://ipco.com/

[35] https://www.labservice.se/

- Nouryon[36] is a global company that manufactures specialty chemicals
- PulpEye[37] is an innovative company in online measurement technology
- Ragn-Sells[38] is one of Sweden's largest environmental and recycling companies
- SEKAB[39] is a green chemical company
- Umeå Energ[40]i is a modern energy and communications company

The Figure 30 illustrates projects concerning these four side streams conducted by RISE from 2012 to 2020 and demonstrates that, with the exception of sawdust, internal projects (involving cluster members) have equalled or surpassed external projects (with organizations outside the cluster) in terms of activity. This indicates that the forestry industry in Västernorrland is actively seeking alternatives beyond simply using these by-products/residues as a low-energy source. Various approaches have been utilized for this valorization. As an initial step in delineating the boundaries of Case Study 4 for mass flow analysis, valorization of these side streams using Hydrothermal Liquefaction (HTL) was proposed. This technology was selected for its capacity to process both dry and wet products, thereby potentially allowing the utilization of all four side streams under study.

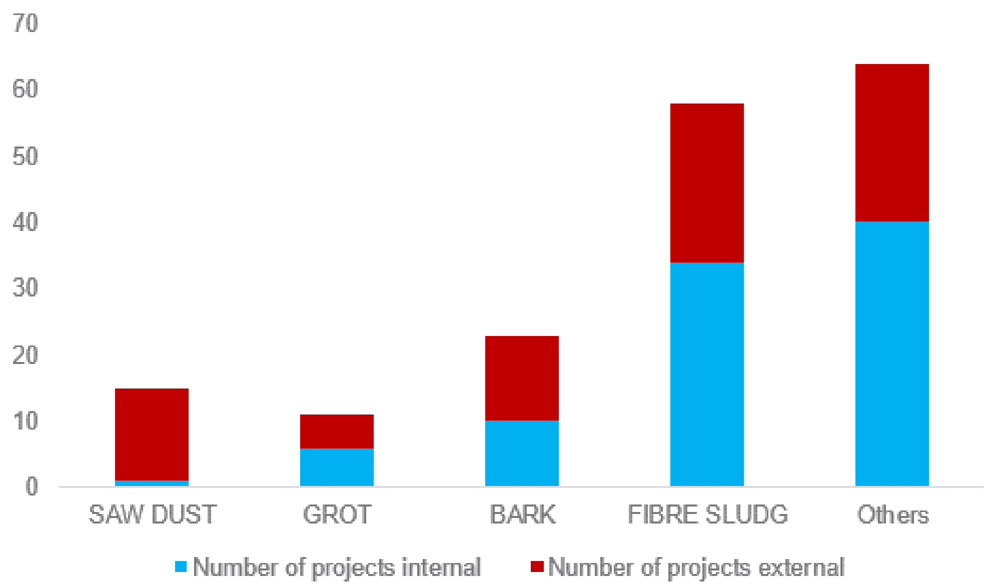


Figure 30. Balance between the number of internal and external projects conducted by RISE between the years 2012 and 2020 for the side streams Sawdust, GROT, Bark, and Fiber Sludge (data from the Internal report).

[36] https://www.nouryon.com/

[37] https://www.pulpeye.com/

[38] https://www.ragnsells.se/

[39] https://www.sekab.com/en/

[40] https://www.umeaenergi.se/

The transition from conventional petroleum-based chemicals to renewable alternatives is rapidly gaining traction, with Hydrothermal Liquefaction (HTL) emerging as a promising technology in this shift. Through the HTL process, wet biomass can be converted into into a crude product via high-temperature and high-pressure water-based reactions, which can later be separated into its light and heavy fractions (Figure 31). This crude product can then be separated into its light and heavy fractions. The heavy fraction, which can be upgraded into biofuel (beyond the scope of the CS4 study), and the light oil has the potential to yield valuable compounds[41] crucial for biobased product manufacturing (in scope with the CS3 study). Nonetheless, substantial advancements are required, particularly in validating the technology's suitability for specific local conditions and optimizing parameters for different feedstocks.

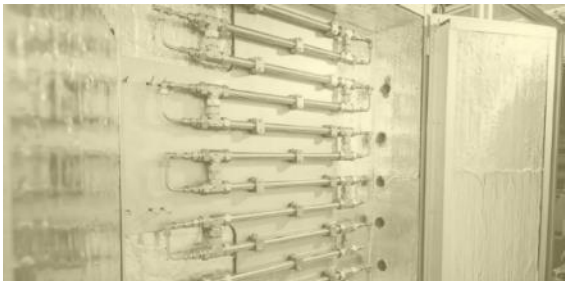


Figure 31. Hydrothermal liquefaction equipment at RISE Processum Biorefinery Cluster.

As agreed within Work Package 2, initially the CS4 study concludes with the use of the side streams as feedstock for the HTL process, without further exploration into the subsequent processing of the resulting product(s).

[41] *On the understanding of bio-oil formation from the hydrothermal liquefaction of organosolv lignin isolated from softwood and hardwood sawdust - Sustainable Energy & Fuels (RSC Publishing)*

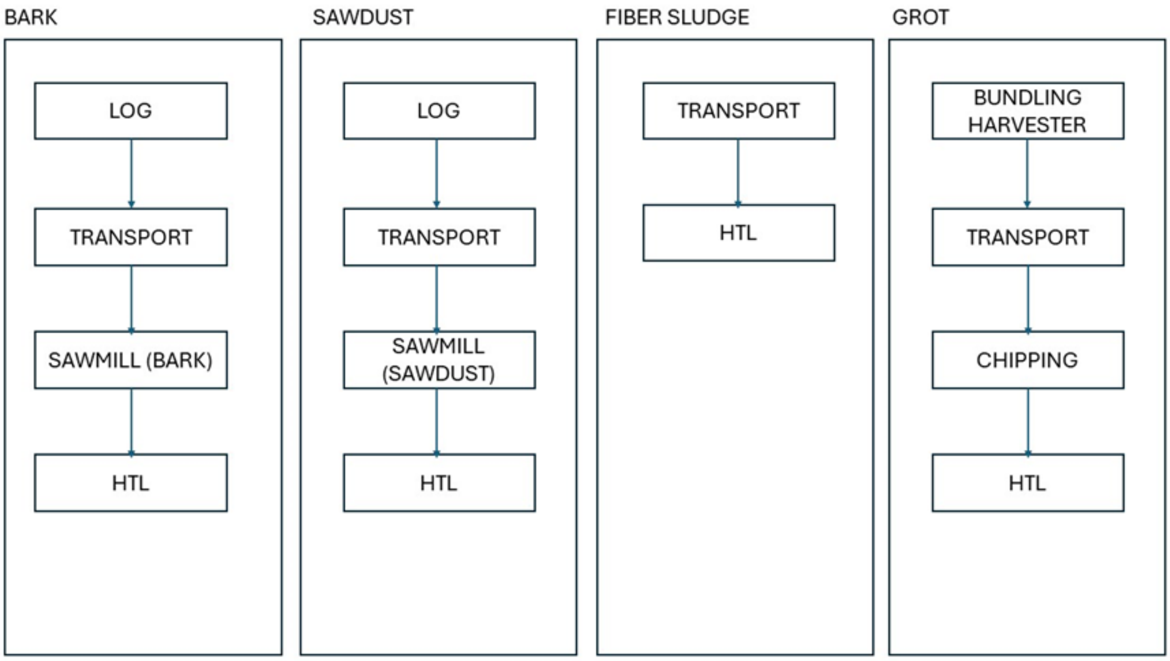


Figure 32. A simplified schematic of the valorization of side streams from the forest industry using HTL, as proposed in CS4.

Below are some examples of projects undertaken by RISE over the years, specifically focusing on the treatment of residual streams (Grot, bark, sawdust, and fiber sludge) from the forest industry in Västernorrland. It's important to note that these projects involve collaborations with private companies, which limits the level of detail that can be disclosed.

- **Fiber sludge** has been the starting point for many projects dealing with fermentation to produce ethanol and other carbon-containing molecules as well as growing microorganisms in it. It has been tested to grow bacterial nanocellulose on fiber rejects and it has been raw material in the production of PLA. Fiber rejects have been co-incinerated with other residual products to optimize the combustion ratio. It has been investigated whether fiber reject can be used as stable litter. By HTC-treating fiber rejects, a material with a high carbon content has been produced that can have various uses, such as for supercapacitors or additive in the steel industry's smelters.

- **Bark** and bark press water. Extraction of bark has been studied in many of the projects. Various extractive substances have been in focus, such as tannins, betulin, suberin, arginine and antimicrobial substances. That extract of bark can be used as a tanning agent has also been investigated. Ground bark has been tested in various materials to improve the properties of the material. Ground bark has also been used in the HTL process to produce bio-oil and has been co-incinerated with other residual products to optimize the combustion ratio. It has been investigated how bark press water can be purified.

- **GROT** has been thermochemically pre-treated and is used to grow single cell protein and to produce ethanol. Attempts have been made to extract arginine from GROT. Torrefaction of GROT has been carried out to produce biofuel, as well as to investigate its potential as biochar and/or soil conditioner. Ground GROT has been used in the HTL process to produce bio-oil. Some projects have tested a new equipment to sort decomposed GROOT by size.

- **Sawdust** as admixture in materials to improve material properties or make the materials cheaper. They have also dealt with the fermentation of pre-treated sawdust into, for example, ethanol and further into biogasoline/biodiesel. Sawdust as starting material in the HTL process to produce bio-oil has been investigated. It has also been investigated how fly ash from burnt sawdust can strengthen gravel material.

3 Stakeholder engagement

3.1 Stakeholder engagement methodology

In the pursuit of collaborative and inclusive research, stakeholder engagement plays a critical role in ensuring that diverse perspectives are considered and integrated into project activities. As part of our commitment to fostering meaningful stakeholder engagement, we have implemented a comprehensive methodology to engage with relevant stakeholders during the development of the BioReCer project. Our approach to stakeholder engagement has been multifaceted, encompassing various outreach strategies and interactive sessions to facilitate dialogue, gather knowledge, and foster collaboration. Through a combination of workshops, focus group meetings, online communications and networking events, we have actively sought to engage diverse stakeholders.

In some cases, for example in CS4, key highlights of their stakeholder engagement efforts include a campaign during 2023 that reached out to over 40 potential stakeholders through personal emails, phone calls, and online meetings. Their aim was to engage them in the stakeholder platform and provide them with relevant project information. Furthermore, their organized workshops and focus group meetings specifically tailored to Case Study 4, facilitating in-depth discussions and collaboration opportunities among stakeholders. These sessions provided a platform for stakeholders to contribute their expertise, insights, and feedback, ultimately enriching the development of the case study and contributing to other Work Packages. In addition to direct engagement activities, they have leveraged communication channels such as newsletters and social media platforms like LinkedIn to disseminate project updates, share insights, and encourage broader participation from stakeholders. Moreover, our participation in events such as the CBE24 Matchmaking Event[42] allowed us to showcase our project and engage with potential stakeholders, further expanding our outreach efforts. Overall, their stakeholder engagement methodology underscores their commitment to fostering collaborative partnerships, gathering diverse perspectives, and co-creating innovative solutions in the field of biorefinery research. Through ongoing engagement, they aim to continue building strong relationships with stakeholders and driving impactful outcomes within the BioReCer project.

3.2 Contributions and activities of stakeholders inside the work package

CS1

From CS1 we have carried out several activities during this time in which we have managed to enroll different companies from several sectors within fishing in the project. In 2023, a

[42] Matchmaking event 2024 | Bio-based Industries Consortium (BIC) (biconsortium.eu)

workshop was held to make a general presentation of the project to aim stakeholders to sign up for the BRSP.

With this type of activities, several companies that represent several points in the fishing sector chain were introduced into the project. For example, in the fish processing sector there are the companies as "Vieirasa" or "Bolton Food", in the seaweed processing sector, the company "CEAMSA" or in product development, the last phase of the value chain, "Caroi'Line Cosmetics" or "Cobiosa".

Like these, there are many more companies that have joined the project through meetings, events, social networks or other types of channels. With them, work is being carried out to validate the value chains, validating that the processes that are introduced into them are correct, validating what type of raw materials or materials are used in the process, if they measure energy, emissions, etc. and, obtain data from their processes.

CS2

CAP HOLDING SPA is a water and waste utility that manages the urban water infrastructural assets (networks and plants) of the Metropolitan city of Milan (Lombardia). It is one of the most important national utilities, providing the urban water cycle service to more than 2,2 million of inhabitants. Moreover, CAP HOLDING SPA is managing organic waste in a cluster of plants and a major biorefinery even involved in the Horizon 2020 project CIRCULAR BIOCARBON. CAP HOLDING SPA is a partner of Horizon Europe Project BioReCer and will benefit directly from the results of the project. Following its example, the latter will be subsequently used by other companies in Europe.

UNIVPM invited association, biomass producers and policy makers stakeholders such as UTILITALIA, SMAT, Water Europe, HERA, Acquedotto Pugliese, ISPRA, ACEA, A2A, CHIMICA VERDE BIONET and ASA LIVORNO to join the BioReCer Stakeholder Platform (BRSP).

UNIVPM presented the general objectives of the Horizon Europe Project BioReCer during a training organized by UNI titled "STANDARDS AND R&I PROJECTS: HOW TO SUPPORT THE BIO-BASED INDUSTRIES", with a particular focus on the Italian case study and the integration of environmental and T&T assessment framework into ISCC PLUS certification schemes.

CS3

The research conducted on the agrifood case study is supported by two companies that are located in the region of interest and produce bio-based products by utilizing residual streams from agricultural and food-processing activities. More specifically, Biosolids SA generates bio-based soil amendments and CHIMAR SA provides the expertise for the production of bio-based composite wood products. The contribution of these companies is invaluable for the validation of the Project's outcomes. In this sense, the quality of the Project's results is enriched with the utilization of real data coupled with the provision of insight and consultation from the perspective of actual, competitive industries.

To accomplish the expected results of the Project an iterative pattern of communication is established between CERTH and the engaged companies. There is a valid need for data provision from the industries in multiple tasks of the Project. Therefore, a close collaboration takes place between CERTH and experts from the two industries (e.g. engineers, managers etc) that have a general overview of the laboratory and production process of the facilities. The involvement of the companies is associated with the provision of consultation, data, qualitative and quantitative information concerning the production process and the biological feedstocks that are processed (e.g., point of origin, properties etc). Within the context of collaboration, the following activities have been performed:

An initial field visit in Biosolids SA as well as in CHIMAR SA has been conducted by the CERTH team. In both field visits, the experts from the industry provided a full overview and elaborate description of the processes that take place, the feedstocks that are utilized, the objectives and philosophy of the company with emphasis on sustainability aspects. As an outcome of these visits, CERTH team was able to elucidate various aspects of the Greek case study, provide details regarding the production processes, requirements and overall value chain within the project partners and set the basis for the analysis of the case study.

An additional field visit in both companies was performed during the third General Assembly meeting that was hosted by CERTH in Thessaloniki. These visits were open to the whole consortium and included a demonstration of the premises of the facilities accompanied by a thorough description of the processing steps and an overview of the companies' background.

In parallel, a dissemination activity of Project's results took place in the Agrotica Fair, on February 4, 2024, in Thessaloniki. More specifically, the Project was presented in a workshop that focused on the circular production of biofertilizers, with the presentation and subsequent discussion on the issue of certification schemes in the field of bio-based fertilizers, resulting in the information exchange and acquisition of very interesting input from experts and industrial representatives of the field.

CS4

As mentioned in section 2.4, in 2020 RISE conducted an Internal Report with the inventory of the available residual streams, assessing their quality and characteristics. This evaluation aimed to identify suitable raw materials for the development of circular biobased value chain in the Forestry Industry in Västernorrland. RISE has utilized this information, along with insights from companies within the cluster and expertise gained over more than 20 years of working with the Swedish and global forestry sectors, to develop the use case.

As an example of contributions from stakeholders outside the cluster, the participation of various entities in the two online Focus Groups conducted in May 2023 showcased their engagement with the project's objectives. The stakeholders, representing diverse sectors such as forestry sector interest associations, big international pulp & paper companies, startups, and SMEs, provided valuable insights into the challenges and opportunities associated with secondary feedstocks. Their inputs, as reported in Deliverable 4.1, highlighted concerns regarding quantity, quality assurance, and sustainability standards, underscoring their understanding of the industry's dynamics. Additionally, stakeholders expressed anticipation for job creation through secondary feedstock deployment and recognized the potential of bio-based products for import substitution and environmental benefits. This collaborative engagement demonstrates the importance of involving stakeholders in shaping the transition towards a sustainable bioeconomy, emphasizing the crucial role of policy makers in facilitating regulatory frameworks and financial support to drive progress and consumer awareness.

3.3 Future activities with stakeholders inside the work package

CS1

Within CS1, in ANFACO facilities, will be carry out in the coming months a workshop with Potential stakeholders within the canning, marine, wastewater and transformation (pharmaceuticals and food sectors) in which will be made a presentation of BIT. Call for engagement and collaboration will be requested to test it and validate it. It is expected to take place between the months of May and October 2024.

CS2

Together with the partner CAP HOLDING SPA and SPRING cluster, where a specific working group on sludge management is active, the topic of certification schemes and BioReCer will be presented and periodically (usually three times per year) discussed with stakeholders from the whole value chain (e.g. water and waste utilities, fertilizer producers, bio-based industries). These stakeholders are SPRING associated members, so their engagement and proactive participation is expected. Further to the first meeting, specific questionnaire will be shared, and information will be elaborated to consider the stakeholders feedback. Finally, to favour a maximization of the engagement and to lock an active participation and input provision to the case study, a proposal will be submitted to the coordinator in order to involve the Working Group coordinator (SMAT - www.smatorino.it) in BioReCer Project.

CS3

Other stakeholders involved in CS3 concerning the biomass from the agricultural sector are farmers and farmers' associations, agro-industries and end-users, such as SMEs that produce commercial products from agricultural residues or by-products. Data collection and feedback concerning the validation of Environmental and Circularity Assessment Framework for bio-based products is going to be acquired through group meetings and individual interviews. Local stakeholders will be also advised to provide data concerning the value chains of the biological feedstocks of interest. The stakeholders will also assess/commend on the collected data from available literature and databases. Finally, the local stakeholders will assess the BioReCer ICT tools and the certification methodologies that will be developed, providing valuable feedback concerning their usefulness, easy-of-use, and applicability to local biological feedstocks. The developed methodologies are going to be demonstrated in order to draw conclusions for replicability/transferability of the model in other main European biomass flows.

CS4

Greater efforts need to be made to engage more stakeholders in the future to continue advancing the use case within Work Package 6 and contributing to the other Work Packages. The engagement methodology will involve customizing channels and content to effectively reach the types of stakeholders needed to obtain the desired information. In the first half of 2024, RISE's strategy involves organizing a Stakeholder Event to call for engagement, foster collaboration and present the BioReCer ICT tool (BIT) developed within Work Package 5. This event will be conducted in person at RISE facilities in Örnsköldsvik on June 13, with a target attendance of 10-15 organizations, and will be organized in collaboration with the Work Package 4 leader. Additionally, a Spring campaign will be launched to attract more stakeholders to the June event, including direct outreach via email/phone and posts on LinkedIn. Furthermore, in February, we plan to participate in the MWC24 event to disseminate the project's mission and engage with more global stakeholders. Moreover, during the Nordic Wood Biorefinery Conference in October 2024, which RISE will organize, networking activities related to the BioReCer Project will take place.

4 Contribution of WP6 to other WPs

From WP6 we collaborate with other work packages in the following areas:

- With work package 2, we are collaborating the development of questionnaires to obtain primary quantitative and qualitative data from stakeholders. Our work is based on analysing the questions posed in the questionnaires by WP2, indicating which ones are more appropriate for each work package, which ones should not be included in the questionnaires and we will be in charge of sending these questions to the partner companies to obtain the necessary information. On the other hand, we also collaborate with this package in the elaboration of the flow diagrams and value chains, in order to adjust them to the most appropriate model possible.

- With work package 4, we will work on conducting the pilot visits to the partner companies in order to monitor and certify that the established certification criteria are being fulfilled. We will also work on stakeholder engagement in the different stages of the value chains in order to validate them.

- With work package 5, we will collaborate in sending quantitative data for its subsequent introduction into the ICT tool, having previously agreed the format of the data with this package.

5 Expected progress in the upcoming months

The work package started in M8 but with little collaboration with other work packages, which made it difficult to obtain indications for the validation work with stakeholders. Currently, in the last few months, collaboration with the different work packages has begun and gradually the necessary tools are being provided so that useful information can be obtained from WP6 to transfer it and help in the development of the different activities of other WPs.

In the coming months we will have all qualitative data (from secondary data) on the value chains entered and we will start entering primary data from the questionnaires provided by WP2. The aim is to be able to enter real data into the ICT tool as soon as possible and to start training it.

Furthermore, we will carry out the pilot visits in coordination with WP4 and the certification bodies with which we will certify the production processes of the associated companies and, therefore, our value chains.

6 Conclusions

Through the BioReCer project, we continue to make progress in improving the traceability and environmental performance of biological feedstocks in the bio-based industry. By implementing and validating the methodologies developed in the project in different case studies, we are exploring the feasibility of strengthening existing certification schemes and setting a precedent for the integration of sustainable practices along different value chains.

In D6.1, preliminary data for the 4 case studies have been obtained from literature studies and through collaboration with the companies. This data is derived from information on the management and production processes of the stakeholders. The aim is to certify the entire production process of bio-based products and to feed this data into the ICT tool platform.

The active participation and engagement of stakeholders throughout the process is critical for long-term success. We also need to ensure that the solutions and methodologies developed are transferable and adaptable to different contexts and sectors to maximize their impact and contribution to the circular economy and global sustainability.

It is imperative that working towards wider adoption of these practices requires closer collaboration between all stakeholders in the value chain, from producers to end users. In addition, strengthening regulatory and certification frameworks will be critical to ensure effective and sustainable implementation of the practices developed in BioReCer.

7 List of abbreviations

WP	Work Package
BRSP	Bioresources Stakeholders Platform
BIT	BioReCer ICT Tool
BRIE-LL	Bioresources Innovation Ecosystem living-lab
T&T	Tracking and Traceability
AHP	Analytical Hierarchy Process
R&D	Research and Development
FG	Focus Group
CS	Case Study
TM	Targeting Metrics
KPI	Key Performance Indicator
SIP	Stakeholder Involvement Plan
OFMSW	Organic Fraction of Municipal Solid Waste
GROT	Branches, roots, tips
GA	Grant Agreement
ACN	Cittadinanzattiva- Active Citizenship Network
DMP	Data Management Plan
GDPR	General Data Protection Regulation
SO	Specific Objective
SC	Supply Chain
ICT	Information and Communication Technologies
ECBF	European Circular Bioeconomy Fund
CET	Central European Time
CR	Consistency Ratio

VFA	Volatile Fatty Acid
CEAMSA	Compañía Española de Algas Marinas
ANFACO	ASOCIACIÓN NACIONAL DE FABRICANTES DE CONSERVAS DE PESCADOS Y MARISCOS-CENTRO TÉCNICO NACIONAL DE CONSERVACIÓN DE PRODUCTOS DE LA PESCA
CETAQUA	FUNDACIÓN CENTRO GALLEGO DE INVESTIGACIONES DEL AGUA
UNIVPM	Università Politecnica delle Marche
RDFM	Regional Development Fund of Central Macedonia
TCG	Technical Chamber of Greece TCG
FSC	Forest Stewardship Council

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