

SYMBIOS: Digital Platform for Industrial Symbiosis & Circular Economy

WORK PACKAGE 2.6

Modelling the Mechanism and the Skills Gap of Industrial Symbiosis

AGRIFOOD SECTOR

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Introduction

Industrial symbiosis (IS) is one of the most concrete operational strategies available for translating the abstract ambition of circular economy into measurable industrial practice. Rather than treating waste, by-products, energy residues and water as a cost to be disposed of, industrial symbiosis reframes them as resources with a market value for another actor, often in a different sector. This model has been developed within Work Package 2 (WP2: "Research on Industrial Symbiosis targeting Agrifood & Leather Sectors") of the Erasmus+ KA220-VET project SYMBIOS – Digital Platform for Industrial Symbiosis & Circular Economy (Project No. 2024-1-PT01-KA220-VET-000253813). It focuses specifically on the agrifood sector, one of the two strategic manufacturing sectors selected by the SYMBIOS partnership because of its size, its environmental footprint and its largely untapped potential for circularity.

Objectives of the Model

The purpose of this document is twofold, mirroring the two specific objectives of Work Package 2 set out in the project's Grant Agreement. First, it reconstructs the symbiotic mechanism that governs the agrifood sector: what industrial symbiosis means in this sector, which resources and flows are involved, which regulatory framework enables or constrains their exchange, which cross-sector connections are most promising, and which best practices already demonstrate that the model works in practice. Second, it maps the knowledge and skills that individuals and organisations need in order to operate professionally within this field, differentiated by target group (young graduates, employed workers, managers and decision-makers, and unemployed or disadvantaged groups), together with training tools and recommendations for VET providers and policy makers. Taken together, the two chapters provide the conceptual and pedagogical foundation on which the SYMBIOS Digital Platform, and specifically its open MOOC on industrial symbiosis (WP 3.1), is built.

Framing Industrial Symbiosis within the Circular Economy

Industrial symbiosis is not a synonym for circular economy, but one of its principal enabling mechanisms. Where the circular economy describes a systemic vision in which the value of products, materials and resources is maintained for as long as possible, industrial symbiosis describes the specific inter-organisational mechanism through which this is achieved when the actor able to create value from a resource is not the one that generated it. Chertow (2000) defined industrial symbiosis as the engagement of traditionally separate industries in a collective approach involving the physical exchange of materials, energy, water and by-products, generating mutual economic and environmental benefit. Twenty years later, the same logic has been formally embedded in European Union policy: the 2020 Circular Economy Action Plan, a cornerstone of the European Green Deal, explicitly identifies industrial symbiosis as a strategy to keep resources

circulating within the European economy, while the revised Waste Framework Directive requires Member States to promote replicable industrial symbiosis practices. For the agrifood sector, this policy alignment is particularly significant because food production is simultaneously one of the largest generators of biological by-products in the economy and one of the sectors facing the strongest pressure, from regulation, from retailers, from investors, and from consumers, to demonstrate measurable progress on sustainability.

Relevance for the Agrifood Sector

The agrifood sector is characterised by very high volumes of raw material, water and energy throughput and, correspondingly, by very large volumes of by-products, wastewater and packaging waste. According to data collected within Work Package 2 across Spain, Italy and Slovenia, the agrifood industry represents one of the largest manufacturing sectors in each partner country by turnover (worth more than EUR 126 billion in Spain, EUR 64 billion in Italy, and around EUR 2.4 billion in Slovenia's food and beverage sector alone). At the same time, it is precisely the sector in which the reuse of by-products is most constrained by food safety, traceability and hygiene rules, making the balance between circularity and safety the central design question of any agrifood symbiosis model. This model is built to help resolve that tension: it shows where the sector already generates value from what would otherwise be waste, where the regulatory framework supports or blocks such exchanges, and what knowledge and skills are needed to scale these practices from isolated best practice to systemic, everyday industrial behaviour.

Methodology and Sources

This model is grounded in the mixed-methods research carried out under Work Package 2 of the SYMBIOS project between late 2025 and mid-2026, complemented by the peer-reviewed and institutional literature on industrial symbiosis. The primary sources used are:

- **Focus groups (WP 2.1)** conducted with agrifood stakeholders in Slovenia (six participants from industry, research, sectoral associations and public administration) by GZS and in Spain (twelve participants from industry and academia) facilitated by IATA-CSIC, used to identify the research objects for the subsequent survey.
- **A cross-country survey (WP 2.3)** administered to 30 agrifood companies (10 each in Spain, Italy and Slovenia) between January and March 2026, covering company profile, production processes, waste management and circular practices, regulatory barriers, and skills and training needs.
- **Semi-structured deep interviews with food industry stakeholders (WP 2.3)** conducted with six companies across Slovenia, Italy and Spain between January and March 2026, exploring current practices, barriers and enabling conditions for industrial symbiosis.

- **Semi-structured deep interviews with academic experts (WP 2.3)** conducted with five researchers based in Spain, Slovenia and Italy between January and March 2026, exploring definitions, best practices, innovation trajectories, and required competences.
- **Desk research and sector-specific literature review (WP 2.4)**, covering the peer-reviewed literature on industrial symbiosis (Chertow, 2000, 2007; Mirabella et al., 2014; Jacobsen, 2006; Van Capelleveen et al., 2018, among others) and the applicable European Union and national legislative framework.
- **A systematic review of existing Industrial Symbiosis learning offers (WP 2.6)**, covering structured education and training programmes for which industrial symbiosis is the primary educational objective, analysed through a purpose-built Industrial Symbiosis Learning Offer Analysis Framework (ISLOAF).

Chapter 1 – Symbiotic Mechanism

1.1 Definition: Key Concepts and Principles

Industrial symbiosis (IS) is a collaborative approach in which traditionally separate industries engage in the exchange of materials, energy, water, services and information in order to improve resource efficiency and reduce environmental impacts. Within the food industry, industrial symbiosis represents a key strategy for implementing circular economy principles by transforming waste streams and by-products into valuable resources for other industries.

According to the classical definition proposed by Chertow (2000), industrial symbiosis involves the mutually beneficial exchange of resources among firms, generating environmental, economic and social benefits. In the food sector this concept extends beyond waste management and includes resource optimisation throughout the value chain, from agricultural production and food processing to distribution and consumption. The European Committee for Standardization (CEN, 2018) definition, used as the baseline definition during the SYMBIOS focus groups to establish a common understanding among stakeholders, situates industrial symbiosis firmly within an industrial context: exchanges of resources such as materials, water, energy and services between otherwise unrelated industrial actors, distinct from ordinary supply-chain trade.

The fundamental principles of industrial symbiosis in the food industry include:

- Resource efficiency through the cascading use of materials, whereby a resource is used at its highest value application before being downgraded to lower-value uses such as energy recovery;
- Valorisation of by-products and residues, converting what would otherwise be a disposal cost into a revenue stream;
- Reduction of landfill disposal and greenhouse gas emissions associated with waste treatment;
- Cross-sector collaboration among industries that would not naturally interact through conventional supply chains;
- Creation of new business opportunities, revenue streams and, in some cases, entirely new companies or business units;
- Support for regional circular economy development, since many symbiotic exchanges are strongly conditioned by geographic proximity.

Food industries generate significant quantities of organic by-products rich in nutrients, fibres, proteins, lipids and bioactive compounds. These streams provide considerable opportunities for reuse and valorisation in sectors such as animal feed, bioenergy, pharmaceuticals, cosmetics,

biotechnology, agriculture and leather processing. As confirmed during the SYMBIOS Slovenian focus group, industrial symbiosis is not a new idea, several participants noted that the underlying logic has existed informally for decades, for example in the traditional use of soybean meal and brewers' spent grain in livestock farming, but its systematic application has in recent years been constrained by increasingly cautious interpretation of European legislation and by the application of the precautionary principle to biological materials.

This industrial symbiosis model aligns closely with the European Green Deal, the Circular Economy Action Plan, and the United Nations Sustainable Development Goals, particularly SDG 12 (Responsible Consumption and Production).

Outputs, Waste and By-products: A Fundamental Distinction

In the context of food industrial symbiosis, outputs, waste and by-products are not viewed merely as residues requiring disposal, but as potential resources that can create value within or across industrial sectors. Food processing industries generate a variety of material streams in addition to their primary products intended for human consumption: by-products, waste materials, wastewater, excess heat and packaging residues.

- A by-product is a secondary material generated during a production process that has a certain and lawful further use without requiring significant additional processing; examples include fruit pomace, dairy whey, brewer's spent grain, grape pomace and animal hides.
- Waste, in contrast, refers to materials that the holder discards, intends to discard, or is required to discard under regulatory frameworks. Industrial symbiosis seeks to transform waste streams into valuable inputs for other processes, thereby reducing resource consumption and environmental impacts. For example, fruit peels and vegetable residues can be converted into animal feed or biofertilisers, whey can be processed into nutritional ingredients, spent grain can be used in food, feed or bioenergy applications, and animal hides can be supplied to the leather industry.
- Through these exchanges, the outputs of one industry become the inputs of another, creating closed-loop systems that enhance resource efficiency, reduce disposal costs, generate additional revenue streams, and support the transition toward a circular economy.

Thus, in food industrial symbiosis, the distinction between outputs, waste and by-products is fundamental because it determines the potential for resource recovery, cross-sector collaboration and sustainable value creation.

1.2 Resources, Flows and Constraints

The Agrifood Production Process: From Raw Material to Finished Product

The food industry depends on a wide range of inputs, including agricultural raw materials, water, energy, packaging materials, processing aids, chemicals and transportation services. During food production and processing, these resources are transformed into final products intended for human consumption, but significant quantities of secondary outputs are also generated, including solid by-products, organic waste, wastewater, packaging residues and excess heat. The nature of these by-products varies considerably according to the food subsector.

Food subsector	Main inputs	Typical by-products / waste streams	Illustrative valorisation pathway
Fruit and vegetable processing	Fresh produce, water, packaging	Peels, seeds, pomace, pulp	Pectin, antioxidants, animal feed, biofertiliser
Dairy processing	Milk, water, energy	Whey, sludge, bactofugate	Whey protein concentrate, lactose, bioethanol, biogas
Meat processing / slaughterhouses	Livestock, water, energy	Bones, blood, fats, hides, trimmings	Collagen, gelatine, biodiesel, leather (hides), animal feed
Fish processing	Raw fish, water, ice	Heads, scales, viscera, skins	Fish meal, fish oil, collagen, biostimulants
Breweries	Malted grain, hops, water, energy	Spent grain, surplus yeast, CO ₂	Animal feed, functional food ingredients, biogas, captured CO ₂ for reuse
Wineries	Grapes, water, energy	Grape pomace (marc), lees	Polyphenols, tartaric acid, distillates, compost
Bakery / confectionery	Flour, sugar, fats, packaging	Off-spec products, packaging waste, unsold bread	Animal feed, brewing feedstock, protein-rich flour

Table 1. Representative input–output profile of the agrifood sector by subsector (compiled from WP 2 desk research, survey and interview findings).

Co-Products: Illustrative Input–Output Examples

The WP 2.6 desk research and WP 2 fieldwork compiled a wide inventory of concrete co-production examples already documented within the sector, illustrating the diversity of valorisation pathways available at different points of the value chain, from the earliest processing stages (highest value, widest range of uses) to end-of-line residues (lower value, narrower range of uses):

Material input	Output / valorisation
Brewer's spent grain (BSG)	Animal feed, protein-rich flour and fibre ingredients, biogas, bioethanol
Dairy whey (sweet and sour)	Whey protein concentrate, lactose, infant-formula ingredients, bioethanol
Fruit and vegetable peels, seeds, pomace	Pectin, antioxidants, essential oils, animal feed, biofertiliser
Grape pomace (marc) and lees	Polyphenols, tartaric acid, distillates, compost
Tomato-processing waste (cutin)	Coatings for tinplate packaging used within the tomato supply chain
Poultry feathers	Keratin for antimicrobial textile fibres (pilot, Slovenia)
Used cooking oil	Biodiesel
Bones, blood and fat from meat processing	Collagen, gelatine, animal feed, biodiesel
Cold-cut trimmings (cured and cooked)	Filled pasta industry raw material (Trascinelli, Italy)
Municipal and industrial wastewater	Reclaimed water for irrigation (Regulation (EU) 2020/741); recovered energy

Table 1bis. Illustrative co-production examples across the agrifood value chain (compiled from WP 2 desk research and fieldwork).

Rather than being treated as waste, many of these streams possess significant valorisation potential. Food by-products can be converted into animal feed, organic fertilisers, compost, bioenergy, bioplastics, biochemicals, pharmaceuticals and cosmetic ingredients. Brewer's spent grain is widely used as livestock feed and as a raw material for bioproduct development, while dairy whey has become an important source of proteins for the food and nutraceutical industries. Organic residues can also be utilised in anaerobic digestion systems to produce biogas and biomethane, contributing to renewable energy generation. The valorisation of food industry by-products represents one of the most important mechanisms for achieving resource efficiency and circularity within industrial symbiosis networks (Mirabella et al., 2014; European Commission, 2020).

The WP 2.3 survey of 30 agrifood companies across Spain, Italy and Slovenia confirms this picture empirically: 39% of respondents identified organic waste as their predominant by-product type, followed by packaging waste (29%) and wastewater (24%). Approximately 70% of surveyed companies already reuse by-products, energy or wastewater internally, most commonly through Cleaning-in-Place (CIP) water recovery, heat recovery from refrigeration compressors used to heat sanitary or process water, and the reuse of off-specification product within the same production

line. However, only 17% of by-products are currently sent for external disposal, while the remainder is retained internally, sold informally, or exchanged only occasionally — evidence that the potential for structured, external industrial symbiosis remains substantially untapped: only 9% of respondents reported a stable, long-term partnership for by-product valorisation, 37% reported formal agreements with selected partners, and 30% described their external exchanges as merely occasional and informal.

Constraints on Valorisation: Perishability, Contamination Risk and Quality Variability

The agrifood sector faces a set of material constraints that do not apply in most manufacturing IS contexts, and that determine, before any regulatory or economic question is even asked, what is physically possible. Perishability is the most fundamental: unlike the chrome shavings or spent grain that can be stored, transported, and processed over days or weeks, a significant proportion of agrifood by-products begins to degrade within hours of generation. This radically compresses the logistics window available for any exchange, and it is one of the principal reasons that geographic proximity, a success factor identified in all three country research strands, is not merely convenient but in some cases strictly necessary. The Italian academic interviewees were explicit on this point: successful valorisation in the Italian context tends to occur when transport distances are short, and ideally when processing happens at or very close to the site of generation.

Contamination risk and food safety requirements add a further layer that has no direct parallel in non-food IS. Any by-product that remains in the food chain, whether for human consumption, animal feed, or food-contact applications, must satisfy HACCP procedures, hygiene protocols, refrigerated and vacuum storage requirements, and full traceability documentation throughout the handling, storage, and transport chain. The compliance bar for food-grade or feed-grade applications is significantly higher than for energy recovery or composting, which is why the project's company interviewees consistently report a tendency to default to biogas or fertiliser as by-product destinations even when they know that a higher-value food-grade application exists in principle: the compliance infrastructure required for the higher-value pathway is simply too costly to build for the volumes involved. Companies typically avoid large inventories of raw materials and rely on short-term ordering systems aligned with actual production needs; in some cases, immediate freezing in advanced cooling systems is applied to selected products or semi-finished goods to extend shelf life, although such solutions are only suitable for specific product categories. This dynamic, technically feasible but economically unviable at current scale and compliance cost, is the dominant pattern across the WP 2.3 company interviews and should be the starting point for any training content on regulatory navigation in the agrifood IS context.

Quality variability adds a final constraint that is less visible but equally consequential. Agrifood by-products are directly shaped by the raw materials and production conditions that generate them, meaning that any variation in input materials or processing parameters translates into

variation in by-product composition, moisture content, or microbiological load. A potential IS partner on the receiving end needs consistency to plan their own operations: they cannot build a production process around a by-product feedstock whose properties fluctuate unpredictably from batch to batch. This is another reason why the monitoring gap identified in the survey (40% of companies with only basic qualitative monitoring of their waste flows, and just 7% using digitally supported systems) is such a foundational obstacle, since a company that cannot characterise and document its own by-product streams with sufficient precision and consistency cannot credibly offer those streams as a reliable industrial input to another company.

1.3 Policies and Regulatory Framework

The development of industrial symbiosis within the food industry is strongly influenced by European and national regulatory frameworks that encourage circular economy practices and sustainable resource management, but that simultaneously impose strict conditions designed to protect human, animal and environmental health.

The European Union Level

At EU level, industrial symbiosis does not operate under a single dedicated legislative instrument. Instead, it is shaped by a combination of general circular economy policy and sector-specific legislation, summarised in Table 2.

Instrument	What it establishes	Relevance for industrial symbiosis
EU Circular Economy Action Plan (CEAP, 2020) & European Green Deal	Resource efficiency, waste prevention, reuse and recycling across value chains; sustainable product design	Explicitly recognises industrial symbiosis as a strategy to keep materials and resources circulating in the EU economy
Waste Framework Directive (2008/98/EC, amended by (EU) 2018/851)	Waste hierarchy, waste prevention, recycling, recovery, disposal; distinction between waste, by-product and end-of-waste status	The single most important legal instrument for IS: under Article 5, a substance qualifies as a by-product, not waste, if further use is certain, usable without further processing beyond normal industrial practice, produced as an integral part of production, and lawful and environmentally safe
Regulation (EC) No 178/2002 – General Food Law	General principles of food safety, traceability and food business operator responsibility	Any by-product intended for further use in food or feed value chains must meet food-safety and

Instrument	What it establishes	Relevance for industrial symbiosis
		traceability requirements, directly conditioning feasibility
Regulation (EC) No 1069/2009 on Animal By-Products & Commission Regulation (EU) No 142/2011	Health rules, risk categorisation, collection, transport, processing and use of animal by-products	Highly relevant for meat- and dairy-based side streams; determines whether hides, blood, fats or offal can be valorised through feed, fertiliser, bioenergy or biomaterials, and under what safety/documentation regime
Regulation (EU) 2019/1009 on EU fertilising products	Requirements for product function categories and component materials of fertilising products	Enables recovered nutrients from agrifood residues to substitute virgin fertiliser inputs, provided quality and safety requirements are met
Regulation (EU) 2020/741 on water reuse	Minimum quality and monitoring requirements for reclaimed water used in agricultural irrigation	Basis for territorial water-symbiosis schemes linking food processors, wastewater treatment plants and irrigation communities, especially relevant in water-scarce regions such as Spain
Regulation on Packaging and Packaging Waste (EU 2025/40)	Stricter requirements on packaging reduction, recyclability, reuse systems and recycled content	Requires collaboration between producers, suppliers and waste managers to establish reuse systems and circular packaging flows
Corporate Sustainability Reporting Directive – CSRD (Directive (EU) 2022/2464)	Mandatory ESG and circular economy reporting for large companies and, increasingly, their suppliers	Creates a reporting-driven incentive for companies to document and expand resource efficiency and industrial symbiosis practices

Table 2. EU legal and policy instruments most relevant to industrial symbiosis in the agrifood sector (compiled from WP 2.4/2.6 legislative review).

The distinction between waste and by-product status carries significant practical consequences. When a residual material legally qualifies as a by-product rather than waste, its circulation is facilitated because it is not subject to the full waste-management regime, making symbiotic

exchange more economically attractive; conversely, uncertainty over classification discourages investment and creates administrative costs. Article 6 of the Waste Framework Directive additionally allows certain wastes to acquire "end-of-waste" status after recovery operations, further enabling secondary raw material markets.

National and Regional Level

At national level, Member States have adopted circular economy strategies, bioeconomy roadmaps and waste management plans that further support industrial symbiosis. In Slovenia, for example, the national Regulation on Waste and the Regulation on Packaging and Packaging Waste set out classification, record-keeping and reporting obligations, while the Food Waste Prevention Strategy and Action Plan "Respect Food, Respect the Planet" specifically supports the identification of new uses for food surpluses and by-products. Supporting instruments identified during WP 2.1 focus groups include financial incentives, grants, tax benefits, innovation funding programmes, industrial clusters and digital platforms that facilitate resource exchange and collaboration among businesses.

Focus groups show that this regulatory framework is perceived by industry as both an enabler and, more frequently, the single most significant barrier to industrial symbiosis. Across the Slovenian and cross-country focus groups and interviews, participants repeatedly identified administrative burden, cautious interpretation of EU rules, and a lack of sector-specific expertise among regulators as factors that discourage otherwise environmentally beneficial exchanges. The WP 2.3 survey confirms this quantitatively: food safety (32%) and environmental compliance (33%) were identified as the two dominant regulatory areas affecting by-product management, and administrative burden associated with permits and the cost of compliance was named as the leading type of regulatory barrier. Occupational health and safety (OSH) requirements linked to biological, chemical or process-related risks were found to be a less decisive constraint, with only 10% of respondents reporting that OSH significantly limits by-product reuse or exchange.

1.4 Cross-Sector Connections

Industrial symbiosis in the food sector relies heavily on cross-sector collaboration, enabling by-products and residual materials to be used as resources in other industries. Several connections recur consistently across the SYMBIOS research.

Inbound Connections: What Flows Into Food and Beverage Production

While the agrifood sector is best known as a generator of outbound by-product flows, it also receives inputs from other sectors that are themselves the product of industrial symbiosis elsewhere in the economy. Reclaimed water from municipal and industrial wastewater treatment, regulated under Regulation (EU) 2020/741, is increasingly used for agricultural irrigation feeding food production, particularly in water-scarce regions. Recovered nutrients from other sectors'

by-products can substitute part of the demand for virgin fertiliser inputs into agricultural production: chrome-free leather by-products, for example, are already valorised into fertilisers and biostimulants by companies such as SICIT and ILSA in the parallel leather-sector model developed under Work Package 2, illustrating a direct inbound flow from the SYMBIOS project's second target sector into agrifood's own primary production. Recovered energy and heat from other industrial processes, following the same logic demonstrated at Kalundborg (Section 1.5), can in principle supply food processing facilities located within the same industrial cluster.

Outbound Connections: Where Food and Beverage By-Products Go

By-product destinations vary by stream and by sector, and several connections recur consistently across the SYMBIOS research:

- **Food and agriculture:** organic residues from food processing are transformed into animal feed, fertilisers and soil amendments; nutrients contained in agricultural and food residues can substitute part of the demand for virgin fertiliser inputs (Regulation (EU) 2019/1009).
- **Food and energy:** organic waste is converted into biogas, biomethane and electricity via anaerobic digestion and combined heat and power systems; CO₂ captured from brewery fermentation is reused as a raw material in the chemical industry, a practice already documented in Slovenia.
- **Food and leather (agrifood–leather symbiosis):** slaughterhouses and meat-processing facilities generate hides and skins that serve as the primary raw material for leather production, representing one of the oldest and most established industrial symbiosis relationships in existence, approximately 99% of global leather production originates from hides and skins generated by the meat and dairy sectors.
- **Food and chemicals / biotechnology / pharmaceuticals / cosmetics:** by-products such as fruit peels, animal fats, protein-rich tissues, bones and connective tissue are converted into essential oils, collagen, gelatine, bioactive compounds, enzymes and biopolymers used in cosmetics, pharmaceuticals and nutraceuticals.
- **Food and construction / materials:** packaging waste and processing residues also feed into materials and coatings applications; for example, cutin extracted from tomato-processing waste has been used to develop a coating applied to the tinplate (banda stagnata) used for packaging within the tomato supply chain itself, an example given directly by an Italian academic expert interviewed under WP 2.

Modes of Collaboration and Interaction

Collaboration between food and beverage companies and their symbiotic partners ranges from informal exchange to highly structured, cluster-based cooperation. Several recurring modes were identified across the WP 2 research:

- **Direct supply between companies:** the clearest documented example is Salumificio Trascinelli Pietro Srl, which supplies selected, packaged cold-cut trimmings directly to the filled pasta industry, recovering meat-based raw materials without an intermediary.
- **Intermediaries and brokers:** particularly important for SMEs, since preserving by-product quality to access higher-value applications and negotiating supply contracts often requires specialised commercial expertise that individual companies do not have in-house (Section 2.1).
- **Industrial and territorial clusters:** multistakeholder associations such as CL.A.N., the Italian National Agrifood Cluster, and Strategic Research and Innovation Partnerships such as Slovenia's SRIP HRANA bring together companies, associations, universities and training centres around joint circular economy activity (Section 2.3).
- **Digital matchmaking platforms:** tools such as Simbylay in Spain, and the SYMBIOS Digital Platform itself, help companies identify potential partners and available resources, directly addressing the awareness gap that the WP 2 research repeatedly identifies as a binding constraint on implementation (Section 2.1).

Cost-Benefit Considerations

The economic benefits of such collaborations include reduced waste management costs, lower raw material expenditure, increased revenue from by-product sales, and improved resource efficiency; environmental benefits include reduced greenhouse gas emissions, lower landfill disposal rates, and decreased extraction of virgin resources. However, successful implementation may be constrained by transportation costs, regulatory complexity, quality-assurance requirements, market uncertainty, and the need for trust and coordination among stakeholders (Van Capelleveen et al., 2018; Pajares et al., 2023).

In Depth: Food–Leather Industry Symbiosis

The relationship between the food and leather industries represents one of the oldest and most established examples of industrial symbiosis, and is of direct strategic relevance to the SYMBIOS project since leather is the partnership's second target sector. Slaughterhouses and meat-processing facilities generate large quantities of animal hides and skins as unavoidable by-products of meat production. Rather than being disposed of as waste, these materials are collected and supplied to tanneries, where they are transformed into leather for use in the footwear, furniture, automotive, fashion and upholstery industries, ensuring that animal-derived

materials are fully utilised, reducing waste generation and maximising economic value throughout the livestock value chain (UNIDO, 2017; Buljan & Kral, 2015).

Beyond hides and skins, other meat-processing by-products can also be valorised through industrial symbiosis pathways. Animal fats and tallow generated during slaughtering and rendering are increasingly used as feedstocks for biodiesel production, oleochemicals, lubricants, soaps, detergents and other bio-based products, reducing dependence on fossil resources while creating additional revenue streams. Protein-rich residues such as connective tissues, bones, tendons and skin trimmings can be processed to extract collagen and gelatine, widely used in the food, pharmaceutical, cosmetic, biomedical and nutraceutical sectors (Lasekan et al., 2013; Gómez-Guillén et al., 2011). The successful implementation of food–leather industrial symbiosis depends on regulatory compliance, material traceability, technological capability and market demand for secondary raw materials, and is increasingly recognised as a strategic pathway for improving resource efficiency and supporting the development of circular bioeconomy systems at regional and national level.

1.5 Best Practices and Benchmark

Several documented cases, gathered both from the international literature and from the SYMBIOS project's own interviews and focus groups, demonstrate how industrial symbiosis can improve resource efficiency, reduce waste generation and create new economic opportunities within food-related industries.

Model 1. Kalundborg Symbiosis Network (Denmark)

Established over several decades, Kalundborg is widely considered the world's first industrial symbiosis system, involving a network of public and private organisations exchanging energy, water, steam, gypsum, biomass and other residual materials. Although not exclusively focused on the food sector, it remains the global benchmark for resource-sharing models applicable to agrifood industries. The system is based on the principle that the output or residual stream from one company becomes a valuable input for another, reducing resource consumption, waste generation and environmental impact while creating economic benefit for all participants.

Inputs	Outputs / Exchanged Resources
Surface water (Lake Tissø) and groundwater	Cooling water and treated wastewater
Biomass, natural gas, fuels and refinery products	Biogas, steam, waste heat, district heating, refinery gas
Industrial raw materials and electricity	Gypsum (to plasterboard manufacturers), fly ash and clinker (to cement industry)

Inputs	Outputs / Exchanged Resources
Agricultural inputs and chemicals	Sludge and fertilisers, sulphur and other by-products
Process water and organic materials	Biomass residues redirected to bioenergy or agriculture

Table 3. Major resource flows in the Kalundborg Symbiosis network (adapted from Chertow, 2007; Jacobsen, 2006).

More than twenty resource exchanges involving water, energy and materials have been developed over several decades in Kalundborg, generating significant reductions in greenhouse gas emissions, freshwater consumption, energy use and waste generation while improving economic performance for participating organisations. The success of Kalundborg is largely attributed to geographic proximity, trust-based relationships among stakeholders, long-term commitment, and the identification of mutually beneficial business opportunities, demonstrating that industrial symbiosis can evolve gradually through market-driven cooperation rather than relying solely on regulatory intervention.

Model 2. Brewer's Spent Grain (BSG) Valorisation

Within the food industry, one of the most successful examples of industrial symbiosis involves the valorisation of brewer's spent grain, the primary by-product of beer production, representing approximately 85% of total brewing by-products by volume. Rich in dietary fibre, protein, cellulose, hemicellulose and bioactive compounds, BSG has moved well beyond its traditional role as low-value livestock feed. According to the European Brewery Convention, more than 70% of brewer's spent grain produced in Europe is currently used as animal feed, through long-term partnerships between major brewers (e.g., Heineken, Carlsberg, AB InBev) and local farmers.

Higher-value pathways are increasingly documented: the Carlsberg Group's Circular Community Project in Denmark has investigated BSG as a source of dietary fibre and protein ingredients for bread, breakfast cereals, snacks and protein-enriched foods. The Belgian company Pure Grain collects BSG from regional breweries to produce protein-rich flour and fibre ingredients for bakery products, meat alternatives and pasta. Breweries in Germany, Belgium and the Netherlands supply spent grain to anaerobic digestion facilities for biogas and biomethane production; and researchers in Portugal have developed fermentation routes converting BSG into bioethanol and other bio-based chemicals. European universities have also incorporated fibres extracted from spent grain into biodegradable composites and packaging materials. The consistent availability, favourable nutritional composition and typically short transport distance of BSG explain why it is widely regarded as one of the most replicable industrial symbiosis models in the agrifood sector.

Model 3. Dairy Whey Valorisation

The transformation of dairy whey from an environmental liability into a high-value industrial resource is another frequently cited success story. Whey, generated during cheese and casein production, was historically considered a problematic waste stream because of its high organic load and disposal cost. Advances in membrane filtration, drying technologies and protein extraction have enabled the dairy industry to convert whey into whey protein concentrates and isolates, lactose, infant-formula ingredients, sports-nutrition supplements and functional foods, while residual streams are used for bioethanol production, biogas generation and microbial fermentation. Interviews conducted with dairy companies within WP 2 confirm that this transition is well under way at company level: whey is typically concentrated to around 30% dry matter and sold in liquid form, mainly for export, although demand for the material is described by industry as currently outpacing available downstream processing capacity (Smithers, 2008; Prazeres, Carvalho & Rivas, 2012).

Model 4. Fruit and Vegetable Processing By-products

Large quantities of peels, seeds, pomace and pulp are generated during juice, wine, tomato, olive oil and vegetable processing operations. These residues contain valuable compounds such as polyphenols, dietary fibres, antioxidants, pigments and essential oils. Industrial symbiosis initiatives have enabled partnerships between food processors, cosmetic manufacturers, pharmaceutical companies and biotechnology enterprises to recover these compounds for use in nutraceuticals, cosmetics, food additives and bio-based materials — for example, grape pomace from wineries is increasingly used to extract antioxidants and phenolic compounds, while citrus peels serve as sources of pectin and essential oils (Mirabella, Castellani & Sala, 2014; Galanakis, 2012).

Food waste-to-energy systems represent another highly replicable model. Across Europe, anaerobic digestion plants receive organic residues from food manufacturers, supermarkets, restaurants and agricultural producers to generate biogas and digestate. Countries such as Germany, Denmark, the Netherlands and Italy have successfully integrated food processing industries with agricultural and energy sectors through regional biogas networks (Ramos-Suárez et al., 2018).

SYMBIOS Focus Groups: Emerging National Case Studies

The WP 2 research also surfaced several concrete cases directly reported by companies and researchers interviewed in the three partner countries, illustrating how the general models above translate into local practice:

- **Italy — tomato cutin for tinplate coating:** cutin extracted from tomato-processing waste used to develop a coating applied to the tinplate (banda stagnata) used for packaging

within the tomato supply chain, an example given directly by an Italian academic expert interviewed under WP 2.

- **Italy — Agrimax and Ecolab 2 projects:** collaborative research and demonstration projects converting food waste into value-added products through biorefinery approaches, including the application of industrial symbiosis principles to municipal and agro-industrial waste streams in the Emilia-Romagna Agrifood Cluster.
- **Slovenia — CO₂ and phosphorus recovery:** capture and reuse of CO₂ emissions from breweries as a raw material for the chemical industry, and phosphorus recovery from wastewater, alongside high-value extraction of pectin, bioactive compounds and whey-derived barrier films.
- **Slovenia — feathers-to-textile fibre:** collaboration between an agrifood stakeholder and university chemistry/textile faculties to extract keratin from poultry feathers for use in antimicrobial textile fibres for sanitary and pharmaceutical materials, illustrating high-potential research-to-industry pathways that, as noted by focus-group participants, frequently fail to progress to commercial implementation.
- **Spain — meat by-products:** conversion of bones, blood and fat from the meat industry into valuable materials, fruit and vegetable by-products redirected to animal feed, and used cooking oil converted into biodiesel, reflecting a practical, market-oriented Spanish approach that prioritises geographical proximity, industrial clustering and intermediary/broker mechanisms, particularly important for SMEs.

Digital Platforms Supporting Industrial Symbiosis

Across Europe, industrial symbiosis has increasingly been promoted through dedicated regional and national facilitation programmes and digital tools identified during the SYMBIOS research, providing direct design references for the SYMBIOS Digital Platform itself (Work Package 3):

- **National Industrial Symbiosis Programme (NISP, United Kingdom):** widely recognised as one of the most successful facilitation initiatives, connecting thousands of companies and diverting millions of tonnes of waste from landfill (Laybourn & Lombardi, 2012).
- **VCG.AI (Value Chain Generator):** an AI- and machine-learning-based platform matching companies across sectors and countries on the basis of products, residuals and waste, turning waste from a cost into a revenue-generating resource.
- **CIRCI baza (Slovenia):** a digital platform for industrial symbiosis connecting companies for the exchange of secondary raw materials and the efficient management of material flows.
- **SCKG Toolkit and the Slovenian Center for the Circular Economy:** an interactive platform offering circularity self-assessment tools, a green business model design tool (Be2GreenHub), and an expert consulting and mentoring scheme for SMEs.

- **SRIP HRANA (Slovenia):** a long-term Strategic Research and Innovation Partnership for Sustainable Food Production, connecting agricultural holdings, companies, cooperatives, research institutions and investors.
- **SYMBIO project:** an EU project bringing together eight partners from six countries to build bio-based business models grounded in circularity from the design stage and industrial symbiosis.

Models That Can Be Copied

Not all of the models documented in this section are equally easy to replicate. Read together, they suggest three tiers of replicability, useful for prioritising where SYMBIOS training and matching support can have the fastest impact.

- **Direct, bilateral by-product supply (Salumificio Trascinelli Pietro srl-style):** the easiest model to replicate. Any company generating a well-characterised, food-safe by-product stream can, in principle, sell it directly to an existing downstream buyer (animal feed, filled pasta, rendering) with minimal investment, provided the material is properly documented and traceable.
- **Established single-stream valorisation (Brewer's Spent Grain, dairy whey, fruit and vegetable by-products):** readily replicable wherever the relevant processing infrastructure already exists, since buyer markets, technical know-how and, in most cases, the necessary regulatory pathway are already established; the main barrier is awareness and connection, not technology.
- **Multi-partner industrial clusters (Kalundborg-style):** the hardest tier to replicate quickly, since it requires long-term governance, trust between multiple organisations, and often public-sector or cluster-level coordination of the kind provided by CL.A.N. or SRIP HRANA; these models scale gradually rather than being adopted wholesale.

1. Direct, bilateral supply of by-products

Easy

Direct sale to an existing downstream buyer (Trascinelli Pietro srl style)
Minimal investment, mainly needs proper traceability

2. Consolidated valorization of single streams

Medium

Brewers' spent grain, whey, fruit and vegetable by-products
Infrastructure and markets exist: barrier is awareness

3. Multi-partner industrial clusters

Hard

Kalundborg-style model, coordination across many organizations
Requires long-term governance and mutual trust

What Works and What Gets in the Way

The literature identifies several critical success factors that determine the effectiveness of industrial symbiosis initiatives: strong regulatory support, stable markets for secondary raw materials, reliable availability of by-product streams, technological innovation, stakeholder engagement, geographic proximity, trust among participants, and effective communication mechanisms, with digital platforms and resource-matching tools increasingly facilitating the identification of symbiotic opportunities (Van Capelleveen et al., 2018). Despite these successes, several barriers continue to limit wider adoption: regulatory uncertainty regarding by-product classification, insufficient infrastructure, transportation costs, limited technical knowledge, lack of investment, quality variability of secondary materials, and concerns related to traceability and food safety. Social and organisational barriers, including reluctance to share information and lack of trust among stakeholders, both confirmed repeatedly during the SYMBIOS focus groups, may also impede collaboration. Consequently, policy support, capacity building, technological development and stakeholder engagement remain essential for scaling up industrial symbiosis and maximising

its contribution to the circular economy and sustainable industrial development (European Commission, 2020; Neves et al., 2020).

Chapter 2 – Knowledge and Skills for Industrial Symbiosis

If Chapter 1 establishes that industrial symbiosis in the agrifood sector is technically viable, environmentally beneficial and increasingly supported by policy, the WP 2 fieldwork consistently shows that its main bottleneck is no longer purely technological: it is the availability of the right knowledge and skills, distributed correctly across the different actors who must act together for a symbiotic exchange to occur. This chapter maps that knowledge and skills gap, drawing directly on the WP 2.3 cross-country survey (30 companies, Spain–Italy–Slovenia), the WP 2.3 deep interviews with company representatives and academic experts, and the Slovenian and Spanish focus groups (WP 2.1).

2.1 Required Knowledge and Skills

Across all data sources, the competences required to operationalise industrial symbiosis cluster into nine interconnected domains, each described below. Each domain is also mapped against the European Qualifications Framework (EQF), the ESCO classification of skills, competences, qualifications and occupations, and GreenComp, the European Sustainability Competence Framework (the full mapping is presented in Annex D). The WP 2.3 survey asked companies to rate their own level of competence in thirteen specific areas. Regulatory-framework knowledge and lean management scored highest, and energy management (ISO 50001) and Environmental Product Declarations (EPD) scored lowest, a pattern that shapes the priorities described below. Investment in training to close these gaps remains strikingly low across the sector: only 7% of surveyed companies invest in training on a regular basis, 60% do so only occasionally, and 33% do not invest in training at all, a finding that reinforces the need, discussed in Section 2.3, for training to be delivered in short, low-cost, easily accessible formats if it is to reach the majority of the sector.

Waste and By-Product Management and Regulatory Framework

EQF 4–5 · ESCO: Environmental Technician, Waste Management Manager · GreenComp: Acting for sustainability

The technical ability to characterise, classify, store, treat and document by-products and waste streams so that they can legally and safely be exchanged. This includes practical knowledge of the difference between waste and by-product status under the Waste Framework Directive, HACCP-compliant handling, refrigerated/vacuum storage, and traceability documentation, skills that companies interviewed under WP 2.3 generally describe as already present internally, but insufficiently supported by dedicated resources and time.

Resource Efficiency, LCA Assessment and Material/Energy Flow Analysis

EQF 5–6 · ESCO: Environmental Engineer, Environmental Expert · GreenComp: Embracing complexity in sustainability

The ability to map material, energy and water flows (e.g., Material Flow Analysis, energy audits) in order to identify what a company has available to offer and what it needs to source. Academic experts interviewed under WP 2.3 identified "the ability to analyse material flows" and "systems thinking" as foundational competences for any manager seeking to operationalise industrial symbiosis, while the survey results show this remains one of the weaker areas of self-assessed company competence, alongside Life Cycle Assessment (LCA) and Environmental Product Declarations, which are closely linked and both scored poorly.

Commercial Negotiation and Business Case Development

EQF 6–7 · ESCO: Environmental Expert (advisory/consultancy function) · GreenComp: Acting for sustainability

The ability to translate an environmental opportunity into a viable business case: pricing a by-product, negotiating supply contracts, and building the cost–benefit and techno-economic evaluation needed to convince internal decision-makers and external partners. Both the academic and company interviews stress this dimension: Spanish researchers, in particular, emphasised the importance of preserving by-product quality to access higher-value applications and of using intermediaries and brokers to make exchanges commercially attractive, especially for SMEs.

Networking and Partnership Building

EQF 5–7 · ESCO: cross-cutting, not tied to a single profession · GreenComp: Acting for sustainability

The relational competence to identify potential partners, build trust, and sustain long-term, often cross-sectoral, collaborations. This emerged as one of the most frequently cited gaps across all WP 2.3 sources: companies report a persistent lack of awareness of potential partners, available resources and existing by-products, and the Slovenian focus group explicitly proposed a dedicated matching platform, functioning as a "business card" for companies, as the single most requested tool.

Project Management

EQF 6–7 · ESCO: cross-cutting, relevant across all four named green professions · GreenComp: Acting for sustainability

The ability to structure, fund and steer a symbiotic initiative from idea to implementation, including navigating public and private funding calls, managing multi-stakeholder projects, and handling the administrative procedures associated with grant applications, a skill explicitly requested by focus-group participants, who noted that promising research collaborations frequently fail to progress to practical implementation. Academic experts interviewed under WP

2.3 specifically pointed to the availability of resourced, funded initial phases for innovative valorisation start-ups as a fundamental enabling condition that project management competences must be able to secure.

Problem-Solving and Systems Thinking

EQF 5–7 · ESCO: cross-cutting foundational competence · GreenComp: Embracing complexity in sustainability

The capacity to think beyond a single company's boundaries and understand how a resource generated in one process might serve a completely different industry. Academic experts interviewed under WP 2.3 repeatedly named systems thinking, sustainability knowledge and cross-sector collaboration as core competences for effective symbiosis managers, alongside "soft" innovation-oriented skills such as openness and problem-solving.

Digital Skills (Platforms, Data Analysis and ESG Reporting)

EQF 4–6 · ESCO: Environmental Technician; Environmental Protection Technologies · GreenComp: Acting for sustainability

The ability to use digital resource-matching platforms and databases, to manage and interpret sustainability data (including for ESG and CSRD reporting purposes), and to apply digital monitoring tools to track waste and by-product flows. The survey shows that only 7% of surveyed monitoring systems are digitally supported, compared with 53% relying on advanced but manual quantitative monitoring and 40% on basic qualitative tracking, indicating substantial room for digitalisation.

Side-Stream Mapping and Characterisation

EQF 4–5 · ESCO: Environmental Technician · GreenComp: Embracing complexity in sustainability

A distinct, more applied competence than general waste management knowledge: the ability to inventory, characterise and document a company's own by-product streams with the specificity needed to identify valorisation opportunities and communicate them credibly to potential partners. Academic experts interviewed under WP 2.3, particularly those based in Slovenia, singled this out as the necessary foundation of any effective industrial symbiosis model, on the grounds that a company cannot access symbiotic opportunities it has not first mapped and understood in its own operations. This distinction has a direct implication for curriculum design: side-stream characterisation deserves treatment as a standalone module rather than being folded into generic waste-management content.

Biotechnology and Advanced Valorisation Pathways

EQF 6–7 · ESCO: Environmental Expert; Environmental Protection Technologies · GreenComp: Envisioning sustainable futures

An emerging, more specialist competence area, identified primarily by Spanish academic interviewees under WP 2.3: enzymatic and microbial bioconversion processes capable of transforming low-value waste into proteins, bioactive compounds, enzymes and biopolymers;

advanced extraction and separation technologies (ultrasound, microwave, supercritical fluids, green solvents); and the integration of these techniques within biorefinery models that combine multiple technologies to maximise resource utilisation. Italian academic interviewees similarly emphasised fermentation and hydrolysis as priority valorisation pathways. While this remains specialist knowledge best suited to researchers, consultants and technical specialists, its growing relevance for high-value agrifood applications justifies its inclusion in advanced and specialist training content.

Country-Specific Perspectives from Academic Experts

The five academic interviews conducted under WP 2.3 across Spain, Slovenia and Italy reveal a degree of geographic differentiation in how researchers frame the competency agenda, which is useful for calibrating the SYMBIOS MOOC's content emphasis. Spanish researchers adopt a practical, application-driven perspective, prioritising diversification of outputs and clear commercial pathways with relatively straightforward technologies, alongside the more advanced biotechnology and extraction competences described above. Slovenian researchers foreground the more systemic and technologically advanced side of the agenda, resource recovery, energy integration and circular system design, while consistently returning to side-stream mapping as the non-negotiable starting point for any company's symbiotic journey. Italian researchers place particular weight on the knowledge-transfer gap: existing industrial symbiosis studies and technical knowledge, in their assessment, remain largely inaccessible to practitioners outside universities, and they are notably more sceptical than their Spanish and Slovenian counterparts about the extent to which EU certifications and policies have, in practice, driven symbiotic innovation, citing the complex procedures required for food-specific compliance (e.g., Regulation (EC) No 1935/2004 on materials in contact with food) as a disincentive for smaller companies. Across all three countries, however, academic interviewees converged on one point: cross-sector collaboration skills, negotiation, openness to unfamiliar partners and business models, and structured problem-solving were considered just as important as technical competence — and, in some respects, harder to teach through conventional curricula.

Summary: Where the Gap Is Widest

Competence area	Self-assessed level (WP 2.3 survey)	Strategic priority for training
Regulatory framework (waste, by-products, OSH)	High	Maintain / update as legislation evolves
Lean management and continuous improvement	High	Maintain; connect explicitly to circularity metrics

Competence area	Self-assessed level (WP 2.3 survey)	Strategic priority for training
ISO 14001 Environmental Management System	Medium–high	Maintain; use as entry point for IS content
Stakeholder engagement / inter-company collaboration for IS	Medium	Strengthen through matching and networking tools
Industrial symbiosis concepts and model	Medium	Strengthen through structured, accessible training (MOOC)
Economic assessment of circular/symbiotic solutions	Medium	Strengthen: cost–benefit and business-model training
Digital tools for monitoring and matching resources	Low–medium	Priority: platform literacy and digital monitoring
ESG data management	Medium	Strengthen in line with CSRD roll-out
Material, energy and water flow mapping (MFA)	Low	Priority training area
Life Cycle Assessment	Low	Priority training area
EPD / environmental labelling (EMAS, etc.)	Low	Priority training area
ISO 50001 Energy Management System	Lowest	Highest priority training area

Table 4. Self-assessed competence levels and training priorities, agrifood companies, Spain–Italy–Slovenia (WP 2.3 survey, n=30).

2.2 Skills by Target Group

Because the SYMBIOS Digital Platform is designed to serve lifelong learners at very different stages of their career, the knowledge and skills identified above must be translated into differentiated learning pathways for four target groups, consistent with the target-group definition adopted in the project's Grant Agreement. The EQF, ESCO and GreenComp mapping introduced in Section 2.1 and detailed in Annex D also broadly tracks this grouping: entry-level and employed-worker content clusters around EQF 4–5, while the strategic content aimed at managers clusters around EQF 6–7, providing an additional, externally recognised reference point for calibrating the difficulty and positioning of each learning pathway below.

2.2.1 Young Graduates: Entry-Level Competencies and Emerging Professional Profiles

Young graduates entering the agrifood labour market, from food science, environmental science, agricultural engineering, chemistry or business backgrounds, need a solid conceptual foundation before they can contribute meaningfully to symbiotic initiatives. Entry-level competencies include:

- understanding of circular economy and industrial symbiosis principles and terminology (by-product vs waste, cascading use, closed-loop systems);
- basic material and energy flow mapping;
- familiarity with the EU regulatory architecture (Waste Framework Directive, animal by-products Regulation, food safety law);
- introductory Life Cycle Assessment;
- digital skills in the use of sustainability data tools;
- project management skills and economic and financial skills.

The research also points to a set of emerging professional profiles for which formal qualification pathways barely exist today, but for which demand is expected to grow:

- the industrial symbiosis officer or circular economy analyst, responsible for mapping a company's side-streams and identifying matching opportunities;
- the industrial symbiosis facilitator or broker, a role of growing relevance given the consistent finding that smaller companies lack the scale and visibility to identify symbiotic partners on their own initiative;
- the sustainability/ESG reporting analyst, increasingly required as CSRD obligations extend down supply chains;
- the biorefinery/valorisation technologist, able to bridge food technology and process engineering to design higher-value uses for by-products (e.g., extraction of collagen, pectin or bioactive compounds).

Graduates entering these roles benefit from placements or internships with agrifood companies, business associations or research institutes such as those participating in SYMBIOS, which provide direct exposure to real by-product streams and regulatory practice.

2.2.2 Employed Workers (C-VET and Lifelong Learning): Upskilling and Reskilling Needs

For workers already employed in agrifood companies, quality managers, production supervisors, environmental/sustainability officers, technicians, the priority is not foundational knowledge but targeted upskilling that can be absorbed alongside full-time employment. The WP 2.3 company interviews are unambiguous on this point: companies generally consider that the necessary technical knowledge and sector-specific expertise already exist internally, and that many

employees already receive some sustainability-related training. The binding constraint is insufficient resources, limited time, and the lack of specialised competencies required to scale existing practice, rather than a lack of basic skills.

Priority upskilling needs identified through the survey and interviews include:

- energy management aligned with ISO 50001;
- Life Cycle Assessment and Environmental Product Declarations;
- digital monitoring and matching tools;
- adaptation to new production models as symbiotic practices are introduced.

The research highlights a number of specific technical and professional skills required, such as: the integration of serum concentration technology, the adoption of closed-loop CIP water systems, or the management of new categories of recovered material (such as silicone-coated paper, which has recently been introduced into recycling streams by some companies). Because these workers cannot easily leave their jobs for extended training, the most effective format combines short, modular, work-based learning units (of the kind envisaged for the SYMBIOS MOOC) with in-company mentoring and access to sector-specific databases and information-sharing platforms, both of which companies identified as current gaps.

2.2.3 Managers and Decision-Makers: Strategic Competencies and Leadership for Sustainability

Managers and decision-makers (CEOs, general managers, plant managers, sustainability directors, etc. and managers and officials in business associations and public administration) require a different, more strategic mix of competences. Academic experts interviewed under WP 2.3 converge on the view that managers need a combination of technical, strategic and collaborative competences:

- systems thinking and sustainability knowledge;
- the ability to analyse material flows;
- expertise in circular business models;
- Life Cycle Assessment and techno-economic evaluation;
- strong digital and data capabilities;
- solid regulatory understanding;
- networking and building partnerships;
- commercial negotiation.

Equally important are soft, innovation-oriented skills, cross-sector collaboration, negotiation, openness and problem-solving, that allow managers to identify and act on symbiotic opportunities, together with the strategic judgement to decide when a by-product should be prioritised for a higher-value application rather than defaulted to low-value uses such as animal feed or energy recovery.

The WP 2.3 survey confirms that companies increasingly view leadership for sustainability through the lens of external accountability: ESG and CSRD reporting requirements, and pressure from customers and supply-chain partners, are already reshaping managerial priorities around waste management and circularity, even where regulatory detail remains, in the perception of many respondents, unclear or subject to frequent change. Managers therefore also need negotiation and partnership-building skills specific to industrial symbiosis: structuring long-term supply agreements for by-products, engaging with industrial clusters and sectoral associations, and building the internal business case for investment in valorisation infrastructure.

2.2.4 Unemployed and Disadvantaged Groups: Reskilling Pathways and Labour Market Reintegration

The SYMBIOS target-group explicitly includes unemployed people and individuals with fewer opportunities, including women seeking a career in STEM, workers over 50 at risk of skills obsolescence, and jobseekers whose previous skills have become less relevant to the green transition. For this group, the priority is an accessible, non-formal entry point into the green economy that does not assume prior technical background:

- basic circular economy and industrial symbiosis literacy,
- an understanding of the emerging green job market (waste sorting and characterisation, quality control of recovered materials, entry-level roles in valorisation or recycling operations),
- confidence in using simple digital tools such as resource-matching platforms.

Because the SYMBIOS MOOC will be designed as an open, free-of-charge, asynchronous and self-paced learning tool with no entry requirements, it is particularly well suited to this group: individuals can study at any time, without a fixed schedule, and combine self-development with active jobseeking. Reskilling pathways for this group benefit from being explicitly linked, wherever possible, to local labour-market intermediaries (public employment services, chambers of commerce, training bodies) that can translate MOOC completion into a concrete next step (an internship, a vocational course, or a direct connection to companies seeking entry-level green skills) through the SYMBIOS Community Section.

2.3 Training Tools and Recommendations

Existing Training Programmes and Support Mechanisms

Several existing programmes, identified through the SYMBIOS national research across all three partner countries, already provide partial models for how industrial symbiosis training and support can be delivered, and offer valuable design references for the SYMBIOS Digital Platform. Slovenia offers the most developed national ecosystem of dedicated circular economy support tools, described below; Italy and Spain instead offer strong existing institutional and research infrastructures, regional industrial clusters, VET foundations and applied research centres, on which sector-specific industrial symbiosis training can be built, even though a dedicated IS platform comparable to the Slovenian model does not yet exist in either country.

- **SRIP HRANA (Slovenia):** a long-term Strategic Research and Innovation Partnership for Sustainable Food Production, connecting agricultural holdings, companies, cooperatives, research institutions and investors around joint R&D activity in the agrifood sector.
- **The Slovenian Center for the Circular Economy and its SCKG Toolkit (Slovenia):** an interactive platform offering circularity self-assessment tools, a green business model design tool (Be2GreenHub), and a public call for individual expert consulting and mentoring targeted specifically at SMEs. The Center also runs a public call for the inclusion of green solution providers in the SCKG database, a national directory giving companies and other stakeholders easy access to circular technologies, products and services.
- **CIRCI baza and VCG.AI (Slovenia):** digital matching platforms connecting material suppliers and recipients, directly comparable in purpose to the Community Section planned for the SYMBIOS Digital Platform.
- **The Slovene Enterprise Fund's ESG Voucher and Online Self-Assessment Tool (Slovenia):** financial and self-assessment support for SMEs preparing sustainability reports and evaluating their sustainability orientation.
- **Slovenian Bioeconomy Hub (Slovenia):** a national initiative bringing together academia, ministries, companies and the agricultural, forestry and food sectors to transform waste and by-product streams into high-value bio-components.
- **CL.A.N. – the Italian National Agrifood Cluster (Italy):** a multistakeholder association bringing together companies, sectoral and territorial associations, universities, research organisations and training centres operating in the agrifood sector. Within CLAN activities, project partner Cisa Parma took part in 2022 in the design and implementation of an experimental training model on "Circular Bioeconomy in agrifood: scenarios, frontiers & success stories", targeting companies and associations within the Cluster, a direct institutional precedent for the kind of sector-specific training the SYMBIOS MOOC is designed to deliver at EU scale.

- **ITS Tech & Food Foundation and Fondimpresa-funded upskilling calls (Italy):** Cisita Parma is a founding member of the ITS Tech & Food Foundation (EQF 5), which manages two-year higher technical courses in Food Technology and Food Development, and has delivered several Fondimpresa-funded worker-training calls directly relevant to circular and green skills, including "New skills for carbon neutral companies" and "Clean Solutions & Green Training", supporting local companies investing in energy efficiency, clean production and waste management.
- **Simbylay (Spain):** a digital platform highlighted by participants in the SYMBIOS Spanish focus group as a valuable existing tool to match waste producers with potential users, enable direct contact between companies, provide geographic localisation, and increase awareness of cross-sector opportunities.
- **IATA-CSIC's long-standing food technology training tradition (Spain):** as a pioneering Food Science institute, IATA-CSIC organised and hosted the highly regarded Specialization Course in Food Technology, which was fundamental in the professional training of numerous food scientists in Spain for over 30 years, and continues to integrate IATA researchers into graduate and postgraduate teaching at several Spanish and international universities.

These existing tools and institutions demonstrate a consistent pattern across all three countries: the most valued forms of support combine:

- A. an accessible knowledge base, research infrastructure or self-assessment tool,
- B. a matching or networking function,
- C. some form of tailored expert consulting, mentoring or applied training, particularly for SMEs that lack in-house sustainability expertise.

The Slovenian ecosystem is currently the most complete on the matching and self-assessment dimensions, while the Italian and Spanish examples are strongest on applied, sector-specific technical training and research infrastructure, confirming that the SYMBIOS Digital Platform, by combining a Learning Section with a Community/matching Section, is designed to close the gap between these two, currently separate, strands of support.

A Systematic Review of Existing Industrial Symbiosis Learning Offers

Beyond these national Slovenian programmes, the SYMBIOS partner UPT conducted a wider, structured review covering the period 2015–2026 to identify existing learning offers worldwide whose primary educational objective is specifically the development of Industrial Symbiosis competences, deliberately excluding courses that treat IS as only one topic within a broader circular economy or sustainability curriculum. Using a purpose-built Industrial Symbiosis Learning Offer Analysis Framework (ISLOAF), which analyses each offer across five dimensions (Learning

Context, Curriculum Design, Pedagogical Approach, Assessment and Recognition, and Educational Insights), nine eligible learning offers were identified and documented. None of these nine offers is agrifood-specific, confirming that a dedicated agrifood learning pathway within the SYMBIOS MOOC fills a genuine gap rather than duplicating existing provision.

Learning offer	Provider / context	Target group	Delivery duration /	Certification
Industrial Symbiosis Facilitator Training Program	INSIGHT Consortium (Erasmus+)	Multiple profiles	Blended, 150h	6 ECVET credits
Industrial Symbiosis Joint Curriculum / Live Course	INSET Consortium (Erasmus+)	Employed workers	Blended, 100h	Professional certificate
Industrial Symbiosis Manager Curriculum and MOOC	FReINDs Consortium (Erasmus+)	Employed workers	Online, 60h	Not reported
Smart Industrial Symbiosis	University of Stavanger (HE)	Young graduates	Hybrid, 5 ECTS	University credits
Industrial Symbiosis (TKMJ38)	Linköping University (HE)	Young graduates	Campus, 6 ECTS	University credits
Industrial Symbiosis	TalTech (HE)	Young graduates	Campus, 3 ECTS	University credits
SUS0310 – Industrial Symbiosis	Steel University (industry academy)	Employed workers	Online, ~3h	Professional certificate
Symbiosis Training Program	Kalundborg Symbiosis / SACI	Employed workers	Blended, not reported	Certificate of participation
Industrial Symbiosis & Eco-Industrial Parks Development	Upskill Development	Employed workers	Online, 5 days	Professional certificate

Table 6. Evidence matrix of existing Industrial Symbiosis learning offers with IS as primary educational objective, 2015–2026 (UPT systematic review, WP 2.6).

Comparative Findings

The comparative analysis of these nine offers shows a relatively small but diverse landscape, converging on several consistent educational characteristics directly relevant to the design of the SYMBIOS MOOC. The offers fulfil four principal educational purposes (academic education, facilitator development, manager development, and continuing professional development) and

address the same three learner groups prioritised in Section 2.2: young graduates (typically through higher-education modules of 3–6 ECTS), employed workers (typically through Erasmus+-funded blended programmes or short industry-academy courses), and professionals acting as facilitators or managers. Curriculum design is predominantly modular, built around explicitly defined learning outcomes, with common topics including IS principles, opportunity identification, stakeholder collaboration, implementation strategies, and analysis of real IS cases. Pedagogically, case-based learning is the dominant methodology across all contexts, complemented by project work and collaborative learning; assessment and certification vary by context, from ECTS credits for university courses to ECVET credits and professional certificates for Erasmus+ and industry programmes, with Erasmus+ projects generally providing the richest public documentation of learning outcomes and materials.

Learning Methodologies

Consistent with the needs identified across target groups, the SYMBIOS partnership recommends a blended methodological approach combining:

- **Work-based learning:** short, self-contained modules that employed workers can complete alongside their jobs, directly addressing real by-product streams and processes within their own company (e.g., mapping one's own production line's inputs and outputs as a practical exercise).
- **Experiential and case-based learning:** use of documented best practices (Kalundborg, brewer's spent grain, dairy whey, fruit and vegetable by-products, food–leather symbiosis, and the national case studies identified in Section 1.5) as concrete teaching material, allowing learners to see how abstract concepts translate into operational reality.
- **Self-assessment and quizzes:** to allow learners to verify their own understanding and progress at their own pace, consistent with the asynchronous, non-formal design of the SYMBIOS Digital Platform.
- **Peer networking and community-based learning:** supported through the Community Section of the Platform, allowing learners, particularly managers and young graduates, to connect directly with companies, business associations and researchers active in the field.
- **Mentoring and guidance:** particularly important for SMEs and for unemployed or disadvantaged learners, following the model already implemented in Slovenia through the SCKG's public call for individual expert consulting.

Recommendations for VET Providers

The findings set out in this chapter translate into a compact set of design principles for VET providers responsible for designing and delivering industrial symbiosis training in the agrifood sector.

- **Adopt a competence-oriented approach, following the pattern identified across the nine existing Industrial Symbiosis learning offers reviewed by UPT:** design curricula around clearly defined competences and identifiable professional profiles (e.g., Industrial Symbiosis Facilitator, Manager, Practitioner) rather than around disciplinary knowledge alone.
- **Prioritise training content on the areas of lowest self-assessed competence identified by the WP 2.3 survey:** energy management (ISO 50001), Life Cycle Assessment, Environmental Product Declarations, and material/energy/water flow mapping, since these represent the clearest and most consistent skills gap across the three partner countries.
- **Design short, modular, work-based learning units rather than long-form courses:** to match the time constraints repeatedly cited by employed workers and SMEs as the main barrier to training uptake.
- **Embed regulatory literacy, specifically the practical distinction between waste and by-product status:** and the animal by-products and food-safety frameworks, as a cross-cutting theme throughout the curriculum, since regulatory uncertainty was identified as the most significant single barrier to industrial symbiosis across all WP 2 data sources.
- **Pair every learning pathway with a matching/networking function:** (as in the SYMBIOS Community Section), since the research consistently shows that lack of awareness of potential partners and available resources, not lack of technical knowledge, is often the binding constraint on implementation.
- **Differentiate content explicitly by target group (Section 2.2):** rather than offering a single generic course, ensuring that young graduates receive foundational and career-orientation content, employed workers receive targeted upskilling modules, managers receive strategic and leadership content, and unemployed/disadvantaged learners receive a genuinely accessible, no-prerequisite entry point.

Recommendations for Policy Makers

Policy makers shape the funding, recognition and regulatory conditions under which VET providers operate; the two recommendations below are addressed to national and regional authorities, and to the European Commission and its agencies, and are complemented by two further, cluster- and provision-related recommendations synthesised from the evidence in this model.

- **Support cluster-based and territorial infrastructure:** specific funding instruments, such as the upskilling calls for proposals funded by Fondimpresa, or best practices in networking, such as the Italian C.L.A.N. cluster or the Slovenian SRIP HRANA partnership (Section 2.3), which help to reduce the risks associated with cooperation for SMEs that are unable, on their own, to justify the investment in shared training or matching infrastructure.

- **Expand specialised educational provision:** the UPT systematic review found that none of the nine existing Industrial Symbiosis learning offers identified worldwide is agrifood-specific (Section 2.3), representing a clear opportunity for policy-driven expansion of sector-specific provision.
- **Recognise learning outcomes against European reference frameworks:** in line with national qualification frameworks referenced to the EQF, the ESCO classification of skills, competences and occupations (including green professions such as Waste Management Manager, Environmental Engineer, Environmental Technician, and green knowledge areas such as Environmental Protection Technologies), and GreenComp, the European sustainability competence framework, so that certificates of attendance or completion issued through IS-specific courses carry recognised value.
- **Provide funding and administrative support for project development:** since a recurring request from industry stakeholders — echoed by both companies and focus-group participants, is easier access to funded pilot phases for symbiotic start-ups and clearer guidance on project applications and administrative procedures.

Taken together, these ten principles describe a training offer that is modular rather than monolithic, practically oriented rather than purely disciplinary, and explicitly connected to a matching function rather than delivered in isolation, precisely the model the SYMBIOS Digital Platform's Learning and Community Sections are designed to embody.

Conclusions

Summary of Key Findings

The combined findings from the WP 2.3 survey, company interviews and academic expert interviews provide a comprehensive overview of the current state of circular economy practice and industrial symbiosis in the European agrifood sector, with evidence drawn from Spain, Italy and Slovenia. Companies are increasingly aware of sustainability and circular economy principles and have made measurable progress in implementing internal circular practices, particularly in waste management, environmental compliance, packaging optimisation, water efficiency, energy recovery and by-product valorisation: the widespread adoption of internal reuse practices and compliance with standards such as ISO 14001 demonstrate a genuine shift toward more resource-efficient production systems.

Despite this progress, the implementation of industrial symbiosis beyond company boundaries remains limited. Stable, long-term collaborations for by-product exchange and cross-sector resource sharing are still relatively uncommon, reflecting persistent structural, regulatory and economic barriers. Regulatory complexity, administrative burden, uncertainty surrounding waste classification, food safety and traceability requirements, and the intrinsic perishability of food by-products all constrain the development of broader industrial symbiosis networks. The relatively small quantities of by-products generated by many companies, especially SMEs, often limit the economic feasibility of collection, transport, storage, testing and certification without external financial support.

The research also identifies significant organisational and knowledge-related challenges. Survey results reveal important skills gaps in technical, regulatory and digital competencies, particularly in energy management (ISO 50001), Life Cycle Assessment, Environmental Product Declarations, and advanced circular economy methodologies. Limited investment in employee training further restricts companies' ability to adopt more sophisticated circular business models and industrial symbiosis practices. Expert interviews reinforce these findings by emphasising the need for specialised technical expertise, digital tools for side-stream mapping and matchmaking, and stronger knowledge transfer between academia and industry.

At the same time, the study highlights numerous opportunities for accelerating industrial symbiosis within the food sector. Companies and experts consistently identified stronger inter-company partnerships, digital collaboration platforms, accessible databases for by-product exchange, clearer and more harmonised regulatory frameworks, and improved policy support as key enablers. Technological innovation, including biotechnology, biorefineries, advanced extraction technologies and resource recovery systems, was recognised as offering significant potential to transform food-sector residues into high-value products while improving resource efficiency and

reducing environmental impact. Growing ESG commitments, sustainability certification requirements and evolving European circular economy policy are also expected to further encourage investment in circular solutions.

Although each participating country demonstrates different strengths and priorities, Spain emphasising practical implementation, industrial clusters and market-oriented collaboration; Slovenia focusing on technological innovation and high-value resource recovery; and Italy highlighting applied research, pilot projects and regional innovation ecosystems (notably the Emilia-Romagna Agrifood Cluster), a common vision emerges: successful industrial symbiosis requires the integration of technological innovation, practical business models, supportive governance and collaborative networks.

Future Opportunities for the Sector

The barriers described above are real, but they are not, for the most part, technological. Almost every opportunity identified through the WP 2.3 research is a case of a solution that already exists somewhere in the sector, piloted in one country, one company, or one supply chain, waiting to be connected, funded, or simply made visible to the companies that could use it. The five opportunities below are therefore framed deliberately as near-term, actionable possibilities rather than long-range aspirations.

- Scaling from isolated best practice to systemic behaviour: most documented symbiotic exchanges in the agrifood sector today remain project-based and dependent on individual initiative rather than embedded in long-term business strategy. The clearest opportunity is to convert these into standard operating practice, supported by stable partnerships and long-term contracts.
- Unlocking under-used high-value streams: whey, brewer's spent grain and animal by-products are already well-valorised in several countries, but streams such as feathers/keratin, fruit and vegetable pomace bioactives, and slaughterhouse residues currently exported abroad rather than valorised domestically (as reported in Slovenia) represent significant untapped domestic opportunity.
- Extending water and energy symbiosis: reclaimed-water schemes under Regulation (EU) 2020/741 and CO₂ capture/reuse pathways already piloted in the brewing sector offer considerable potential for replication, particularly in water-scarce regions.
- Digitalisation of matching and monitoring: the low current uptake of digital monitoring (7% of surveyed companies) and matching tools represents the single largest opportunity for near-term improvement, which will be directly addressed by the SYMBIOS Digital Platform's Community Section.

- Strengthening the agrifood–leather symbiosis corridor: as the SYMBIOS project's two target sectors, agrifood and leather already share one of the oldest symbiotic relationships in industry (hides and skins); explicit cross-sectoral training and matching between the two SYMBIOS sector communities is a natural next step.

What unites these five opportunities is that none of them depends on a technological breakthrough still to come: the enabling knowledge, the regulatory basis, and in most cases a working example, already exist somewhere within the evidence gathered for this model. The task ahead is one of connection, replication and scale, which is precisely the gap the operational recommendations below are designed to help close.

Operational Recommendations

This model is written to be used, not only read. The recommendations below are addressed directly to you, whoever you are as you reach this page, a company representative exploring your own by-product streams for the first time, a student or jobseeker considering a career in the circular economy, a trainer or VET provider designing a course, an association or cluster officer, or a policy maker, rather than to the SYMBIOS partnership alone. Each one is a practical starting point, grounded in the evidence of this model, for turning an understanding of industrial symbiosis into action; the SYMBIOS Digital Platform will be designed to be the first concrete resource for taking any of the steps below.

- If you work in an agrifood company: begin with an internal material/energy/water flow mapping exercise to identify currently under-valorised streams, using the WP 2.3 self-assessment areas in Table 4 as a checklist; prioritise turning informal, occasional exchanges into stable partnerships and long-term contracts.
- If you represent a business association, industrial cluster, or sectoral network: you are well placed to play the trusted-intermediary role that this research shows is often missing, connecting companies, particularly SMEs, that lack the in-house capacity to search for symbiotic partners on their own.
- If you train, teach, or design educational programmes: adopt the differentiated, target-group-specific approach described in Chapter 2, delivered through short modular units, and seek recognition against the EQF, ESCO and GreenComp reference frameworks so that what learners gain is portable and credible.
- If you shape policy or regulation: prioritise improving regulatory clarity and consistency of interpretation regarding by-product versus waste classification, since this was identified as the single most significant barrier across all data sources. Look for ways to de-risk the early, pilot phase of new symbiotic initiatives through targeted funding instruments.

- If you are a student, recent graduate, or jobseeker curious about this field: you do not need a technical background to start. The SYMBIOS MOOC (Work Package 3.1) will be designed as a free, self-paced entry point with no prerequisites, use it to build the foundational knowledge and skills mapped in Section 2.2, and use the Community Section to connect with the companies and organisations named throughout this model.

None of these steps requires waiting for ideal conditions or a finished regulatory framework. The evidence gathered for this model shows, repeatedly, that the binding constraint on industrial symbiosis in the agrifood sector is more often a lack of awareness, mapping, or connection than a lack of technology or willingness, which means that reading this document and taking one of the steps above is, in a very concrete sense, already a contribution to closing that gap.

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Annexes

Annex A – Glossary

Term	Definition
Industrial symbiosis (IS)	A collaborative approach in which traditionally separate industries exchange materials, energy, water, services and information to improve resource efficiency and reduce environmental impact (Chertow, 2000).
Circular economy	An economic model in which the value of products, materials and resources is maintained in the economy for as long as possible, minimising waste generation.
By-product	A secondary material generated during a production process that has a certain and lawful further use without requiring significant additional processing (Waste Framework Directive, Art. 5).
Waste	A material that the holder discards, intends to discard, or is required to discard under regulatory frameworks.
End-of-waste status	The point at which certain wastes cease to be considered waste after undergoing recycling or another recovery operation, subject to specified conditions (Waste Framework Directive, Art. 6).
Cascading use	The sequential use of a resource across successive applications, from highest to lowest value, before final disposal or energy recovery.
Valorisation	The process of converting a waste or by-product into a material or product of economic value.
Life Cycle Assessment (LCA)	A methodology for assessing the environmental impacts associated with all stages of a product's life, from raw material extraction to disposal.
Environmental Product Declaration (EPD)	A standardised, verified document communicating transparent and comparable information on the life-cycle environmental impact of a product.
Material Flow Analysis (MFA)	A systematic assessment of the flows and stocks of materials within a system defined in space and time.
Industrial cluster	A geographic concentration of interconnected companies, suppliers and associated institutions in a particular field, facilitating cooperation and resource sharing.

Term	Definition
ESG / CSRD	Environmental, Social and Governance reporting criteria; CSRD (Directive (EU) 2022/2464) is the EU directive mandating corporate sustainability reporting.
ESCO	The European Skills, Competences, Qualifications and Occupations classification, a multilingual classification used across the EU to describe skills, competences, qualifications and occupations.
GreenComp	The European Sustainability Competence Framework (European Commission, January 2022), describing the key competences needed to act in an environmentally sustainable way.
EQF	The European Qualifications Framework, a common reference framework linking national qualification systems across Europe.

Annex B – Overview of Data Collection Instruments (Surveys and Interviews)

B.1 Focus groups (WP 2.1)

Slovenia: six participants (SRIP HRANA advisor; sustainability/animal welfare expert, Ljubljanske Mlekarne; EMONA RCP researcher/SRIP HRANA board chair; biotechnology professor and MycoMedica founder; Director, Environment/Climate/Energy Dept., Chamber of Commerce and Industry of Slovenia; sustainability reporting expert, Mlekarna Celeia), online via Microsoft Teams, 12 December 2025, 75 minutes, led by CCIS-Chamber of Agricultural and Food Enterprises.

Spain: twelve participants from industry (8) and academia (4), facilitated by IATA-CSIC, held on 17 and 24 November 2025 at 12:00, covering current understanding of industrial symbiosis, examples of waste valorisation, barriers to implementation, the role of geography and digital platforms, and conditions for success.

B.2 Survey structure (WP 2.3)

Administered to 30 companies (10 each in Spain, Italy and Slovenia) via Google Forms, translated into partner languages and structured in five sections:

- Company profile (size, role of respondent, food subsector, markets served, certifications/standards).
- Production process (process type, by-product types generated, internal reuse practices).
- Waste management and circular practices (destination of by-products, partnership stability, monitoring sophistication).
- Regulatory barriers and constraints (regulatory areas affected, type of barrier, OSH impact).
- Skills and training needs (investment in training, skills gaps, self-assessed competence across 13 areas).

B.3 Interview protocols (WP 2.3)

Study I (food industry practitioners): six semi-structured interviews (Slovenia: 3; Italy: 2; Spain: 1), 45–60 minutes each, conducted January–May 2026, covering: company production characteristics; food-specific constraints on by-product reuse (perishability, contamination risk, shelf-life, sanitary rules); critical by-product/waste streams and strategic decision-making; internal circular practices; external pressures (ESG, supply chain); missing skills/competences; and conditions needed for further development.

Study II (academic experts): five semi-structured interviews (Spain: 3; Slovenia: 1; Italy: 1), conducted January–April 2026, covering: definitions and perceptions of industrial symbiosis; best practices in waste reduction/by-product reuse; innovation trajectories (biotech, circular processing); cross-sector collaboration examples; supply/demand studies on food-processing

waste; the influence of certifications and EU policy; adoption challenges successfully addressed; conditions for further development; recommended core logic/mechanisms for the SYMBIOS model; and required managerial competences.

Annex C – Detailed Competence Framework by Target Group

Target group	Core knowledge	Core skills	Recommended entry point
Young graduates	Circular economy & IS principles; EU regulatory basics; introductory LCA	Basic MFA; digital sustainability literacy; data report writing; Project Management and economic and financial skills.	SYMBIOS MOOC general + sector-specific units; internships with agrifood companies/associations
Employed workers (C-VET)	Sector-specific by-product streams; ISO 14001/50001 basics; HACCP & traceability	Digital monitoring tools; process adaptation; basic negotiation with suppliers	Short, modular work-based learning units; in-company mentoring
Managers / decision-makers	Circular business models; techno-economic evaluation; CSRD/ESG frameworks; regulatory strategy	Negotiation; partnership building; strategic leadership; systems thinking	Strategic modules + Community Section networking; sectoral cluster engagement
Unemployed / disadvantaged groups	Basic circular economy literacy; green job market overview	Digital platform navigation; entry-level waste/quality-control skills	Open-access, no-prerequisite MOOC units; links to public employment services

Annex D – Mapping of Competences to European Reference Frameworks (EQF, ESCO, GreenComp)

As required by the SYMBIOS Grant Agreement, the nine competence domains identified in Section 2.1 are mapped below against three European reference standards: the European Qualifications Framework (EQF), the ESCO classification of skills, competences, qualifications and occupations, with explicit reference to the green professions and green knowledge area named in the Grant Agreement (Waste Management Manager, Environmental Engineer, Environmental Expert, Environmental Technician, Environmental Protection Technologies), and GreenComp, the European Sustainability Competence Framework (European Commission, January 2022), whose four competence areas (Embodying sustainability values; Embracing complexity in sustainability; Envisioning sustainable futures; Acting for sustainability) provide the structuring logic for the right-hand column. This mapping is intended to give the SYMBIOS MOOC's learning outcomes, and any certificate of attendance or completion issued through the SYMBIOS Platform, a transparent and recognised anchor in existing European frameworks, rather than a self-referential competence list.

Competence domain (Section 2.1)	Indicative EQF level	Closest ESCO reference profession(s) / knowledge area	GreenComp competence area
Waste and By-Product Management	4–5	Environmental Technician; Waste Management Manager	Acting for sustainability
Side-Stream Mapping and Characterisation	4–5	Environmental Technician	Embracing complexity in sustainability
Resource Efficiency and Material/Energy Flow Analysis	5–6	Environmental Engineer; Environmental Expert	Embracing complexity in sustainability
Biotechnology and Advanced Valorisation Pathways	6–7	Environmental Expert; specialist researcher roles linked to Environmental Protection Technologies	Envisioning sustainable futures
Commercial Negotiation and Business Case Development	6–7	Environmental Expert (advisory/consultancy function)	Acting for sustainability
Networking and Partnership Building	5–7	Cross-cutting; not tied to a single ESCO profession	Acting for sustainability

Competence domain (Section 2.1)	Indicative EQF level	Closest ESCO reference profession(s) / knowledge area	GreenComp competence area
Project Management	6–7	Cross-cutting; relevant across all four named green professions	Acting for sustainability
Problem-Solving and Systems Thinking	5–7	Cross-cutting foundational competence	Embracing complexity in sustainability
Digital Skills (Platforms, Data Analysis and ESG Reporting)	4–6	Environmental Technician; Environmental Protection Technologies	Acting for sustainability

Table 7. Mapping of the WP 2.6 agrifood competence domains to EQF, ESCO and GreenComp, as required by the SYMBIOS Grant Agreement (WP 2.6 quality indicators).

Read alongside Table 4 (self-assessed competence levels) and Annex C (competence framework by target group), this mapping shows that the domains where company self-assessed competence is lowest, resource efficiency/flow analysis, biotechnology-adjacent valorisation, and digital skills, cluster mainly around EQF levels 5–7 and around the "Embracing complexity in sustainability" and "Acting for sustainability" GreenComp areas, reinforcing the priority given to these domains in the recommendations in Section 2.3.

End of document.