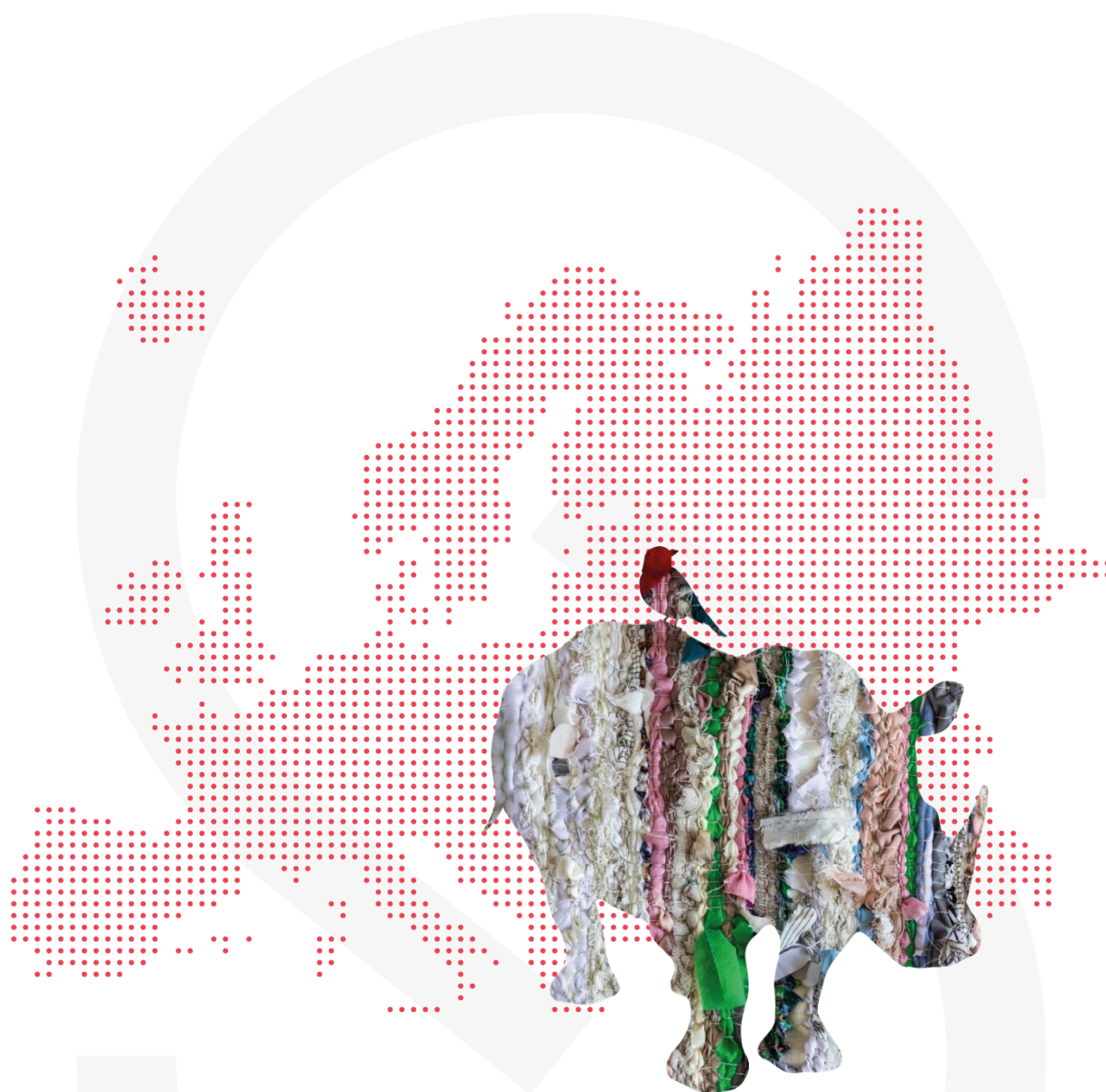




D3.1. Report on existing training and future learning framework related to
Industrial Symbiosis

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Project Action Context

In the context of addressing climate change, industrial sectors play a significant role as major contributors to carbon dioxide emissions, energy consumption, and waste generation. To combat these challenges, adopting a Circular Economy strategy is imperative. The Circular Economy model diverges from the traditional linear approach by promoting sustainable production and consumption practices while considering societal, environmental, and economic factors in a balanced manner.

Industrial Symbiosis (IS) emerges as a practical solution within this framework. In IS, waste or by-products generated by one industry are repurposed as resources for another, presenting opportunities for environmental sustainability and economic efficiency. Despite its potential, many companies and industrial actors lack awareness of IS, and its development is hindered by various barriers, including environmental, economic, technical, regulatory, organizational, social, and cultural challenges.

To address these issues, the LIAISE COST Action seeks to foster an inclusive and holistic IS approach. By fostering synergies among stakeholders from diverse sectors and laying the groundwork for knowledge enhancement, LIAISE COST Action aims to bridge the gap between theory and practice. This initiative will involve developing a participatory approach to support cross-sector collaborations and establishing Key Performance Indicators (KPIs) for assessing the effectiveness of IS business models in industry.

The LIAISE COST Action represents a collective effort to make Industrial Symbiosis a reality across Europe, fostering collaboration among researchers, practitioners, and policymakers. To achieve these objectives, LIAISE COST Action will leverage the expertise of four interdisciplinary Working Groups (WGs) and integrate their findings through a reference framework. This holistic approach aims to drive meaningful progress towards sustainable industrial practices and contribute to a more Circular Economy.



Executive Summary

This report constitutes Deliverable D3.1 of the LIAISE COST Action. It focuses on training and learning related to Industrial Symbiosis (IS), addressing one of the main barriers to the wider implementation of IS: the lack of knowledge and understanding of this cooperation model. Limited knowledge and access to learning resources often lead to low engagement, misunderstandings between stakeholders, and difficulties in implementing IS initiatives.

The main objective of this deliverable is to support awareness, acceptance, and engagement with the Industrial Symbiosis concept and its contribution to society at economic, environmental, and social levels. The work focuses on training and learning as key instruments to strengthen capacities across different stakeholder groups involved in IS processes. A particular strength of this deliverable lies in its methodological approach, which goes beyond a conventional review of existing literature and learning resources by combining desk research with an empirical assessment conducted among Industrial Symbiosis experts. This approach provides a broader evidence base for identifying current educational practices, competency needs, and barriers, and for informing the development of the proposed conceptual framework.

This deliverable addresses two main tasks. First, it identifies and reviews existing training content and other learning resources related to Industrial Symbiosis that are already available. The analysis covers university courses, online learning opportunities, project-based educational resources, toolkits, and other training initiatives developed at European and international levels, providing a comprehensive overview of the current educational landscape.

Second, based on the findings of the desk research, the mapping of existing learning resources and the empirical results obtained through the expert survey, the report develops a conceptual framework for future training and learning materials. Rather than proposing a single educational model, the framework is intended as a flexible reference that can support the development of relevant, practice-oriented, and transferable learning resources for different educational contexts, target groups, and professional needs within the LIAISE COST Action and beyond.

1. Introduction

Industrial Symbiosis (IS) is an integrated and sustainable industrial concept based on the identification and use of underutilized or unused resources. Within IS, resources such as materials, energy, and information are exchanged between different industrial actors in a mutually beneficial way, creating economic, environmental, and social value (Chertow, 2000). This approach enables networks of interconnected organizations to cooperate on the principles of efficient resource use, waste reduction, and process optimization, contributing to the long-term sustainability and resilience of industrial systems.

IS has been recognized by the European Union as a key element in the transition to a circular economy. Accordingly, several policies, strategies, and initiatives have been developed to foster adoption and implementation. However, broader and more effective application still requires the development of knowledge, skills, and organizational capacities, as well as continued collaboration among relevant stakeholders.

Building capacity, knowledge, and learning is therefore essential for the wider uptake of IS. Adequate knowledge allows stakeholders to understand the principles and processes of IS, identify potential resource exchanges, and establish mutually beneficial relationships. Training and learning activities help develop the skills needed to plan, coordinate, and manage IS initiatives, enabling organizations to integrate IS practices into their operations. By strengthening these capacities, risks are reduced, stakeholder engagement is increased, and the scalability of IS practices is enhanced, supporting sustainable economic, environmental, and social outcomes.

This report constitutes Deliverable D3.1 of the LIAISE COST Action initiative, focusing on the identification and analysis of existing training content and learning resources related to Industrial Symbiosis (Task 3.1), as well as the development of conceptual frameworks for future training materials (Task 3.2). In addition, the report considers the potential for creating an AI/ML-based open-source platform to support broad skills assessment, providing innovative tools to facilitate capacity building and learning across the IS community.

The activities carried out in this deliverable directly support the LIAISE COST Action's objectives, particularly RCO5 and RCO6. Task 3.1 contributes to RCO5 by synthesizing and improving existing knowledge from local, regional, national, European, and international settings, integrating diverse disciplinary perspectives, and providing a coherent overview to support the design of IS synergies. At the same time, this task supports RCO6 by establishing the foundation for a collaborative platform that links the IS community, offering access to training materials, peer-to-peer communication tools, reports, and other documentation to strengthen engagement and knowledge sharing.

1.1. Objectives of the Report / Deliverable D3.1

This report constitutes Deliverable D3.1 of the LIAISE COST Action. Its primary purpose is to provide a structured and comprehensive overview of training and learning resources related to Industrial Symbiosis (IS), as well as to define conceptual frameworks for the development of future training materials.

Specifically, Deliverable D3.1 addresses the following objectives:

1. Mapping existing training content and learning resources (Task 3.1)

- Systematically identify and review existing knowledge and skills requirements for effective participation in Industrial Symbiosis, based on academic literature and relevant policy frameworks
- Systematically identify and review available courses, platforms, project-based resources, and other learning initiatives on Industrial Symbiosis at local, regional, national, European, and international levels.
- Highlight the scope, formats, target audiences, and thematic focus of these resources, and identify gaps or limitations.

2. Developing conceptual frameworks for future training materials (Task 3.2)

- Propose structured approaches for designing new training resources that are accessible, effective, and tailored to the needs of diverse stakeholders involved in IS.
- Support the creation of coherent learning pathways that enhance knowledge, skills, and capacities across industrial, policy, and academic actors.

3. Exploring the potential of AI/ML-based tools for skills assessment

- Explore how AI/ML-based tools could support the identification, assessment, and profiling of competencies relevant to Industrial Symbiosis.
- Examine the potential for linking skills assessment with competency gaps and personalised learning pathways, while considering the technical, data, ethical, and governance requirements of future solutions.

Through these objectives, Deliverable D3.1 aims to strengthen knowledge sharing, improve training effectiveness, and facilitate the broader uptake of Industrial Symbiosis practices, while laying the groundwork for future learning initiatives within the LIAISE COST Action.

The added value of this report lies in the fact that its conclusions and the proposed conceptual framework are not based solely on literature review and analysis of existing educational resources. In addition to desk research, the report includes an empirical analysis conducted among experts in the field of Industrial Symbiosis, providing insights into current educational practices, priority competencies, and key challenges for the development of future learning programmes. By combining theoretical knowledge, an overview of existing educational solutions, and expert perspectives, this report provides an evidence-informed basis for the development of future educational and training materials in the field of Industrial Symbiosis.

2. Scope and methodology

2.1. Scope of the report

This report focuses on identifying gaps and needs in the field of education and training for Industrial Symbiosis (IS), with the aim of contributing to the development of a future learning framework that can support the creation of relevant and applicable educational and training materials. The proposed framework is intended to address the needs of different stakeholders, including policymakers, industrial organisations, educational institutions, and other actors involved in circular economy processes, both at the European and wider international level.

The report is based on a comprehensive analysis of existing knowledge, experiences, and available resources related to education and training in Industrial Symbiosis. Its development combines various sources of information, including a review of relevant literature, analysis of existing educational and training materials, overview of available programmes and initiatives, as well as the collection of perspectives and experiences from experts and other relevant stakeholders. This approach enables an understanding of the current state of education and training in IS, identification of existing gaps, and definition of areas requiring further development of educational content and learning models.

The analysis covers formal, non-formal, and online forms of education and training related to Industrial Symbiosis. It includes university programmes and courses, educational activities developed within European and international projects, as well as digital platforms and online courses contributing to knowledge and skills development in this field. In this way, the report provides an overview of different learning approaches, ranging from institutionalised education to flexible and project-based competence development models.

The geographical scope of the report primarily covers the European context, while also considering relevant international examples. Considering that Industrial Symbiosis is a globally applicable concept developed across different regional and institutional settings, international practices are used as a comparative basis for a broader understanding of approaches to education and capacity building in this field.

Regarding target groups, the analysis includes students, academic staff, industry professionals, and other stakeholders involved in sustainability, resource management, and the transition towards a circular economy. These groups also represent potential users and beneficiaries of future educational content and learning models.

It is important to emphasise that this report does not represent an evaluation of existing courses, programmes, or training materials, nor does it aim to measure learning outcomes or rank existing educational solutions. Instead, its purpose is to provide an overview of the current situation, map the existing educational landscape, and identify key gaps that can serve as a basis for the future development of educational content and learning models in the field of Industrial Symbiosis.

2.2. Methodology

The methodological approach applied in the preparation of this report is based on the combination of different data sources and complementary research activities, enabling a multi-perspective understanding of education and training in the field of Industrial Symbiosis (IS). This approach allows not only the identification and analysis of existing educational resources but also a broader

understanding of the context in which knowledge and skills related to Industrial Symbiosis are developed, transferred, and applied.

The research conducted for the purpose of this report is primarily exploratory and descriptive in nature, focusing on the identification of existing patterns, needs, and gaps rather than on statistical evaluation or hypothesis testing. Quantitative data are used to support the analysis, while the interpretation of findings is mainly qualitative, with the aim of identifying key thematic and structural insights relevant for the development of a future learning framework.

The methodological framework includes three complementary research activities, each addressing a different dimension of Industrial Symbiosis education and training. These activities include: (1) mapping of existing training and learning resources related to Industrial Symbiosis, (2) assessment of the current integration of Industrial Symbiosis content within higher education curricula, and (3) identification of relevant knowledge areas, skills, and competencies required for effective participation in Industrial Symbiosis processes.

2.2.1. Mapping existing training and learning resources on Industrial Symbiosis

As part of the research activities conducted for this report, a structured exploratory mapping of existing training and learning resources related to Industrial Symbiosis was performed. The objective of this activity was to identify and consolidate available educational materials, training initiatives, online courses, toolkits, and project-based learning resources developed at various levels (local, national, European, and international). The mapping included resources originating from academic institutions, EU-funded projects, research initiatives, and other relevant stakeholders involved in sustainability and circular economy education.

A structured database was developed to ensure a consistent and comparable description of each identified resource. For this purpose, a predefined set of descriptors was applied, enabling categorisation of materials according to their main characteristics. The analysed criteria included the type of resource (e.g. online course, toolkit, training/workshop, academic module), delivery format (online, on-site, self-paced), target group, educational level, geographic scope, key content characteristics, and identified gaps.

The purpose of this structured approach was not only to catalogue available resources but also to enable a comparative analysis of their key features, thematic focus, and educational orientation. In this context, the mapping provides insight into how Industrial Symbiosis is currently represented in different learning environments, including formal, non-formal, and project-based education, as well as how available resources address different target groups and levels of expertise.

Importantly, the mapping was not intended to provide a comprehensive evaluation of individual training programmes or to assess their learning outcomes. Instead, its purpose was to provide an overview of the existing educational landscape and identify emerging patterns related to content focus, delivery approaches, target audiences, and areas requiring further development.

The results of this mapping exercise are presented in Section 3, where the main characteristics of the identified resources are analysed in detail, together with the key gaps and limitations observed across the dataset.

2.2.2. Survey on Industrial Symbiosis content in higher education curricula

To complement the findings obtained through the mapping of existing training and learning resources, a targeted survey was conducted among academic and training institutions to gain deeper insight into the presence and integration of Industrial Symbiosis (IS) within formal higher education curricula.

While the mapping activity focused primarily on publicly available training materials and project-based educational resources, it also provided an indication of the visibility and availability of educational content specifically addressing Industrial Symbiosis. This highlighted the need to further explore how and to what extent IS is embedded within structured educational programmes at universities and other higher education institutions.

The survey was designed to capture the extent and modes of IS integration within curricula, as well as the knowledge areas, skills, target groups, and challenges associated with its implementation. It examined whether Industrial Symbiosis is offered as a dedicated course or integrated within broader subject areas such as circular economy, industrial ecology, environmental management, or related disciplines. In addition, the survey explored the educational levels at which IS-related content is delivered, including undergraduate and postgraduate programmes, doctoral studies, and lifelong learning initiatives.

A further objective of the survey was to assess the depth and intensity of IS coverage within curricula, distinguishing between introductory exposure to the topic and more comprehensive integration through dedicated courses or modules. This enabled a more detailed understanding of whether Industrial Symbiosis is primarily addressed as an emerging sustainability concept or developed as a structured area of knowledge and competence development.

The survey also examined the knowledge domains and competencies associated with Industrial Symbiosis education, including circular economy principles, resource efficiency, industrial ecology, material flow analysis, and sustainability assessment, as well as transversal skills such as systems thinking, interdisciplinary collaboration, and analytical problem-solving. This provided insight into the extent to which current IS education reflects broader sustainability and innovation competence frameworks.

Furthermore, respondents were asked to identify the main target groups of IS-related educational activities, including engineering students, environmental science students, business and policy students, postgraduate researchers, and industry professionals. This dimension was included to assess the interdisciplinary scope and reach of Industrial Symbiosis education within higher education institutions.

Finally, the survey explored the main barriers and challenges affecting the integration of Industrial Symbiosis into curricula, including lack of expertise, limited availability of teaching materials, insufficient institutional support, and curriculum constraints. Respondents were also asked about future perspectives regarding the expansion or introduction of IS-related educational activities.

The survey was distributed by email to all WG3 members between May and June 2026. Of the 68 responses received, 64 were considered valid, while four incomplete responses were excluded. Detailed questions on existing IS provision were completed by the 39 respondents who reported its presence in their curricula, whereas all valid respondents were able to complete the remaining

sections of the questionnaire. Participation was voluntary, and the responses were collected anonymously and analysed in aggregate form.

Overall, the survey provides a complementary evidence base to the mapping of existing educational resources, enabling a more comprehensive understanding of the current position of Industrial Symbiosis within formal education systems and the institutional, structural, and pedagogical factors influencing its further development.

2.2.3. Identification of knowledge areas, skills, and competencies relevant for Industrial Symbiosis education

In addition to questions concerning the presence and integration of Industrial Symbiosis within higher education curricula, the same questionnaire included a second component addressing the knowledge areas covered by existing learning activities and assessing the relevance of skills and competencies for effective Industrial Symbiosis implementation. The list of competencies was developed based on the scientific literature and relevant policy documents reviewed in Chapter 4. Chapter 4 presents this conceptual basis in greater detail and provides the context for the competency assessment results discussed in Chapter 5.

The purpose of this analysis was to identify the key knowledge domains and competence areas that should be considered in the development of future educational and training approaches. The review provided a conceptual basis for understanding the types of knowledge, technical capabilities, and transversal skills required by different stakeholder groups involved in Industrial Symbiosis implementation.

The identified knowledge areas, skills, and competencies were considered in relation to the findings obtained through the mapping of existing learning resources and the survey on higher education curricula. By combining these perspectives, the analysis supports the identification of existing gaps between required competencies and currently available educational opportunities.

This integrated approach provides the foundation for the development of a future learning framework for Industrial Symbiosis, ensuring that proposed educational and training materials are aligned with both identified competence needs and the current state of educational practice.

By combining these three research activities, the report provides a comprehensive and coherent understanding of the current state of education and training in the field of Industrial Symbiosis. The integration of findings from the mapping of existing educational resources, the survey on higher education curricula, and the analysis of relevant knowledge areas, skills, and competencies enables a clear understanding of the relationship between current educational provision, competency requirements, and the needs of different stakeholder groups. This integrated perspective provides the basis for identifying key gaps and informs the development of a future learning framework for Industrial Symbiosis. The findings generated through this methodological approach are presented and discussed in the following chapters.

3. Overview of existing training and learning resources on Industrial Symbiosis

3.1. Mapping of Training and Learning Resources

A structured exploratory mapping of existing training and learning resources was conducted to provide a broad overview of educational materials relevant to Industrial Symbiosis. All 185 members of Working Group 3 were invited by email to contribute to the activity by identifying relevant resources from different countries, institutions, and educational contexts. Data was collected between January and June 2026.

The analysis was structured around a set of predefined descriptors, including the title of the resource, resource type, developing institution or project, delivery format, target groups, educational level, geographical scope, as well as key content characteristics and identified gaps or limitations. Most fields contained predefined response options, with multiple selections permitted where appropriate, as well as the possibility of adding information not covered by the proposed categories. Additional explanations were provided to support the classification of key characteristics and gaps. This structured approach ensured that the collected information could be consistently organised and compared across different educational and training initiatives.

No common set of databases, websites, keywords, or language restrictions was prescribed, as WG3 members were invited to contribute resources available through their respective professional, institutional, and national contexts. Following the data-collection period, the submitted entries were reviewed and checked for duplication. No duplicate resources were identified.

The objective of the mapping exercise was to provide an overview of existing training materials and educational initiatives relevant to Industrial Symbiosis, including their scope, structure, and thematic coverage. The findings establish an evidence base for the subsequent analyses presented in this report and contribute to a better understanding of the current educational landscape in this field.

The results are particularly important for the later stages of this work, as they inform the development of a future learning framework that will support the design of new educational and training materials based on identified needs, existing gaps, and current practices.

The following sections summarise the main characteristics of the training and learning resources identified through the mapping exercise, while selected examples of the identified resources are presented in greater detail in Appendix 1.

The exploratory mapping identified a limited number of training and learning resources specifically addressing Industrial Symbiosis. This should not be interpreted as an exhaustive assessment of all available educational provision, but it indicates that dedicated IS resources were not easily identifiable through the contributing members' institutional and professional contexts. It may also reflect the fact that Industrial Symbiosis is frequently incorporated into broader subject areas, such as the circular economy, industrial ecology, or sustainable resource management, making dedicated IS-related educational resources more difficult to identify.

The mapping identified 18 training and learning resources relevant to Industrial Symbiosis, which form the basis for the analysis presented in the following sections. Although the number of identified resources is small, their analysis provides valuable insight into the characteristics of existing educational initiatives, the way Industrial Symbiosis is currently represented within

education and training, and the areas where further development of educational and training materials may be needed.

3.1.1. Types of Existing Training and Learning Materials

The analysis of the identified resources by resource type shows that flexible learning formats dominate the current educational landscape. Online courses (33.3%) training programmes and workshops (27.8%) represent the largest share of the identified initiatives. This distribution indicates that education in the field of Industrial Symbiosis is currently developed primarily through non-formal and continuous learning approaches, which provide greater accessibility for different target groups and allow educational content to be more easily adapted to emerging practical needs.

In addition to these formats, several resources (22.2%) could not be classified into standard categories of educational materials. This reflects the diversity of approaches used to deliver Industrial Symbiosis education, many of which have been developed within individual projects or specific initiatives. While this diversity increases flexibility and allows resources to address different audiences and learning needs, it also highlights the absence of a common and systematic approach to the development of educational content.

By contrast, academic modules explicitly dedicated to Industrial Symbiosis accounted for 5.6% of the mapped resources. Although this review does not imply that such programmes do not exist, the findings suggest that they are neither widely visible nor easily identifiable through publicly available sources. This is likely because Industrial Symbiosis is more often incorporated into broader subject areas, such as the circular economy, industrial ecology, or sustainable resource management, rather than being offered as a standalone course or module.

The small number of identified guidelines and toolkits (11.1%) further points to the limited availability of structured teaching resources that could support educators and trainers in developing or improving educational programmes. Overall, the findings suggest that the current educational landscape is characterised by a certain degree of fragmentation, with learning resources distributed across different formats and initiatives rather than being organised within a coherent and systematic framework for Industrial Symbiosis education.

The analysis of resource delivery formats further confirms this pattern. Most of the identified resources are available online (61.1%), reflecting an effort to make educational content accessible to a broader audience regardless of geographical location. At the same time, just over one-quarter of the identified resources are delivered on-site (27.8%), highlighting the continued importance of face-to-face interaction, knowledge exchange, and collaborative problem-solving for competency development in Industrial Symbiosis. Self-paced learning resources accounted for 11.1%, suggesting that there is still limited availability of structured educational content designed to support fully independent learning.

3.1.2. Target Groups Addressed

The analysis of target groups shows that most of the identified training and learning resources are intended for industry professionals and other practitioners involved in the implementation of Industrial Symbiosis (50.0%). This distribution indicates that the existing educational offer is focused on building capacities and strengthening the competencies of stakeholders already engaged in circular economy and resource management activities, with the aim of supporting the practical

implementation of Industrial Symbiosis. Resources specifically intended for facilitators account for 5.6% of the identified materials.

At the same time, one-third of the identified resources (33.3%) is intended for a broad audience without a clearly defined target group, indicating an effort to increase general awareness and improve access to knowledge on Industrial Symbiosis. In contrast, resources aimed at students accounted for 11.1%. This may indicate the limited presence of Industrial Symbiosis within formal education or, alternatively, that the topic is more commonly addressed as part of broader subject areas rather than through dedicated courses or educational modules.

Overall, the findings indicate that existing educational initiatives are primarily focused on developing the competencies required for the practical application of Industrial Symbiosis, while there is still scope for stronger integration of this topic into formal education programmes and for the development of educational content intended for future professionals.

When analysed according to the level of complexity, intermediate-level materials accounted for 61.1% of the identified resources while introductory and advanced learning materials accounted for 22.2% and 16.7%, respectively. This distribution suggests that the existing educational offer is primarily aimed at strengthening existing competencies, targeting users who already possess a certain level of knowledge in the fields of sustainability, the circular economy, or related disciplines.

At the same time, the lower representation of introductory resources may represent a barrier to engaging new target groups encountering Industrial Symbiosis for the first time, while the relatively small number of advanced resources indicates that the current educational offer does not yet support the continuous development of competencies across different levels of expertise. Taking them together, these findings point to the need for more systematically structured educational content that would enable the gradual development of knowledge, from a basic understanding of the concept to the advanced competencies required for its successful application in practice.

The analysis of the geographical and institutional coverage of the identified resources shows that educational materials related to Industrial Symbiosis are developed at national (44.4%), European (16.7%), and international levels (38.9%). However, classification by geographical scope alone does not fully reflect the actual reach and accessibility of these resources. Their language, delivery format, and openness of access must also be considered.

The mapped national resources include materials available in local languages, which may limit their wider international use even though many of them are accessible online. Although these materials contribute to knowledge development within specific national contexts, their linguistic and contextual specificity may limit their wider dissemination and use beyond their original setting.

By contrast, resources classified as international are, in most cases, developed through European projects and initiatives involving partners from different countries and, in some cases, from different continents. These resources are developed in English and intended for a broader international audience, making them more accessible and transferable.

Overall, this structure indicates that educational resources in the field of Industrial Symbiosis are being developed through a combination of locally specific and internationally oriented initiatives. Internationally developed resources contribute to contextualisation and adaptation to local needs, international and project-based resources facilitate knowledge exchange and support the establishment of common learning approaches.

At the same time, differences in language, accessibility, and the level of openness point to a fragmentation in the way educational resources are distributed, which may affect their visibility and wider use. In this context, the development of a structured and shared learning framework could contribute to better integration of existing resources and improve their accessibility for different target groups.

3.1.3. Key Characteristics of Existing IS Training Content

The analysis of the key characteristics of the identified educational and training resources in the field of Industrial Symbiosis is based on the assessments made by researchers during the process of entering resources into the database. Each resource could be assigned one or more characteristics, meaning that the categories are not mutually exclusive but often overlap and appear in combination. This approach provides a more realistic understanding of the nature of existing educational resources, which in practice rarely appear as clearly defined or strictly separated formats. Consequently, the percentages presented for the individual characteristics do not add up to 100%.

Overall, the results indicate that oriented and applied learning approaches are prominently represented among the mapped resources. Practical and case-based learning was the most frequently identified characteristic (38.9%), followed by interdisciplinarity (33.3%). Project-based and theoretical approaches were equally represented, with each identified in 27.8% of the resources. These findings show that concrete examples, case studies and project activities have a key role in Industrial Symbiosis education. They also indicate an emphasis on applying knowledge in real or simulated contexts, although this orientation is not present in all mapped resources.

An interdisciplinary component was identified in one-third of the mapped resources (33.3%), which is consistent with the nature of Industrial Symbiosis as a field connecting industry, ecology, engineering, resource management, and broader circular economy concepts. The presence of interdisciplinarity as one of the key characteristics indicates that competency development in this area cannot be considered within a single disciplinary framework but requires the integration of knowledge from different scientific and professional domains.

Compared with practical and interdisciplinary approaches, theoretical content was identified in 27.8% of the mapped resources. It most commonly appears either as a separate component or as part of combined educational formats. This suggests that theoretical foundations are present, but they do not represent the dominant focus of existing training resources; rather, they serve as support for more practice-oriented learning approaches.

Tool-oriented resources are also present, accounting for 11.1% of the mapped resources. Their presence indicates an effort to move beyond conceptual understanding and include the development of concrete tools and methods that can be applied in practice. However, their limited representation may suggest that a widely developed set of standardised tools supporting the learning and implementation of Industrial Symbiosis is still lacking.

Short-term training programmes also accounted for 11.1% of the mapped resources, further indicating that formalised and time-structured educational programmes are not the dominant form of learning in this field. Instead, educational activities are more frequently delivered through flexible, project-based, and modular formats.

When considered together, these elements reveal that practical and case-based learning was the most frequently identified characteristic, while interdisciplinary, theoretical, and project-based approaches were also represented to varying degrees. Such an orientation reflects the nature of the field itself, which requires the integration of diverse knowledge areas and their application in real industrial and systemic contexts.

At the same time, this profile of resources also points to a certain degree of fragmentation, as different characteristics (practical, theoretical, interdisciplinary, and tool-oriented) appear in various combinations without a clearly defined and standardised educational model that would enable consistent competency development across different learning levels. While this diversity represents an advantage in terms of flexibility and adaptation to different users, it also highlights the need for greater structure and integration of existing approaches.

In this context, the results of this part of the analysis contribute to a better understanding of the current state of Industrial Symbiosis educational resources and provide an important basis for identifying key gaps in the following sections of the report, particularly in relation to the development of a future learning framework for Industrial Symbiosis.

3.1.4. Gaps and Limitations in the Current IS Training Landscape

As part of the analysis of existing educational and training resources, researchers also identified key limitations recorded during the data collection and database development process. These limitations represent an essential element for understanding the current state of Industrial Symbiosis education, as they provide insight not only into what resources are available, but also into the structural and systemic gaps within the existing educational landscape.

The most frequently identified limitation relates to the limited scalability of existing resources. This finding indicates that many educational and training initiatives are developed within individual projects or specific contexts, while their potential for wider application and replication remains limited. In other words, although resources may be well developed at a local or project level, their integration into broader educational systems and long-term structures may remain challenging.

Another important group of limitations relates to the lack of structured learning pathways. This finding suggests that, although numerous individual resources are available, they are not always connected into coherent learning sequences that would enable the progressive development of knowledge from basic to advanced levels. This limitation may affect the possibility of systematic learning and long-term competency development in the field of Industrial Symbiosis.

In addition, fragmented content was identified as an important limitation, reflected in the existence of many diverse but insufficiently connected educational initiatives. This fragmentation makes it more difficult for learners and other users to develop a comprehensive understanding of the field, as available resources are distributed across different platforms, projects, and institutional contexts without a common structure or central access point.

Finally, limitations were also identified regarding the lack of EU-level harmonisation of educational content. Although a considerable proportion of available resources originates from European projects, their structure, approaches, and methodological frameworks are not fully aligned, which limits their integration into a common European educational framework. This finding highlights the need for greater coordination and standardisation, particularly in the context of developing shared educational approaches for Industrial Symbiosis.

Overall, the identified limitations indicate that the current educational landscape in the field of Industrial Symbiosis is characterised by a high degree of fragmentation, limited scalability, and a lack of systematically connected learning pathways (Table 1). These findings clearly point to the need for the development of an integrated and structured learning framework that would support not only the availability of educational resources but also their interconnection, scalability, and alignment at the European level.

Table 1. Summary of key findings across dimensions

DIMENSION	DOMINANT PATTERN	INTERPRETATION
Type of resource	Online courses and training/workshops	Dominance of flexible, non-formal learning formats
Delivery format	Predominantly online, complemented by on-site delivery	Combination of digital accessibility and experiential learning
Target group	Industry / practitioners	Orientation towards professional and applied learning
Knowledge level	Intermediate	Assumes prior knowledge; limited entry-level materials
Geographic scope	National and international	Development across different geographic contexts
Key characteristics	Practical, project-based, interdisciplinary	Strong emphasis on applied, real-world learning
Identified gaps	Limited scalability and lack of structured learning pathways	Lack of coherent educational framework

Source: LIAISE WG3 mapping of Industrial Symbiosis training and learning resources (2026).

Selected examples of the identified Industrial Symbiosis learning resources are provided in Appendix 1. The examples were selected to illustrate the diversity of educational formats, target groups and learning approaches observed through the mapping, rather than to provide an exhaustive inventory of available resources. They include examples of formal academic provision, online and practice-oriented training, as well as resources developed for professional and other target groups. These examples provide additional insight into the characteristics of the existing learning landscape and complement the aggregated findings presented in this chapter.

3.2. Industrial Symbiosis in Higher Education

Although the first part of the research, which focused on mapping existing training and educational resources, identified a small number of resources originating from academic environments, this finding highlighted the need for a deeper understanding of the role of Industrial Symbiosis within formal higher education. Namely, the limited visibility of academic curricula within publicly available and project-based educational resources does not necessarily indicate their absence. Instead, it may suggest that Industrial Symbiosis-related content is often integrated into broader subject areas and therefore not explicitly identified as resources dedicated to Industrial Symbiosis.

For this reason, additional research was conducted focusing on academic curricula and teaching practices, with the aim of gaining deeper insight into the way Industrial Symbiosis is represented in

formal education. This research complements the findings of the previous desk-based analysis of training resources by examining the actual presence of Industrial Symbiosis-related content within university programmes, as well as the ways in which this content is integrated into curricula.

By combining the analysis of publicly available educational resources with the investigation of academic curricula, this approach provides a more comprehensive understanding of the Industrial Symbiosis educational landscape, covering both non-formal and formal education contexts.

The survey was distributed by email to all WG3 members and was open from May to June 2026. A total of 68 responses were received, of which 64 were retained as valid. Three responses were excluded because the respondents completed only the first question and provided no further data. The valid responses represented 22 countries: Albania, Armenia, Bosnia and Herzegovina, Croatia, Czechia, Germany, Greece, Israel, Italy, Kosovo, Latvia, Lithuania, Moldova, the Netherlands, North Macedonia, Portugal, Serbia, Spain, Sweden, Türkiye, the United Kingdom and Ukraine. The largest share came from Greece (32.8%), followed by Albania, Portugal, and Türkiye (9.4% each).

Most respondents were affiliated with universities (85.9%), while 12.5% represented research institutes and 1.6% a company. Regarding their professional roles, 39.1% were academic staff, 25.0% researchers, 18.8% students, 7.8% programme coordinators, 7.8% trainers or educators and 1.6% project managers. Of the 64 valid respondents, 39 reported that IS-related content was present in their curricula and therefore completed the detailed questions concerning its forms, educational levels, and extent of coverage. All valid respondents were able to answer the subsequent questions concerning knowledge areas, competencies, target groups, barriers, and future plans. Participation was voluntary, and the responses were collected anonymously and analysed in aggregate form. Specific information on respondents' previous experience in Industrial Symbiosis was not collected. The complete questionnaire is provided in Appendix 2.

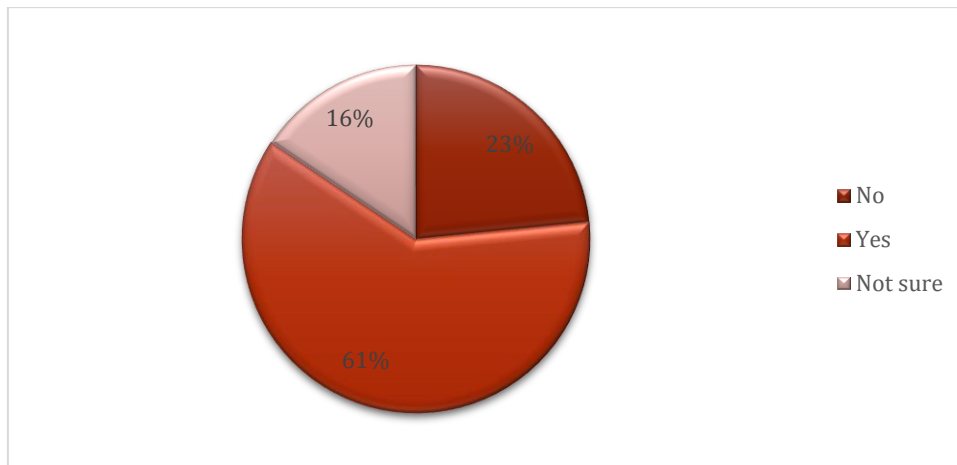
3.2.1. Presence of Industrial Symbiosis in Curricula

Survey results indicate that Industrial Symbiosis is present in a majority of responding institutions, although the level of certainty and degree of integration vary. Among the respondents, 60.9% reported that Industrial Symbiosis or closely related topics are included in their curricula or educational activities, while 23.4% indicated that such content is not present. A further 15.6% of respondents were not sure about its inclusion, which may suggest that the topic is indirectly addressed within broader subject areas without explicit identification as Industrial Symbiosis (Figure 1).

The high share of positive responses suggests that Industrial Symbiosis is increasingly recognized within higher education and training systems, particularly through its integration into related fields such as circular economy, industrial ecology, and environmental management. However, the notable proportion of uncertain responses indicates that IS is not always explicitly defined or systematically integrated as a distinct topic within curricula.

The proportion of negative responses further indicates that, in a considerable number of institutions, Industrial Symbiosis is still not formally included in teaching activities. This reinforces the observation that its integration remains uneven across educational systems and may depend on individual academic initiatives rather than structured programme-level approaches.

Figure 1. Presence of Industrial Symbiosis in Higher Education Curricula (n = 64 valid responses).



Source: LIAISE WG3 survey on Industrial Symbiosis Content and Training Programs in Higher Education (2026).

Overall, these findings suggest that Industrial Symbiosis is currently at a transitional stage of integration within higher education, where the topic is present in many contexts but is not yet consistently formalised or clearly identifiable across institutions.

3.2.2. Educational Levels and Degree of Integration

These questions were answered by the 39 respondents who had reported the presence of Industrial Symbiosis-related content in their curricula or educational activities. Due to the multi-select nature of the question, respondents were able to indicate multiple educational levels at which Industrial Symbiosis-related content is delivered. Therefore, the analysis is based on the frequency of mentions per category rather than mutually exclusive responses. Percentages represent the proportion of respondents referring to each educational level and do not represent a distribution summing to 100% (Figure 2).

The results indicate that the most represented level of Industrial Symbiosis integration in higher education is the Master level (64.1%). This suggests that IS is most frequently addressed within more advanced and specialised study programmes, where students already possess basic knowledge in sustainability, engineering, or related disciplines. The Bachelor level is also significantly represented (48.7%), indicating that Industrial Symbiosis is increasingly introduced at earlier stages of academic education, although its integration is not yet systematic.

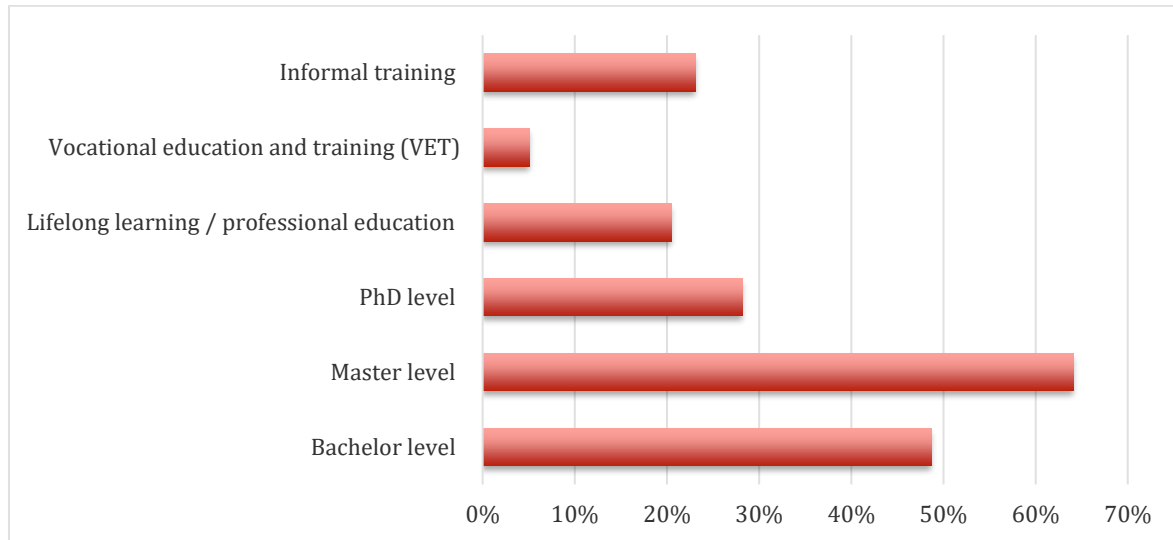
PhD-level education shows moderate representation (28.2%), suggesting that Industrial Symbiosis is also present within research-oriented programmes, but it is not yet a dominant area of study. A similar pattern can be observed in non-formal and flexible learning formats, where lifelong learning is present in 20.5% of cases and informal training in 23.1%. These findings indicate the existence of additional channels for professional development, although without a strong level of systematic integration.

The lowest representation was observed within the VET system (5.1%), indicating a significant gap in technical and vocational education, where Industrial Symbiosis could play a key role in developing practical and operational competencies.

Overall, the results show that the integration of Industrial Symbiosis is most pronounced at Master and Bachelor levels, while VET and other formalised vocational education pathways remain less

represented. This indicates an uneven distribution of IS-related education across different educational levels.

Figure 2. Educational Levels at Which Industrial Symbiosis Is Taught (n = 39; multiple responses permitted).



Source: LIAISE WG3 survey on Industrial Symbiosis Content and Training Programs in Higher Education (2026).

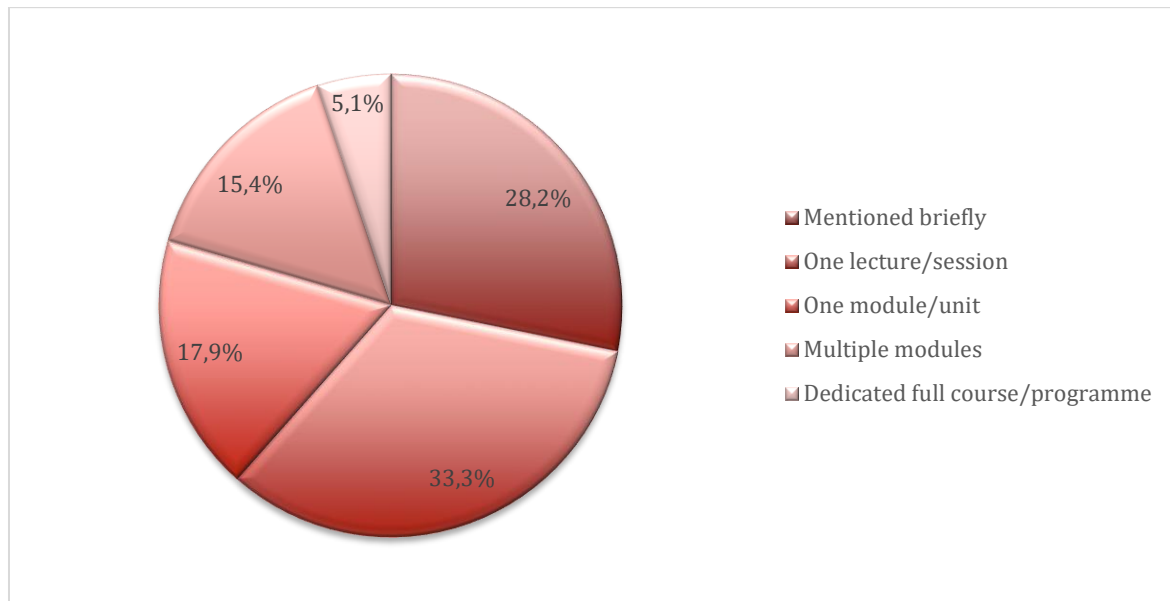
The results regarding the depth of Industrial Symbiosis integration within curricula show that the topic is most frequently incorporated in a limited manner. The highest proportion of respondents indicated that Industrial Symbiosis is addressed through a single lecture or teaching session (33.3%), while a similar share reported that the topic is only briefly mentioned within existing curricula (28.2%) (Figure 3). These findings suggest that, in many educational programmes, IS is primarily treated as a complementary or introductory topic rather than as a systematically developed area of learning.

More comprehensive forms of integration are present in a smaller number of cases. A total of 17.9% of respondents reported that Industrial Symbiosis is covered through a dedicated module or teaching unit, while 15.4% indicated that the topic is included across multiple teaching modules. Although these examples demonstrate more advanced forms of integration, they remain limited.

The smallest proportion of respondents (5.1%) reported that their institutions offer a dedicated course or study programme fully focused on Industrial Symbiosis. This confirms that fully developed standalone educational programmes in this field remain rare, despite the growing importance of Industrial Symbiosis within European sustainability and circular economy agendas.

Overall, the findings indicate that Industrial Symbiosis in higher education is still predominantly integrated through partial or individual learning activities, while implementation through dedicated courses or programmes remains limited. This pattern highlights the need for more structured educational content and clearer integration pathways that would enable students to develop a deeper and more continuous understanding of Industrial Symbiosis.

Figure 3. Extent of Industrial Symbiosis Coverage in Curricula (n = 39).



Source: LIAISE WG3 survey on Industrial Symbiosis Content and Training Programs in Higher Education (2026).

3.2.3. Modes of Integration and Educational Approaches

The results show that Industrial Symbiosis is most integrated indirectly, through broader educational contexts and different forms of teaching activities, rather than through dedicated courses focused exclusively on this topic (Figure 4).

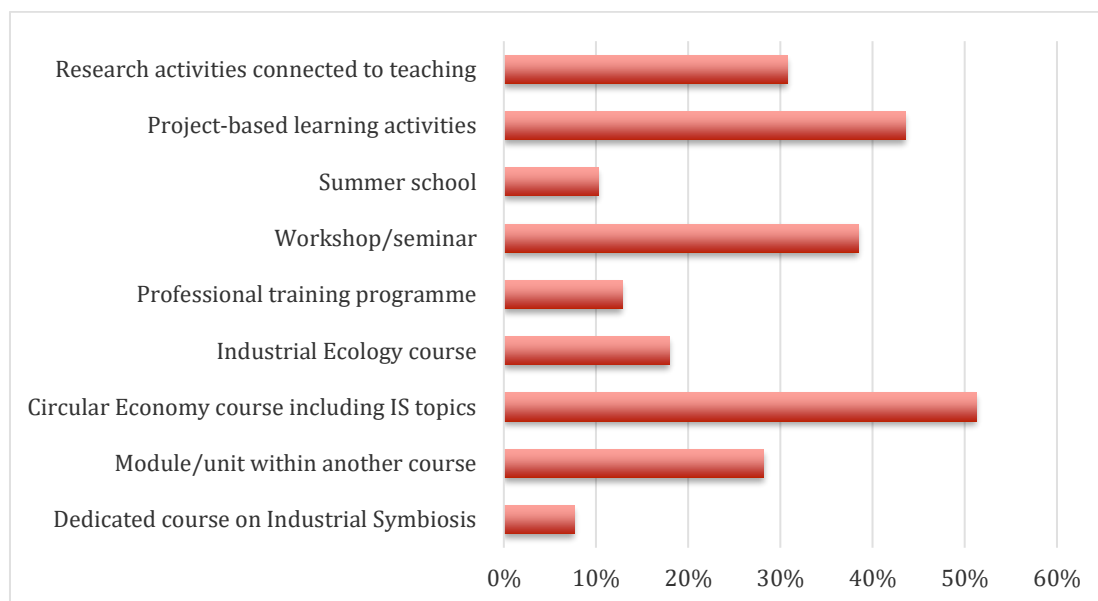
The largest proportion of respondents (51.3%) indicated that Industrial Symbiosis-related content is addressed within circular economy courses. This confirms that IS is most frequently considered as part of the broader circular economy concept rather than as an independent educational area. In addition, 43.6% of respondents reported that Industrial Symbiosis is included through project-based learning activities, while 38.5% identified workshops and seminars as one of the main approaches for knowledge transfer. These findings indicate a strong presence of practical and interactive learning approaches that support the connection between theoretical knowledge and real-world challenges related to Industrial Symbiosis implementation.

A considerable proportion of respondents (30.8%) indicated that Industrial Symbiosis relates to research activities integrated into teaching, highlighting the key role of research in developing student competencies and bringing current scientific knowledge closer to the educational process. At the same time, 28.2% of respondents reported that IS is addressed through modules or teaching units within other courses, further confirming that its integration is interdisciplinary and distributed across existing curricula.

A smaller proportion of responses relates to industrial ecology courses (17.9%), professional development programmes (12.8%), and summer schools (10.3%), while only 7.7% of respondents reported the existence of a dedicated course fully focused on Industrial Symbiosis. This result clearly indicates that standalone educational programmes in this field remain the exception, while dominant approaches are based on integrating IS into related disciplines and different forms of non-formal or project-based learning.

Overall, the findings confirm that Industrial Symbiosis education is currently developed through interdisciplinary and flexible educational approaches, particularly within circular economy education, project-based learning, and research-related activities. While such approaches support the connection of different knowledge areas and the development of practical competencies, the results also indicate a limited number of formalised and systematically structured courses dedicated exclusively to Industrial Symbiosis. This highlights the need for clearer educational structures and learning frameworks that would enable more consistent and comprehensive integration of Industrial Symbiosis into higher education.

Figure 4. Forms of Industrial Symbiosis Learning Provision (n = 39; multiple responses permitted).



Source: LIAISE WG3 survey on Industrial Symbiosis Content and Training Programs in Higher Education (2026).

3.2.4. Challenges and Barriers for Integrating Industrial Symbiosis into Education

To identify the main challenges affecting the development of Industrial Symbiosis education, experts were asked to indicate the barriers that hinder the integration of IS-related topics into existing curricula, educational programmes, and training activities. As multiple responses were possible, the results represent the percentage of respondents identifying each of the listed barriers.

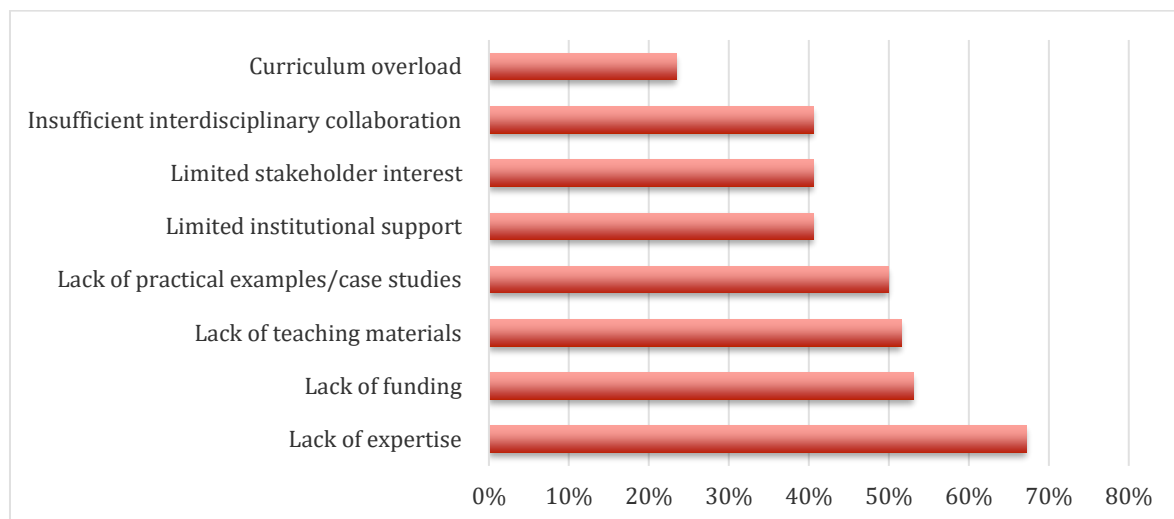
The results indicate that experts identified the lack of expertise as the most significant barrier to integrating Industrial Symbiosis content into educational programmes and training activities (67.2% of respondents). This finding suggests that the main challenge is not related to the concept itself, but rather to limited human capacities for developing and delivering appropriate educational content. In other words, successful integration of this field into education requires the development of teaching competencies and strengthening the capacities of educators and practitioners.

More than half of the respondents identified lack of financial resources (53.1%), lack of teaching materials (51.6%), and lack of practical examples and case studies (50.0%) as important barriers. These findings indicate that the development of Industrial Symbiosis education requires not only adequate expertise but also access to high-quality educational resources that enable the connection between theoretical knowledge and practical application.

Approximately two-fifths of respondents identified limited institutional support (40.6%), insufficient stakeholder interest (40.6%), and insufficient interdisciplinary collaboration (40.6%) as factors limiting the development of educational programmes in this field. Although these barriers were less frequently reported compared to lack of expertise and resources, their presence indicates that successful implementation of Industrial Symbiosis education requires coordinated action among educational institutions, industry stakeholders, and policymakers.

An important finding is that curriculum overload was identified as a barrier by only 23.4% of respondents, representing the lowest-ranked challenge. This indicates that experts do not perceive the existing curriculum structure as the primary limitation for introducing Industrial Symbiosis-related content. Instead, the results suggest that the main challenges are associated with human capacity development, availability of educational resources, and institutional support.

Figure 5. Main Barriers to Integrating Industrial Symbiosis into Curricula and Training Programmes (n = 64; multiple responses permitted).



Source: LIAISE WG3 survey on Industrial Symbiosis Content and Training Programmes in Higher Education (2026).

Overall, these findings provide an important basis for defining the future learning framework, which should address not only competency development but also the creation of quality teaching materials, practical learning opportunities, and mechanisms for stronger cooperation between education and industry.

3.2.5. Knowledge areas covered by existing training and learning activities

The survey also explored which knowledge areas are currently addressed through these courses and activities. Respondents could select multiple areas, allowing the results to capture the breadth of knowledge covered across the existing learning provision.

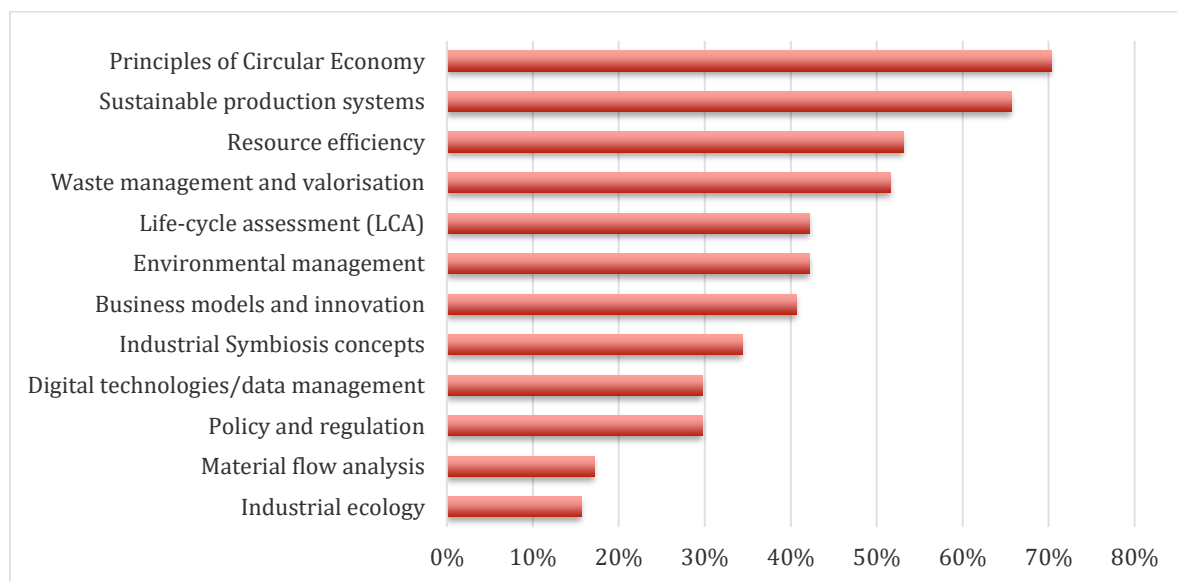
The results indicate that existing learning activities are most strongly oriented towards broader Circular Economy and sustainable production concepts. Principles of Circular Economy represent the most frequently addressed knowledge area, reported by 70.31% of respondents, followed by sustainable production systems (65.63%). Resource efficiency (53.13%) and waste management and valorisation (51.56%) are also covered by more than half of the respondents. This suggests that much of the existing learning provision approaches Industrial Symbiosis through its wider Circular

Economy and resource-efficiency context rather than treating it exclusively as a separate field of knowledge.

A second group of knowledge areas shows a moderate level of representation. Environmental management and Life-cycle assessment (LCA) are each reported by 42.19% of respondents, while business models and innovation are addressed by 40.63%. Industrial Symbiosis concepts, although central to the topic, are explicitly reported by 34.38% of respondents. Policy and regulation and digital technologies/data management are each represented in 29.69% of the reported learning activities. These results indicate that several dimensions relevant to the implementation and management of Industrial Symbiosis are present in existing provision but are not consistently integrated across learning activities.

The least frequently reported knowledge areas are Material Flow Analysis (17.19%) and Industrial ecology (15.63%). Their limited representation is notable because both areas provide important conceptual and analytical foundations for understanding resource flows and the relationships between industrial activities. Their lower presence may therefore indicate opportunities for strengthening specific technical and analytical content within future learning provision.

Figure 6. Knowledge Areas Addressed in Industrial Symbiosis Learning Activities (n = 64; multiple responses permitted).



Source: LIAISE WG3 survey on Industrial Symbiosis Content and Training Programs in Higher Education (2026).

Overall, the results show that existing IS-related learning provision covers a broad range of knowledge areas, but the distribution is uneven. The strongest coverage concerns the wider principles and practices of Circular Economy and sustainable production, while more specialised IS-related, analytical, and enabling areas are less consistently represented. This pattern is relevant for the development of the future learning framework, as it indicates that future learning resources should not only build on the existing strong coverage of Circular Economy fundamentals, but also provide opportunities to connect these foundations with more specific Industrial Symbiosis concepts, analytical approaches, policy dimensions, business models and digital tools.

3.2.6. Summary of findings

The analysis of existing training and learning resources, complemented by the survey of higher education institutions, provides a comprehensive overview of the current educational landscape related to Industrial Symbiosis. Overall, the findings indicate that Industrial Symbiosis is increasingly recognized within educational contexts and that a variety of learning opportunities already exist. However, the current educational offer remains fragmented, unevenly distributed across educational contexts, and insufficiently structured to support the systematic development of competencies required for effective Industrial Symbiosis implementation.

The desk-based mapping identified a diverse range of educational resources, including online courses, training workshops, toolkits, academic modules, and project-based learning materials. Most identified resources are delivered through online or blended formats and frequently emphasize practical learning, interdisciplinary approaches, and project-based activities. Nevertheless, the limited number of identified resources suggests that dedicated educational materials specifically addressing Industrial Symbiosis remain limited. Furthermore, many existing resources have been developed within individual research or innovation projects, resulting in materials that are often tailored to specific project objectives, sectors, or geographical contexts rather than designed as comprehensive educational programmes.

The survey findings further confirm that Industrial Symbiosis has gradually entered higher education curricula, with most respondents indicating that related topics are included within their institutions. However, the analysis also demonstrates that this integration is rarely systematic. Rather than being offered as dedicated courses, Industrial Symbiosis is most incorporated into broader subjects such as Circular Economy or Industrial Ecology, or delivered through workshops, project-based learning, and research activities. Similarly, although the topic is represented across different educational levels, it is concentrated at master's level, while vocational education and dedicated lifelong learning programmes remain less represented.

An additional finding relates to the depth of curricular integration. In most cases, Industrial Symbiosis is introduced through individual lectures, brief curriculum components, or single teaching modules, whereas comprehensive courses or full educational programmes remain uncommon. This suggests that students are often exposed to Industrial Symbiosis concepts without having the opportunity to develop a coherent and progressive understanding of the subject through structured learning pathways.

The analysis of knowledge areas addressed through existing learning activities further indicates that the current educational offer is primarily grounded in broader Circular Economy and sustainable production concepts. More specialised areas related to Industrial Symbiosis, analytical approaches, policy and regulation, and digital tools are less consistently represented. This suggests that existing provision provides a relevant foundation for IS learning, but that the breadth and balance of knowledge content could be strengthened.

When considered together, the desk research and survey results reveal several familiar challenges. Existing educational resources are characterized by fragmentation, limited scalability, and a lack of harmonised approaches across institutions and countries. The absence of clearly structured learning pathways, together with the small number of dedicated educational programmes, indicates that current educational provision does not yet fully correspond to the growing need for professionals capable of implementing Industrial Symbiosis in practice. Expert responses further

suggest that the most significant barriers to integrating Industrial Symbiosis into education are related to the lack of expertise, insufficient funding, limited availability of teaching materials and practical case studies. Institutional support, stakeholder engagement, and interdisciplinary collaboration were also identified as relevant enabling factors, whereas curriculum overload was perceived as a comparatively less significant obstacle. Together, these findings suggest that the main challenge is less related to curriculum overload than to the availability of expertise, teaching materials, funding, and practical resources required for effective implementation. These findings highlight the need for the development of a coherent and transferable learning framework designed to address the needs of different stakeholder groups, educational contexts, and professional profiles. Such a framework should build upon existing good practices while addressing the identified gaps through structured competency development, interdisciplinary learning approaches and greater alignment between academic education, professional training and the practical needs of industry and policy stakeholders.

4. Literature Review of Skills Requirements for Industrial Symbiosis

Industrial Symbiosis represents a complex concept aimed at improving resource efficiency through the optimisation, closing, and slowing of material flow within industrial systems. Although it is increasingly recognised as an important approach within sustainable transition pathways, its implementation remains challenging for companies facing various technical, organisational, and institutional barriers (LIAISE WG1 & WG2, 2025).

The literature particularly highlights the challenge of organisational readiness for adopting Industrial Symbiosis (Agudo et al., 2023), which is closely related to the ability of organisations to establish and maintain so-called “exchange capacity”. This concept refers to the capability of actors to exchange resources effectively, where trust, willingness to establish new partnerships, and the development of long-term relationships play a significant role. In addition, exchange capacity includes the ability to share information on production processes, capacities, and financial resources, as well as the ability to create and maintain networks for resource exchange.

In this context, regulatory and institutional frameworks that support the development of Industrial Symbiosis, as well as the availability and use of shared infrastructure, also play a key role. Within this approach, waste is increasingly perceived as a resource, while understanding material flows and optimising production processes become essential elements of industrial transformation. However, successful implementation of these principles depends on the knowledge, skills, and competencies of individuals involved in these processes. It also requires changes in labour market structures and in the competencies and profiles needed within contemporary industrial systems. This is particularly relevant for positions requiring an elevated level of adaptability, including activities related to managing complex and interconnected material and resource flows between different systems.

When discussing competencies required for Industrial Symbiosis implementation, contemporary literature emphasises the need to combine general transferable skills, such as digital literacy, understanding of ecological processes, and analytical problem-solving, with specialised technical knowledge related to specific industrial domains. The role of education in this process is therefore essential. Additional entrepreneurial education and professional development are particularly important, especially for individuals with previous experience in different industrial fields, as they can facilitate the development of competencies required for Industrial Symbiosis implementation. By integrating technical knowledge with business, technological, and organisational skills, the capacity to identify resource exchange opportunities, develop innovative solutions, and establish effective cross-sectoral collaboration can be strengthened (Del Vecchio et al., 2021).

At the same time, formal education systems have a crucial role in developing these competencies from the earliest stages of education, enabling students to understand sustainability principles and apply them in creating economic value through sustainable business models. The rapid development of technologies and engineering disciplines further increases the need for competencies that support the transition towards highly efficient and technology-driven sustainable systems.

Industrial Symbiosis as a concept is rarely addressed directly within literature focusing, specifically on competencies. However, existing competency frameworks from the fields of circular economy and sustainability can provide a valuable analytical basis for identifying relevant knowledge and

skills, considering that Industrial Symbiosis represents a specific application of broader circular transition principles within industrial systems.

Within this context, the Knowledge–Attitude–Behavior (KAB) model is frequently used as an analytical approach, based on the assumption that knowledge influences the development of attitudes, while attitudes further shape the willingness to apply sustainable practices in behaviour and professional activities (Indiran et al., 2025; Wardani et al., 2025). This framework is particularly relevant for Industrial Symbiosis, where successful implementation depends on both conceptual understanding and the development of competencies necessary for practical application.

Empirical studies show that, although awareness of circular economy principles is increasing among students and young professionals, understanding of their practical implementation often remains at a general or basic level. Research also indicates that respondents more easily recognise individual circular economy practices, such as recycling, repair, and reuse, than the broader circular economy concept itself. This suggests that understanding of the wider systemic framework behind these practices remains limited (Indiran et al., 2025; Wardani et al., 2025; Łuka et al., 2025).

In this regard, institutional sources such as ANE & Ethica (2021), Akyazi et al. (2023), and Circular Economy Institute (n.d.) indicate that applicable knowledge in the field of circular economy needs to cover multiple levels, ranging from basic conceptual understanding to systems thinking, regulatory frameworks, technological solutions, and principles of material flow management. Importance is given to understanding circular design, life-cycle approaches, and the distinction between biological and technical systems.

According to Circular Economy Institute (n.d.), higher levels of competency refer to the ability to apply knowledge in complex real-world situations, including identifying opportunities for improving resource efficiency and actively participating in cross-sectoral collaboration. Similar findings are reported by Sumter et al. (2020) and Schlüter et al. (2022), who emphasise the importance of social and organisational competencies, including communication, negotiation, and teamwork, as essential conditions for successful Industrial Symbiosis systems.

Furthermore, the Circular Economy Institute (n.d.), along with Renfors (2024) and Vitti et al. (2024), highlights that these competencies form an integrated set of abilities, including systems thinking, interdisciplinarity, innovativeness, and adaptability, necessary for managing complex transition processes.

Finally, Karra Sillaman and De Colle (2024) further emphasise that successful implementation of circular economy principles in entrepreneurial and organisational contexts requires the development of strategic and innovation competencies. These competencies enable organisations to adapt to regulatory requirements, engage different stakeholders, and develop sustainable business ecosystems, which is directly relevant for Industrial Symbiosis implementation as well.

The sustainability competency framework proposed by Ploum et al. (2018) can be considered an important starting point for developing a competency framework for Industrial Symbiosis, as it includes key elements of sustainable transformation and provides a basis for further extension with specific technical, analytical, and organisational competencies. The framework includes systems thinking competence, anticipatory competence, normative competence, strategic action competence, interpersonal competence, and integrated problem-solving competence. Each of these competencies contributes to understanding and managing complex socio-ecological-economic systems.

In addition to the scientific literature, which, as discussed above, does not provide a single set of competencies specifically developed for Industrial Symbiosis, an examination of selected practical frameworks and initiatives points to similar limitations. The selected European-level approaches differ in their scope, purpose and target groups and do not provide a single comprehensive framework for IS competency development. Nevertheless, several relevant approaches to skills identification and development can support the selection, adaptation and structuring of the competencies required for effective Industrial Symbiosis implementation.

Among the broader European reference frameworks relevant to this analysis, GreenComp provides a common basis for developing sustainability-related knowledge, skills, and attitudes across formal, non-formal and informal learning contexts. It comprises 12 competencies organised into four areas: embodying sustainability values, embracing complexity in sustainability, envisioning sustainable futures, and acting for sustainability. For the identification of skills relevant to Industrial Symbiosis, GreenComp offers useful transversal competencies, particularly systems thinking, critical thinking, problem framing, adaptability, and collective action. However, its broad sustainability focus does not capture the specific technical, organisational and inter-organisational capabilities required for establishing and managing Industrial Symbiosis. It therefore provides a basis for selecting relevant general competencies, which need to be complemented and adapted to the specific requirements of Industrial Symbiosis (Bianchi et al., 2022).

While GreenComp focuses on sustainability competencies in education, ESCO provides a multilingual European classification of occupations, skills, and competencies relevant to the labour market, education, and training. By linking skills to occupational profiles, ESCO offers a common terminology that can support the identification and consistent description of competencies relevant to different professional contexts. Since Industrial Symbiosis involves actors from different occupations, organisations and industrial sectors, this common terminology provides a useful reference for describing competencies across target groups and linking learning needs with professional roles. It is therefore relevant to the LIAISE objective of supporting the development of learning materials for diverse educational and professional contexts. However, ESCO does not provide a competency framework, learning pathway or curriculum specifically for Industrial Symbiosis, meaning that relevant competencies still need to be selected and organised according to the specific requirements of IS implementation (European Commission, n.d.-b).

A more Industrial Symbiosis-specific approach is provided by SPIRE-SAIS, which examines workforce and training requirements associated with Industrial Symbiosis and energy efficiency in energy-intensive industries. The identified requirements combine technical expertise with knowledge of energy, circular economy, waste management, and legislation, as well as commercial, financial, and business model skills. Importance is assigned to systems thinking, networking, collaboration, communication, entrepreneurship, autonomous working, and the facilitation of collective decision-making. The initiative also highlights the role of Industrial Symbiosis facilitators as neutral and trusted actors who require knowledge of local opportunities, available technologies, regulatory conditions, and business culture. In addition to workplace training, SPIRE-SAIS recommends incorporating Industrial Symbiosis into the education of engineering and business students to prepare future professionals to identify opportunities, develop business cases and support implementation (Bayón, 2024).

Taken together, the reviewed literature and initiatives indicate that there is no single, universally applicable set of knowledge areas and competencies developed specifically for Industrial Symbiosis and its different target groups.

5. Research on IS Awareness and Skills Needs

Based on the competency framework identified through Ploum et al. (2018), the Knowledge–Attitude–Behavior (KAB) model, and recommendations from relevant institutional sources, and the competency and skills approaches provided by GreenComp and SPIRE-SAIS, a structured set of key knowledge areas and competencies was developed for assessment. The set included specific knowledge domains related to Industrial Symbiosis, such as circular economy principles, resource efficiency, industrial ecology, material flow analysis, and sustainability assessment, as well as broader transversal competencies including systems thinking, interdisciplinary collaboration, and analytical problem-solving.

These competency areas provided the basis for collecting expert perspectives on the knowledge and skills considered necessary for the development of future educational content and training programmes in the field of Industrial Symbiosis.

Experts in the field of Industrial Symbiosis were asked to evaluate the relevance of the identified competencies for the development of education and training activities in this area. The assessment was conducted using a five-point Likert scale, where higher values indicated a higher perceived importance of individual competencies. The competency assessment included 64 valid responses, with no missing data in this section. The results provide insight into the competencies considered most relevant by the expert community and provide guidance for the development of future learning materials and training approaches (Table 2).

Table 2. Relevance of Skills and Competencies for Effective Industrial Symbiosis Implementation (n = 64; competencies rated on a five-point Likert scale).

COMPETENCY	MEAN SCORE	RANK
Circular economy integration	4,23	1
Analytical and problem-solving skills	4,02	2
Resource management and flow analysis	3,98	3
Innovation and entrepreneurship	3,92	4
Collaboration and networking	3,84	5
Technical and process engineering skills	3,81	6
Interdisciplinary thinking	3,81	7
Sustainability assessment	3,80	8
Data analysis and interpretation	3,78	9
Strategic decision-making	3,78	10
Communication skills	3,72	11
Systems thinking	3,63	12
Digital and data-driven skills	3,61	13
Project management	3,59	14

Source: LIAISE WG3 survey on Industrial Symbiosis Content and Training Programs in Higher Education (2026).

Overall, all evaluated competencies received positive ratings, with mean values ranging from 3.59 to 4.23, indicating that experts considered all proposed competencies relevant for Industrial Symbiosis education and capacity-building activities. The ranking of competencies shows that

Industrial Symbiosis education is not perceived as an isolated technical discipline, but rather as part of a broader transition towards circular economy and sustainable industrial systems.

The balanced distribution of scores suggests that Industrial Symbiosis cannot be supported through the development of a single dominant competence area. Instead, experts recognize the need for a combination of technical, analytical, organisational, and transversal competencies that together enable effective participation in Industrial Symbiosis activities.

In this context, the highest importance was attributed to the ability to connect circular economy principles with Industrial Symbiosis concepts. The strong position of analytical skills and resource management competencies further indicates that education in this field should include practical approaches for analysing material flows, identifying opportunities for resource exchange, and supporting data-informed decision-making.

The high ranking of innovation and entrepreneurship competencies also highlights their importance for enabling professionals to identify new value creation opportunities through the Industrial Symbiosis perspective. For practitioners who already possess domain-specific knowledge of particular industrial sectors, the development of these competencies is not related to acquiring general entrepreneurial skills, but rather to strengthening their ability to recognize innovation opportunities, explore alternative resource flows, identify potential collaborations, and develop new business models based on Industrial Symbiosis principles. In this sense, innovation and entrepreneurship competencies support the transition from a traditional resource-efficiency perspective towards collaborative approaches based on resource exchange and shared value creation.

An interesting finding relates to the position of systems thinking, which is widely recognized in sustainability literature as a fundamental competence. Although positively evaluated by experts, it received a lower ranking compared to more application-oriented competencies. This may indicate that, in the specific context of Industrial Symbiosis, experts associate successful implementation more directly with competencies enabling the identification, assessment, and realization of concrete symbiotic opportunities, such as resource analysis, collaboration, and practical problem-solving. However, this should not be interpreted as a reduced importance of systems thinking, but rather as an indication that experts may prioritize competencies closer to the operational implementation of Industrial Symbiosis.

Transversal competencies, including collaboration and networking (3.84), interdisciplinary thinking (3.81), and innovation and entrepreneurship (3.92), were also assessed highly. This confirms that competency development for Industrial Symbiosis should not be approached exclusively from a technical perspective. Instead, educational approaches should combine technical knowledge with the ability to collaborate across sectors, connect different stakeholders, and identify new business and sustainability opportunities.

The results indicate that no single competency can be considered the dominant requirement for Industrial Symbiosis education. Rather, Industrial Symbiosis is perceived as a multidisciplinary field requiring a combination of complementary knowledge areas and skills. While technical and analytical competencies remain important foundations, the findings highlight the additional importance of collaboration, innovation, and interdisciplinary understanding for successful implementation. The ability to recognize opportunities, analyse resource flows, establish

partnerships, and develop new collaborative models represents an essential component of effective participation in Industrial Symbiosis processes.

Although digital skills and project management received comparatively lower rankings, they were still evaluated positively, indicating that they represent relevant supporting competencies rather than primary areas of expertise for Industrial Symbiosis education.

Overall, the findings are consistent with previous studies indicating that individuals often recognize specific circular practices more easily than the broader concepts and systemic approaches behind them. Therefore, future learning approaches should first support the development of conceptual understanding of Industrial Symbiosis and circular systems, followed by the acquisition of specific tools, methods, and competencies required for practical implementation.

The results of this analysis provide an important evidence base for the development of future Industrial Symbiosis training materials and conceptual learning frameworks. They highlight the need for competency-based approaches that integrate technical knowledge, analytical capabilities, interdisciplinary collaboration, innovation-oriented thinking, and practical application.

6. Conceptual Framework for Future Industrial Symbiosis Learning

6.1. Rationale and purpose of the framework

The results presented in the previous sections indicate that education and training related to Industrial Symbiosis have gradually developed in recent years, both through academic programmes and through various forms of non-formal education and project-based training initiatives. At the same time, the analysis of literature, mapping of existing educational resources, and survey results demonstrate that the current educational landscape still does not provide a sufficiently coherent and systematic approach for developing the competencies required for effective Industrial Symbiosis implementation. Although numerous initiatives have been identified, the observed patterns reveal several common limitations that provide the basis for defining a future learning framework.

First, existing educational resources have been developed through individual projects and independent initiatives, resulting in a collection of educational contents that are often not mutually connected. Differences in scope, format, target groups, and thematic focus indicate that there is currently no common approach to developing Industrial Symbiosis education, nor a clearly structured framework that would support progressive and continuous competency development. While such diversity contributes to the flexibility of available educational offers, it also limits their wider application, transferability across different educational contexts, and long-term sustainability.

The analysis further demonstrated that Industrial Symbiosis is still not systematically integrated into higher education. In most cases, the topic is addressed as part of broader educational areas, particularly within Circular Economy-related courses, while dedicated courses or study programmes focused specifically on Industrial Symbiosis remain rare. In addition, most respondents indicated that Industrial Symbiosis is covered through a single lecture or a limited number of teaching units, suggesting that its presence in curricula depends on individual educators or institutional initiatives rather than on systematically defined educational structures.

The mapping of educational resources also showed that most existing learning opportunities are targeted at professionals already involved in Industrial Symbiosis implementation, while students and future professionals are less represented as a target group. At the same time, the dominance of resources aimed at learners with an intermediate level of prior knowledge, combined with the limited availability of introductory and advanced materials, indicates that a clearly structured progression of competency development from basic understanding to advanced expertise is still lacking.

Finally, the identified differences in content, competency focus, learning approaches, and expected outcomes demonstrate the absence of a harmonised approach to Industrial Symbiosis education at the European level. Most existing educational materials have been developed within individual projects, with learning objectives and competency requirements defined according to the specific needs of initiatives or institutions. As a result, the current educational landscape does not represent an integrated system for competency development, but rather a collection of valuable yet largely disconnected initiatives.

Therefore, these identified limitations provide the rationale for developing a conceptual framework for future Industrial Symbiosis learning, aimed at establishing a more coherent, competency-based, and sustainable approach to the development of future educational and training materials.

In addition to the structural limitations identified within the existing educational offer, the development of future training materials also requires a clear understanding of the competencies that different target groups should develop. Therefore, alongside the analysis of existing educational resources, the perceptions of respondents regarding the importance of specific competencies for effective Industrial Symbiosis implementation were also considered.

This chapter presents a conceptual framework for guiding the development of future educational and training materials in the field of Industrial Symbiosis. The framework has been developed based on the findings presented in previous sections, including the analysis of existing educational resources, the review of available programmes and materials, as well as consultations with experts in the field of Industrial Symbiosis.

The purpose of the framework is not to define a single curriculum or a predefined training programme, but rather to provide a common foundation for the development of flexible and adaptable educational content that can respond to the needs of different target groups, educational contexts, and professional profiles.

6.2. Guiding principles for future Industrial Symbiosis training

Following the identification of key limitations within the existing educational landscape, a set of guiding principles has been defined to support the development of future educational and training materials in the field of Industrial Symbiosis. These principles represent general directions for creating flexible, competency-based, and practice-oriented learning approaches that can respond to the needs of different target groups and contribute to wider adoption and implementation of Industrial Symbiosis.

Future development of educational materials for Industrial Symbiosis should be based on the following principles:

- **Competency-based learning approach** – Educational content should be oriented towards the development of competencies that enable understanding, planning, implementation, and evaluation of Industrial Symbiosis initiatives. The focus should not be limited to the acquisition of theoretical knowledge, but rather on the ability to apply such knowledge in different professional contexts.
- **Interdisciplinarity** – Future educational materials should integrate technical, economic, organisational, environmental, and social aspects of Industrial Symbiosis, enabling learners to understand the complexity of industrial systems and the interconnections between different disciplines.
- **Practical application orientation** – The learning process should be based on addressing real-world challenges through case studies, project-based tasks, simulations, and other forms of experiential learning that connect theoretical knowledge with concrete examples from industrial practice.
- **Flexibility and adaptability** – Educational materials should be modular and adaptable to different target groups, levels of prior knowledge, and educational contexts, enabling their application in formal education, professional training, and lifelong learning initiatives.
- **Linking education and industrial practice** – The development and implementation of educational materials should be supported by continuous cooperation between academia,

industry, public sector organisations, and other relevant stakeholders, ensuring that learning content corresponds to real implementation needs and evolving practices related to Industrial Symbiosis.

- **Structured competency development** – Educational materials should be organised in a way that enables progressive competency development through clearly defined learning levels, ranging from a basic understanding of the Industrial Symbiosis concept to advanced knowledge and skills required for its independent implementation in different organisational and industrial contexts.

6.3. Proposed Industrial Symbiosis Learning Framework

Based on the guiding principles defined in the previous section, the proposed Industrial Symbiosis Learning Framework provides a conceptual structure for the development of future educational and training materials. The framework is designed to support the organisation of learning content around key competencies required for effective participation in Industrial Symbiosis initiatives.

Rather than defining a fixed curriculum or a standardised training programme, the framework provides a flexible reference structure that can be adapted to different educational levels, target groups, and professional contexts. It builds upon the identified gaps in existing educational resources, the competency needs recognised through the research, and the principles required for more coherent and practice-oriented learning approaches.

The framework consists of interconnected competency domains, learning objectives, and guiding elements that together support the development of educational content aimed at building the knowledge, skills, and abilities necessary for understanding and implementing Industrial Symbiosis.

6.3.1. Competency Domains

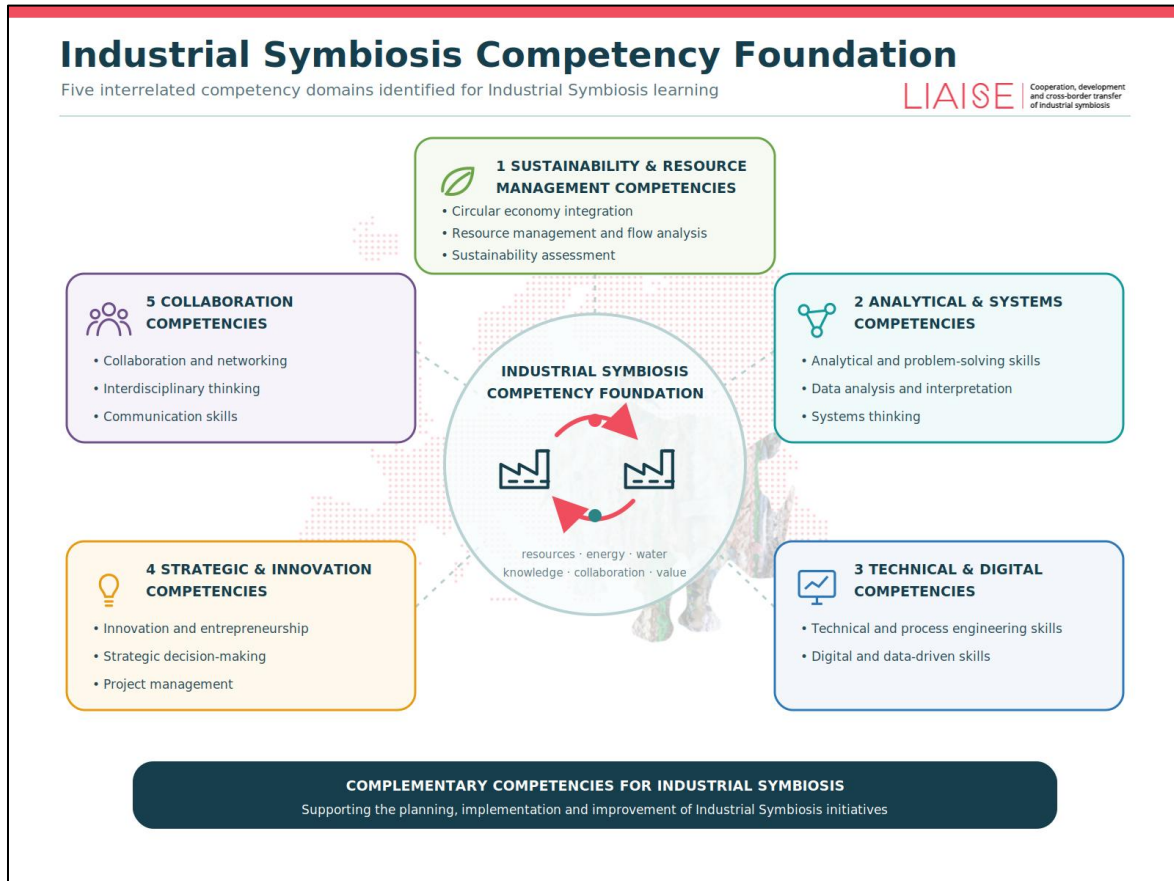
While the previous chapter analysed individual competencies and their importance from the respondents' perspective, the purpose of this section is not to reconsider them individually, but to consolidate them into broader competency domains that can serve as a basis for the development of future educational programmes and training materials.

The research results show that Industrial Symbiosis requires a broader set of competencies than technical knowledge alone. Highly ranked competencies include circular economy integration, resource management, analytical and problem-solving skills, strategic decision-making, collaboration, communication, and interdisciplinary thinking. This structure of results indicates that successful implementation of Industrial Symbiosis requires the simultaneous development of several types of competencies that complement each other and cannot be considered in isolation.

For this reason, the individual competencies were grouped into five interrelated competency domains through a conceptual synthesis rather than a statistical grouping procedure. Following the approach used by Ploum et al. (2018) to systematise related sustainability competencies into broader categories, the survey competencies were organised according to their functional connections and practical relevance for Industrial Symbiosis education, while also reflecting the survey findings and specific requirements of Industrial Symbiosis. This grouping does not aim to modify or simplify the survey results, but rather to organise them conceptually into a coherent structure that facilitates the definition of learning objectives, content, and learning outcomes. Instead of basing the future educational framework on many individual competencies, the proposed approach relies on several broader domains that together encompass the knowledge, skills and abilities required for the development and implementation of Industrial Symbiosis. Figure

7 provides a visual overview of the five interrelated competency domains that form the competency foundation for Industrial Symbiosis learning.

Figure 7. Industrial Symbiosis Competency Foundation.



Source: LIAISE WG3 (2026); visualisation developed with AI assistance.

Competency domains should also be considered in connection with the knowledge content addressed through IS-related learning activities. While knowledge areas provide the substantive foundation of learning, competencies describe the ability to analyse, connect, and apply this knowledge in different Industrial Symbiosis contexts.

1. Sustainability and Resource Management Competencies

This domain includes competencies that represent the foundation for understanding Industrial Symbiosis as one of the key approaches supporting the Circular Economy transition. It includes competencies related to the integration of Circular Economy principles, resource flow management, and sustainability assessment. The common objective of these competencies is to enable understanding of how resources are used, exchanged, and valued within industrial systems, as well as to assess their economic, environmental, and social impacts.

2. Analytical and Systems Competencies

Industrial Symbiosis requires the identification of collaboration opportunities between different organisations, analysis of material and energy flows, and decision-making within complex systems. Therefore, analytical problem-solving, systems thinking, and data analysis have been combined into a single competency domain. Their shared role is to support understanding of the interconnections

between processes, resources, and stakeholders, as well as the identification of opportunities for establishing Industrial Symbiosis relationships.

3. Technical and Digital Competencies

The practical implementation of Industrial Symbiosis requires an understanding of production processes, technological constraints, and opportunities for resource exchange between companies. At the same time, digital tools and data analysis are becoming increasingly important for identifying potential partners, monitoring resource flows, and supporting decision-making processes. Therefore, technical competencies and digital skills are considered interconnected areas that support the operational implementation of Industrial Symbiosis.

4. Strategic and Innovation Competencies

The implementation of Industrial Symbiosis involves not only technical solutions, but also the ability to plan, manage change, and develop new business models. This domain includes strategic decision-making, innovation, and entrepreneurship, as well as project management. Together, these competencies enable the planning, organisation, and long-term management of Industrial Symbiosis initiatives.

5. Collaboration Competencies

Industrial Symbiosis is based on collaboration among multiple stakeholders with different objectives, interests, and areas of expertise. Therefore, this domain includes communication, networking, and interdisciplinary thinking. The development of these competencies contributes to building trust among partners, facilitating knowledge exchange, and coordinating activities required for the development of Industrial Symbiosis initiatives.

Based on these defined competency domains, a learning framework can be developed that is not focused on isolated skills, but rather on the systematic development of interconnected competencies that together enable effective planning, establishment, and management of Industrial Symbiosis initiatives.

6.3.2. Framework Components and Design Recommendations for Future Training Materials

Building upon the defined competency domains and the knowledge areas identified through the mapping of existing learning resources, future educational and training materials should be designed to support the systematic development of the knowledge, skills, and abilities required for understanding and applying Industrial Symbiosis in different professional and educational contexts. The purpose of the proposed framework is to guide the development of educational content that, regardless of the target group or delivery format, connects relevant knowledge with the competencies required for effective planning, implementation, and improvement of Industrial Symbiosis initiatives. The selection and depth of knowledge content should reflect the intended learning objectives and the competencies to be developed, while also considering gaps and areas that are less consistently covered in existing learning provision.

In this context, the objectives of future training materials should go beyond a traditional approach based solely on the transfer of theoretical knowledge. Educational contents should enable learners to understand the fundamental principles of Industrial Symbiosis while also developing the ability to apply these principles in addressing concrete resource management challenges, identifying

potential symbiotic partnerships, assessing opportunities for resource exchange, and making decisions within complex industrial systems. In this way, the learning process becomes focused on competency development rather than solely on knowledge acquisition.

The structure of training materials should follow a logical and progressive competency development approach. Educational contents should be organised in a way that first enables learners to understand the basic concepts, principles, and terminology of Industrial Symbiosis, followed by the development of analytical and practical abilities through case studies, resource flow analyses, simulations, and project-based tasks. The advanced levels of learning should focus on addressing more complex challenges, strategic planning, and the development of new collaboration models among different stakeholders. Such an organisation enables progressive competency development and directly addresses one of the key limitations identified in the analysis of existing educational resources, namely the lack of clearly structured learning pathways.

At the same time, the framework should enable adaptation of training materials to different target groups. While the core competencies remain common, their level of depth, content complexity, selection of examples, learning methods, and expected outcomes should be adjusted according to learners' prior knowledge, professional roles, and specific needs. For example, educational materials designed for students may focus on developing conceptual understanding of Industrial Symbiosis and basic analytical capabilities, while materials intended for industry professionals may place greater emphasis on identifying implementation opportunities, decision-making, and the application of relevant tools. Similarly, content designed for policy makers and decisionmakers may focus more strongly on regulatory, organisational, and strategic aspects of Industrial Symbiosis development.

Finally, the development of training materials should ensure alignment between all elements of the learning process. Learning objectives, competencies, content, learning methods, and evaluation approaches should not be considered as separate elements, but rather as interconnected components of a coherent educational framework. Such alignment enables the development of flexible and adaptable training materials that can be applied in formal education, professional training, and lifelong learning contexts, while maintaining a common conceptual foundation.

Based on the findings from the mapping of existing learning provision and the identified knowledge areas and competency domains, the following conceptual framework is proposed for the development of future Industrial Symbiosis learning materials. The framework brings together these elements into a structured reference for designing learning content, activities, and assessment approaches across different target groups and learning contexts. To make its structure easier to follow, the framework components are presented in three related groups.

Table 3. Learning Design and Competency Development

FRAMEWORK COMPONENT	DESIGN RECOMMENDATION	KEY CONSIDERATIONS FOR IMPLEMENTATION
Learning objectives	Define measurable learning objectives aligned with the Industrial Symbiosis competency domains and covering the knowledge, skills and attitudes required for practical application.	• Align objectives with competency domains. • Address analytical thinking, problem-solving, collaboration, and decision-making. • Adapt objectives to learners' prior knowledge and professional context.

		• Align objectives, learning activities and assessment.
Training structure	Organise Industrial Symbiosis content into interconnected modules that can be delivered independently or combined into learning pathways suited to different competency levels and training contexts.	• Divide content into thematic modules. • Allow standalone or combined delivery. • Define prerequisites and expected outcomes for each module. • Support short courses and comprehensive training programmes.
Learning progression	Structure learning through progressive levels of complexity, from conceptual understanding to practical application and strategic implementation of Industrial Symbiosis.	• Use Foundation, Intermediate and Advanced levels, or equivalent. • Build each level upon previously acquired competencies. • Support continuous professional development. • Avoid fragmented learning experiences.
Competency integration	Ensure that every module contributes to one or more competency domains and, where appropriate, integrates technical, managerial, and sustainability-related competencies.	• Map competencies to each module. • Encourage interdisciplinary learning. • Integrate knowledge, skills, and attitudes within learning activities. • Avoid the isolated treatment of competencies.

Source: LIAISE WG3 (2026).

Together, components presented in Table 3 provide the structural basis for a coherent and competency-oriented learning process. Measurable objectives establish a clear direction for learning, while modular organisation and progressive levels enable materials to support both short courses and more comprehensive learning pathways. Explicit competency mapping further ensures that knowledge, skills, and attitudes are developed in an integrated rather than fragmented manner.

Table 4. Learning Delivery, Adaptation and Assessment

FRAMEWORK COMPONENT	DESIGN RECOMMENDATION	KEY CONSIDERATIONS FOR IMPLEMENTATION
Teaching and learning methods	Use active, learner-centred methods that engage learners in analysing resource flows, identifying Industrial Symbiosis opportunities, and addressing collaboration challenges.	• Case-based analysis of Industrial Symbiosis initiatives. • Project- and problem-based identification of resource-exchange opportunities. • Collaborative resource-flow mapping and stakeholder exercises. • Simulations of cross-organisational decision-making. • Interdisciplinary teamwork.
Practical orientation	Integrate authentic Industrial Symbiosis challenges and industrial practice, enabling	• Real industrial case studies. • Resource-flow mapping exercises. • Identification of Industrial Symbiosis opportunities.

	learners to apply theoretical concepts in realistic situations.	• Company visits and guest lectures, where possible. • Projects developed with external stakeholders.
Digital learning environment	Use digital learning environments to support access to Industrial Symbiosis cases and data, resource-flow analysis, collaboration, and learner self-assessment across face-to-face, blended, and online formats.	• Learning management and collaborative platforms. • Digital repositories of Industrial Symbiosis cases. • Interactive resource-flow mapping and visualisation tools. • AI-supported analysis and learning tools, where appropriate.
Target group adaptation	Adapt the depth, examples and activities to learners' prior knowledge and their expected roles in Industrial Symbiosis initiatives, while retaining the framework's common competency structure.	• Adapt terminology and depth of explanation. • Select examples relevant to each audience. • Adjust workload and learning activities. • Consider learners' prior knowledge and professional needs. • Maintain common competency domains across training versions.
Assessment and feedback	Assess both Industrial Symbiosis knowledge and learners' ability to analyse resource flows, identify collaboration opportunities, and justify proposed solutions.	• Analysis of Industrial Symbiosis cases. • Resource-flow mapping tasks. • Evaluation of proposed exchange opportunities. • Collaborative projects and presentations. • Peer, instructor, and industry-expert feedback.

Source: LIAISE WG3 (2026).

Components presented in Table 4 translate the framework into learning experiences that connect theoretical understanding with practical competency development. Active methods and authentic industrial challenges support learner engagement and the application of knowledge, while digital delivery and target-group adaptation extend the accessibility and relevance of the materials. Integrated assessment and feedback provide evidence of learning achievement and support continuous improvement throughout the learning process.

Table 5. Stakeholder Engagement and Continuous Improvement

FRAMEWORK COMPONENT	DESIGN RECOMMENDATION	KEY CONSIDERATIONS FOR IMPLEMENTATION
Industry and stakeholder engagement	Involve industry, higher education institutions, public authorities, and other stakeholders relevant to Industrial Symbiosis networks in the development, delivery,	• Co-development of training content. • Industry mentoring and joint workshops. • Participation of practitioners in teaching. • Projects addressing real industrial challenges. • Stakeholder feedback during programme evaluation.

	and evaluation of training materials.	
Quality assurance and continuous improvement	Regularly update learning materials to reflect emerging Industrial Symbiosis practices, scientific and technological developments, stakeholder feedback, and changes in sustainability policy.	• Periodic content review. • Learner satisfaction surveys. • Feedback from trainers and industry partners. • Monitoring emerging Industrial Symbiosis practices. • Alignment with evolving European sustainability policies. • Continuous revision of learning resources.

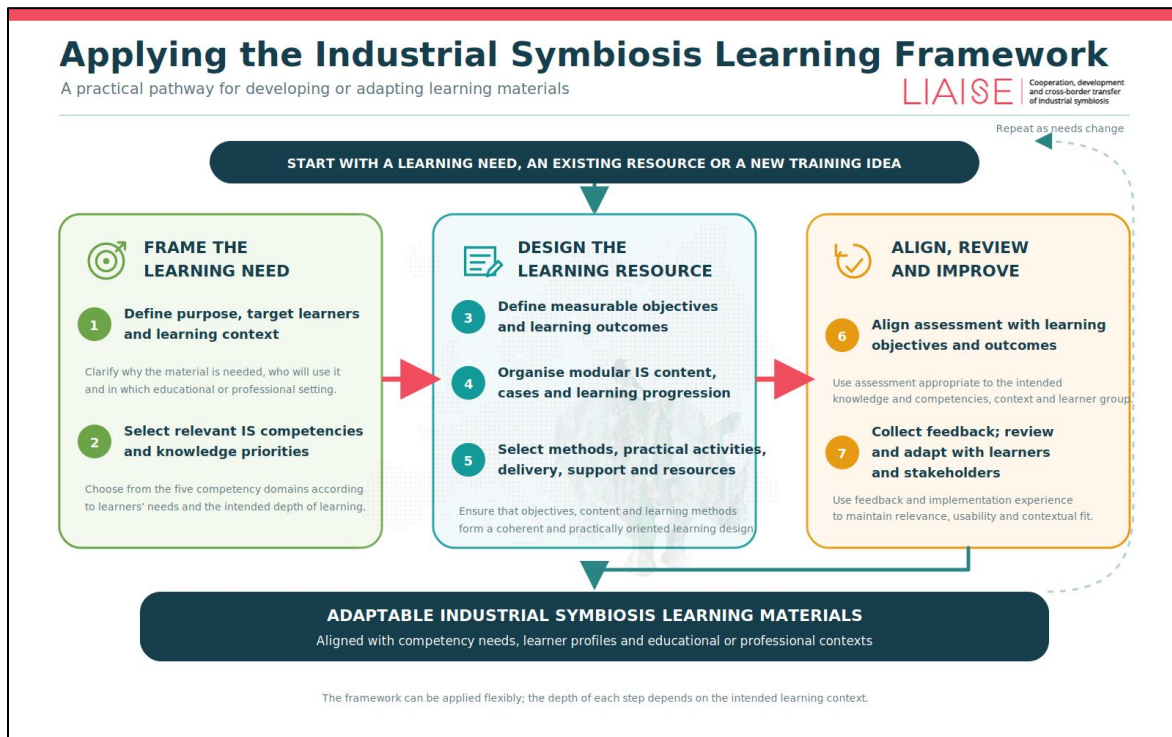
Source: LIAISE WG3 (2026).

Stakeholder participation strengthens the relevance, credibility and practical value of training materials and facilitates knowledge exchange between education and practice. At the same time, structured exploratory mapping and updating help ensure that learning resources remain aligned with scientific advances, emerging Industrial Symbiosis practices, technological developments, and evolving sustainability policies.

6.3.3. Applying the Framework to Different Training Contexts

The proposed framework provides a structured basis for designing future Industrial Symbiosis learning activities. Its application involves considering a set of interconnected questions concerning the intended learners, the competencies to be developed, the learning objectives, the organisation of content, the selection of learning methods, practical application, and assessment. The answers to these questions should be determined according to the specific target group and learning context. In this way, the framework provides a common structure while allowing the design of learning activities to respond to different educational and professional needs. Figure 8 summarises the recommended sequence for applying the framework. The steps represent a flexible and iterative decision-support process and may be revisited as learner needs, context and feedback evolve.

Figure 8. Applying the Industrial Symbiosis Learning Framework.



Source: LIAISE WG3 (2026); visualisation developed with AI assistance.

The first step in designing training materials is to clearly define the competencies that the learning process is expected to develop. Although the framework identifies a common set of competency domains relevant to Industrial Symbiosis, different educational and professional contexts may require various levels of emphasis. Consequently, training developers should first determine which competencies are essential for the intended learners and how these competencies contribute to the overall purpose of the training.

Once competency priorities have been established, the structure of the training materials should be considered. Rather than developing a sequence of isolated learning units, materials should be organised into coherent and modular learning components that progressively support competency development. A modular organisation allows individual units to be used independently or combined into more comprehensive learning pathways, increasing both flexibility and scalability.

The next consideration concerns the progression of learning. Training materials should provide a logical transition from fundamental concepts towards more complex analytical, practical, and strategic applications of Industrial Symbiosis. Such progression ensures that learners gradually build their knowledge and competencies instead of acquiring disconnected pieces of information.

Equally important is the selection of appropriate teaching and learning methods. Since Industrial Symbiosis requires interdisciplinary thinking, collaboration and practical problem solving, learning activities should extend beyond traditional lectures and incorporate case studies, project-based learning, collaborative exercises, simulations, and other learner-centred approaches. The choice of methods should always reflect the intended learning objectives and the characteristics of the target group.

Training developers should also carefully consider the practical dimension of learning. Wherever possible, educational materials should integrate authentic industrial examples, resource flow analyses, stakeholder interactions, and real implementation challenges. Such activities strengthen the connection between theoretical concepts and professional practice while improving learners' ability to apply acquired competencies in real-world situations.

Although the conceptual framework remains the same, its implementation should be adapted to different target groups. Differences in learners' prior knowledge, professional responsibilities and expected learning outcomes require adjustments in content complexity, examples, learning activities and assessment approaches. However, these adaptations should not alter the overall competency structure of the framework, ensuring consistency across different educational settings.

Finally, assessment should be viewed as an integral component of the learning process rather than its final stage. Evaluation methods should provide evidence not only of knowledge acquisition but also of competency development, practical application, and reflective learning. Continuous feedback should support learners throughout the training process while also providing valuable information for the future improvement of training materials.

Accordingly, the proposed framework should be interpreted as a structured decision-support framework that guides developers through the key design decisions required for developing Industrial Symbiosis learning materials.

6.4. Towards European-level alignment and transferability

The diversity of existing educational approaches and training resources identified through the mapping also points to the potential value of a common reference framework for Industrial Symbiosis education and training. The proposed framework can provide a shared basis for the development, comparison, adaptation, and exchange of learning materials across institutions, countries, and educational contexts, while preserving the flexibility required by different target groups and learning environments.

European-level alignment should not be understood as the standardisation of curricula or the creation of a single training model. Instead, it can be supported through a common competency structure, shared design principles, and a consistent approach to defining learning objectives, organising learning content and assessing competency development. Training developers and institutions using the framework should therefore be encouraged to indicate how their learning materials correspond to the competency domains and other framework components. Such an approach would make different educational initiatives easier to compare and adapt, while allowing institutions to retain their own disciplinary, national and sector-specific characteristics.

The framework can also support the transferability of existing good practices. Where effective learning resources, case studies, teaching methods, or assessment approaches have been developed in a particular institutional or national context, their adaptation to other contexts can be facilitated by relating them to the common framework structure. This would help move beyond the current situation in which many resources remain linked to individual projects or specific local contexts and would increase the potential for their wider use and further development.

For future initiatives, the framework therefore provides a basis for developing shared or interoperable learning resources, establishing common reference points for competency development, and encouraging collaboration between universities, industry, public authorities, and

other relevant stakeholders. Where appropriate, future European and international projects could further develop this approach by creating shared repositories of learning materials, cross-institutional training activities, joint case-study collections, and mechanisms for exchanging and updating educational resources.

In this way, the framework can contribute to a more connected Industrial Symbiosis learning ecosystem in which knowledge and educational resources can be developed locally but shared, adapted and further improved across organisational and national boundaries. The intended outcome is not uniformity, but greater compatibility, transferability, and collective capacity to develop the competencies required for the wider implementation of Industrial Symbiosis.

6.5. Exploring the Potential of AI/ML-based Tools for Skills Assessment

6.5.1. Purpose, Potential Users and Conceptual Assessment Process

Industrial Symbiosis is becoming increasingly important, supported by numerous successful practical examples dating back several decades, such as Kalundborg Symbiosis in Denmark.

Industrial Symbiosis is based on cooperation among different stakeholders, whereby the activities or resources of one business create value and benefits for another. Its successful implementation requires stakeholders with competencies covering different disciplines, sectors, and professional areas. Relevant competencies should therefore be identified and mapped, while their assessment can support appropriate learning recommendations. AI/ML can assist with competency-gap identification and personalisation of learning paths. The main purpose of such tools would be to assess the existing competencies of learners and practitioners in the light of competencies which are considered relevant for Industrial Symbiosis, as well as to identify areas where further development or learning activities are needed. Potential users could include learners, practitioners, businesses, educators, and other stakeholders involved in Industrial Symbiosis.

From one perspective, the concept appears straightforward – one business has resources or by-products that another business needs. From another perspective, however, it presents a significant challenge, as the activities, processes, and needs of potential partners must first be understood and analysed. AI/ML tools may support these broader applications by analysing available information, identifying potential synergies, and helping stakeholders understand the activities, resource flows, and potential cooperation opportunities of other businesses. Recent research has also proposed machine learning-based methodologies that support the preliminary identification of industrial symbiosis opportunities without requiring extensive information sharing by participating companies (Zhao et al., 2025). These examples demonstrate the wider potential of AI/ML in Industrial Symbiosis; however, the remainder of this section focuses specifically on skills assessment and related learning recommendations.

The availability of literature on industrial symbiosis is not the main problem. Rather, challenges arise from the fragmentation and limited visibility of existing training resources and limited awareness of what is already available. The importance of education has also been recognised in the context of Digital Industrial Symbiosis. Prymon-Ryś (2024) points out that its implementation requires education at various levels, particularly for entrepreneurs and SME owners. This further highlights the need for learning frameworks and digital tools supporting Industrial Symbiosis education.

The proposed process begins with the LIAISE competency framework and uses learner evidence to develop competency profiles, identify competency gaps and generate learning recommendations

that are subject to human validation. When preparing a competence framework, it is important not only to define competency domains, but also to provide clearly understandable competency levels. Structured evidence would support the creation of individual competency profiles that could be compared with the competencies considered relevant for Industrial Symbiosis. The identified competency gaps could then be linked with relevant learning resources. The resulting recommendations should be reviewed and validated by a responsible person, preferably an expert or educator.

6.5.2. Inputs, Outputs, Reference Frameworks and Technological Options

The first crucial step in preparing any learning material is to identify and map what has already been written in the relevant field. This requires a structured and periodically updated mapping of relevant competencies, learning resources and practical Industrial Symbiosis cases to avoid duplication of existing knowledge and identify gaps where additional information or research is needed.

Successful and unsuccessful industrial symbiosis practices, available databases, and data suitable for analysis provide a solid basis for education on industrial symbiosis. They also support the identification of competencies considered important for successful Industrial Symbiosis implementation. One open platform for learning is the Industrial Symbiosis DATA repository (ISDATA), which collects and provides structured information on Industrial Symbiosis. In the context of educational and training materials, it is important to ensure that repositories are regularly maintained and updated. Any future repository or platform would therefore require arrangements for the long-term maintenance, regular updating, and continued availability of relevant learning resources.

The mapped learning resources may also serve as a potential knowledge base for future skills assessment and learning support. Once learners' or practitioners' competency gaps are identified, such resources could be linked to the relevant skills and used to recommend suitable learning opportunities. Relevant data inputs could include professional and educational background, training experience, and knowledge-assessment results. Data collection should be limited to the information necessary for the intended assessment purpose. Expected outputs could include an individual competency profile, identified competency gaps and links to relevant learning opportunities and resources. These outputs should be considered decision-support tools rather than definitive assessments. Where learning is organised into separate modules, recommendations could also identify suitable modules and their sequence according to the learner's existing competencies and learning needs.

The identification and mapping of competencies relevant to Industrial Symbiosis would still require expert involvement, particularly because this field combines knowledge and competencies from different disciplines, sectors, and professional contexts. Expert judgement would be needed to determine which competencies are relevant, how they relate to one another and how they should be represented in a competency matrix before any digital or AI-supported assessment is applied.

Some functions, such as comparing an individual competency profile with a predefined competency matrix, could be implemented through conventional or rule-based digital tools and would not necessarily require artificial intelligence or machine learning. AI-based approaches may provide additional value when less structured information needs to be analysed, while machine learning would be relevant only where the intended functionality requires learning patterns from available data. The selection of an appropriate technological approach should therefore follow the definition

of the assessment design, required functionality and data requirements. A feasibility assessment would need to determine whether machine learning is necessary and whether sufficient, reliable, and appropriately structured data are available.

One source for skills mapping and assessment in the field of industrial symbiosis is the work carried out by the SPIRE-SAIS Alliance (A. SPIRE). The project focused on updating curricula, qualifications, knowledge, and skills required to support cross-sectoral collaboration and Industrial Symbiosis activities. It also identified cross-sectoral job profiles and skills requirements and developed a training framework that may serve as a valuable basis for competency mapping and AI-supported skills assessment. A particularly useful source is the Training Framework developed by the SPIRE-SAIS Alliance (Muract et al., 2024). The authors recognise that the list of skills required to implement and operate industrial symbiosis should be continuously updated, considering the experience gained from testing the proposed mechanisms. The SPIRE-SAIS Training Framework can therefore be considered a complementary reference for comparing and further refining the competency areas identified in this report and exploring how they could be operationalised for future skills assessment.

Another reference structure is the European Skills, Competencies, Qualifications and Occupations classification (ESCO). As officially stated, “The ESCO classification identifies and categorises skills, competencies, and occupations relevant for the EU labour market, education, and training. It systematically shows the relationships between the different concepts” (European Commission, n.d.-a). However, ESCO does not provide a ready-made Industrial Symbiosis competency profile. Relevant occupations and skills would need to be selected and mapped against the LIAISE competency domains using ESCO’s mapping (“thesaurus alignment”) approach (European Commission, n.d.-b), complemented with Industrial Symbiosis-specific competencies where necessary, and validated by experts. The LIAISE framework may also include competencies that do not directly correspond to existing ESCO concepts. One challenge when using ESCO is that it links skills and competencies to occupational profiles, whereas Industrial Symbiosis combines knowledge and competencies from several sectors and professional areas. Once the relevant occupations and ESCO concepts have been identified, a competency matrix covering the competencies required for Industrial Symbiosis could be developed. Combining such reference frameworks and competency classifications could potentially support broader competency profiling across different learner and practitioner groups, allowing the assessment to capture competencies that span multiple sectors and professional backgrounds. The practical application of competency mapping is also supported by several digital solutions. One example is SkillSync, introduced by its developers as a tool to identify skill gaps and bridge them through tailored training recommendations (EIT Community AI, n.d.).

6.5.3. Governance, Risks, and Implications for LIAISE

AI/ML tools may also contribute to a better understanding of the regulatory framework applicable to Industrial Symbiosis by facilitating the navigation of relevant legal requirements, supporting the identification of applicable legal obligations, and improving access to legal information. Although such tools cannot replace legal analysis or professional legal advice, they can enhance legal awareness and support informed decision-making by stakeholders. As this represents a broader application of AI/ML beyond skills assessment, it is noted only as contextual information here. The development and use of AI/ML and digital tools should also comply with the applicable requirements under the AI Act. The applicability of requirements would depend on the tool's

intended purpose, users, data processed, functionality and risk classification. Depending on this assessment, requirements related to data governance, transparency, human oversight, and accuracy may be relevant. Such considerations are particularly relevant where AI supports skill assessment, learning recommendation or decision-making processes (European Parliament & Council of the European Union, 2024).

Appropriate rules for collecting and handling data should be established. The GDPR and its main principles should be considered where educational and professional profiles contain personal data. In accordance with the principle of data minimisation, the personal data collected should be limited to what is necessary for the intended purpose.

AI-powered skills assessment and learning recommendation require validation and human oversight. Generated outputs, such as competency profiles, competency gaps and learning recommendations should be reviewed and then validated. Transparency of the assessment and recommendation process, as well as privacy throughout the entire process should be ensured. Bias in the assessment results should be considered. The role and responsibilities of stakeholders should be clearly defined.

The process should be flexible, considering that different data may be received from different stakeholders, jurisdictions, sectors, and contexts. Incomplete, outdated, or self-reported information may affect the reliability of the results. Such as social and facilitation competencies, may be difficult to assess through automated processes. Learning resources may also become outdated, while automated competency scores may be inaccurate or create a false impression of precision. Considering these limitations, it is important to consider automated assessment as an approach that should coexist with and support the work of experts and educators.

LIAISE COST Action can build upon the competencies, training frameworks, and good practices already developed by previous initiatives and focus on further developing learning frameworks, collaborative repositories, technology watch platforms, and training activities to improve knowledge sharing and capacity building in the field of Industrial Symbiosis. By bringing these elements together, LIAISE could contribute to a coherent learning ecosystem supporting Industrial Symbiosis.

Building on these existing frameworks, learning resources, and digital approaches, the feasibility and conceptual requirements of an open-source AI/ML-based platform for broad skills assessment could be further explored. Such an assessment would help determine the potential scope, data requirements, expected outputs, result validation, human oversight, and applications of the platform without presupposing its subsequent development. This would support the selection of the most appropriate technological tools.

7. Implications for the LIAISE COST Action International IS Learning Network

7.1. Sharing and Building upon Existing Learning Resources

The mapping undertaken within this report has demonstrated that a diverse set of Industrial Symbiosis learning resources already exists, while also revealing fragmentation in their development, structure, and accessibility. The value of the LIAISE network is therefore not primarily in generating another isolated collection of training materials, but in creating the conditions for existing knowledge and resources to be connected and further developed through international collaboration.

The framework for developing training materials within this Action provides an important basis for this process. It brings together findings from the mapping of existing learning resources and activities, the analysis of competency needs and the perspectives of different stakeholders involved in IS education and practice. As a result, it can serve as a common reference for members of the LIAISE network when reviewing existing resources and developing new ones. In particular, the competency domains, learning objectives and design principles defined by the framework can be used to assess how individual resources contribute to IS learning and where complementary content or further development may be needed.

This provides an opportunity to move from the exchange of information about individual training initiatives towards a more coordinated approach to learning resource development. Existing materials can be reviewed against the common framework, retained where they already provide relevant content, and adapted or complemented where gaps are identified. In this way, the framework can support the reuse of knowledge generated through previous projects while reducing the need to repeatedly develop similar content in separate initiatives.

As a practical mechanism for supporting this process, the LIAISE network could consider establishing a shared repository or resource hub for existing and subsequently developed IS learning materials. Such a resource base could document materials according to common characteristics, including target groups, learning level, competency domains, learning objectives, format, and potential use. The purpose would not be to impose a single format on existing resources, but to make them easier to identify, compare, combine, and adapt within different learning contexts.

The combination of an internationally developed framework and a network bringing together researchers, educators, practitioners, and other relevant stakeholders therefore provides a basis for building upon existing resources rather than treating each training initiative as a separate effort. The immediate value of the framework for the LIAISE network is consequently its potential to provide a shared reference for the continued development, adaptation, and exchange of IS learning resources.

The future development of such a shared learning resource base should also consider the increasing role of AI-supported learning and skills assessment. As discussed in Section 6.5, AI/ML-based approaches may support the identification of competency gaps, the matching of learners with relevant learning resources and the development of more personalised learning pathways. A shared resource structure based on the competency framework would provide an appropriate foundation for such applications, as learning resources could be described and connected through

common competency and learning-outcome dimensions. This would allow emerging digital and AI-based tools to complement, rather than replace, the human and collaborative processes underlying the development and validation of IS learning resources.

7.2. Co-development of New Training Resources

The future development of Industrial Symbiosis learning resources would benefit from greater coordination across institutions, disciplines, and stakeholder groups. Existing resources demonstrate a range of useful approaches, but their development has taken place within individual projects or institutional contexts. At the same time, the competency analysis and the proposed learning framework provide a more structured basis for defining what future learning resources should address. These findings support a shift from developing isolated training initiatives towards more coordinated co-development of learning resources within the LIAISE network.

The LIAISE network provides an appropriate setting for such collaboration because the development of the framework itself has brought together different areas of expertise and perspectives relevant to Industrial Symbiosis. This experience demonstrates the value of combining academic, technical, organisational, and practical perspectives when defining learning needs. Future training resources should build upon this approach by involving relevant contributors from different disciplines and stakeholder groups in their development, particularly where the subject requires knowledge extending beyond a single field.

The framework developed in this report should be used as a common reference for this co-development process. Its competency domains, learning objectives and design principles can provide a shared basis for defining the scope and expected outcomes of new learning resources, while leaving sufficient flexibility for contributors to adapt the content to sectors, learner profiles, and national contexts. This would allow resources developed by different members of the network to remain context-specific while following a compatible overall learning logic.

Priority should be given to resources that complement rather than duplicate existing provision. Future collaborative development could address areas identified through the mapping and gap analysis, including structured learning pathways, progression between learning levels, practical and industry-based applications, and resources that connect different competency domains. Joint development of case studies representing different industrial sectors and geographical contexts could be particularly valuable, as it would allow learners to examine how Industrial Symbiosis principles are applied under different conditions and would strengthen the transferability of learning.

The LIAISE network should therefore use the framework as a basis for identifying complementary expertise, defining shared learning objectives, and coordinating the development of novel resources. Where appropriate, these activities could be pursued through future collaborative projects and funding opportunities, including European research and education programmes. In this way, the framework can serve not only as a reference for individual training developers, but also as a common foundation for coordinated development of IS learning resources across the network.

7.3. Supporting Curriculum and University-level Integration

The findings of the academic survey indicate that Industrial Symbiosis is already present in a considerable proportion of higher education contexts, but that its integration is limited in scope. In

most cases, IS is addressed within broader courses, particularly those related to Circular Economy, or through individual lectures, modules, or selected topics rather than through dedicated courses. The learning framework developed within this report can provide a structured reference for strengthening this existing integration without requiring institutions to introduce a separate Industrial Symbiosis course.

For university curricula, the framework can be used when reviewing existing courses and identifying where relevant IS-related knowledge areas, competencies and learning objectives are already addressed and where additional content may be appropriate. The knowledge areas identified through the mapping of existing learning resources can provide a useful reference point for reviewing the breadth of IS-related content within a course or programme, while the competency domains provide a basis for considering whether students are developing the analytical, technical, resource-management, sustainability, innovation, collaboration and other competencies required for the application of Industrial Symbiosis. This can support a more systematic integration of IS across related subjects instead of treating it as an isolated topic within individual courses.

The framework can also support various levels of curriculum integration. Where the introduction of a dedicated IS course is not feasible, selected competency domains, learning objectives, case studies or practical activities can be incorporated into existing courses in Circular Economy, Industrial Ecology, sustainability, engineering, management, and related fields. Where a stronger institutional focus on IS is appropriate, the same framework can support the design of a dedicated module or course and its progression towards more advanced learning activities. In this way, the framework provides a common structure while allowing universities to determine the appropriate depth and format according to their existing curricula, programmes, and institutional context. It should therefore be considered as a reference for curriculum review and development rather than as a prescribed curriculum model.

An important implication is that curriculum development should not be considered separately from the wider IS learning ecosystem. University programmes can benefit from learning resources developed through international projects and networks, while academic institutions can contribute research findings, case studies, methodological approaches, and student learning activities to the wider resource base. The framework can therefore serve as an interface between existing university curricula and the broader collection of IS learning resources developed through the LIAISE network, while also providing a basis for inter-institutional and international academic cooperation. Universities using the framework could identify opportunities to jointly develop modules, teaching activities, case studies or other learning resources around shared Industrial Symbiosis learning objectives and competency needs. Such cooperation could be pursued through existing European and international academic collaboration mechanisms, including Erasmus+ cooperation and other research and education projects. In this way, the framework can support not only the integration of Industrial Symbiosis within individual curricula, but also the development, exchange, and adaptation of shared learning activities across institutions and countries.

7.4. International Transferability and Wider Uptake

The development of the learning framework within the LIAISE network provides a basis for extending its relevance beyond individual institutions and national educational contexts. The framework was developed in response to evidence collected from existing Industrial Symbiosis learning provision and higher education practice, combined with the identification and organisation

of competencies relevant to IS learning. Its purpose is therefore not to define a single model of Industrial Symbiosis education, but to provide a common reference that can be interpreted and applied across different educational and professional contexts.

A key value of the framework in this respect is its potential to improve compatibility between different approaches to Industrial Symbiosis learning. Existing provision varies in terms of content, depth, delivery format, target groups, and institutional context. A shared reference framework can help different providers describe learning objectives, knowledge content and competency development using a more comparable structure, while still allowing individual institutions and organisations to determine the appropriate content and level for their learners. This approach supports transferability without requiring standardisation of curricula or training programmes.

The framework may also facilitate the exchange and adaptation of learning approaches across countries and institutions. Resources developed in one context can be reviewed against the framework and adapted for use in another context by considering the relevant competencies, knowledge areas, learning objectives, and characteristics of the intended learners. This can reduce the need for institutions to develop learning resources independently and can support the wider reuse and adaptation of effective educational approaches. In this sense, the framework can function as an interface between diverse learning resources rather than as a replacement for them.

At the European level, the framework can also provide a basis for stronger alignment with wider developments in competence-based and sustainability-oriented education, including approaches reflected in the OECD Learning Compass 2030 (OECD, 2019) and the European sustainability competence framework, GreenComp (Bianchi et al., 2022). The emphasis of these frameworks on competencies, adaptability, interdisciplinary learning, and sustainability provides a broader reference context for the LIAISE framework. At the same time, the specific application of the LIAISE framework to Industrial Symbiosis provides a more focused reference for this emerging field. Such alignment can facilitate dialogue between institutions and initiatives working on Circular Economy, Industrial Ecology, sustainability, resource efficiency, and related areas.

Wider uptake can be further supported through international academic and professional cooperation, including collaborative education and research projects, staff and learner exchanges, joint development of learning activities and other forms of institutional cooperation. Existing European programmes and initiatives, including Erasmus+ and Horizon Europe, provide established mechanisms through which such cooperation may be pursued. The framework can serve as a common starting point for partners from different countries when defining shared learning objectives, developing educational activities or integrating Industrial Symbiosis into broader sustainability and Circular Economy initiatives.

The potential for wider uptake should therefore be understood primarily in terms of transferability, compatibility, and reuse, rather than as an expectation of uniform implementation. The framework offers a common conceptual and design reference that can support the continued development of Industrial Symbiosis learning across different contexts while preserving the diversity of educational systems, professional needs, and regional priorities. In this way, the work undertaken through LIAISE can provide a foundation for continued international exchange and for the gradual strengthening of Industrial Symbiosis learning beyond the immediate network.

8. Limitations

Several limitations should be considered when interpreting the findings of this report. The mapping of training and learning resources was conducted as a structured exploratory exercise based on contributions from WG3 members and information available during the data-collection period. The findings therefore reflect the resources identified through this process, while internal company training, proprietary materials and resources with limited public visibility remained outside its main scope. The geographical and language coverage also reflects the resources available to the contributors and within the LIAISE network. The resource inventory can be progressively expanded and updated through continued contributions from LIAISE members, cooperation with external organisations and links with relevant educational repositories.

The survey was distributed within LIAISE COST Action WG3 and participation was voluntary. The resulting sample provided perspectives from different countries and institutional and professional profiles, although its size and uneven geographical distribution limit broader generalisation of the findings. In addition, conditional routing, multiple-response questions, and differences in response rates resulted in varying numbers of valid responses across individual questions. These differences are indicated in the relevant figures and tables and should be considered when interpreting the reported percentages. Future surveys could broaden participation beyond WG3, seek more balanced geographical coverage, and include additional information on respondents' institutional backgrounds and experience with Industrial Symbiosis.

The analysis focused on describing the characteristics, content and accessibility of the identified resources and recognising recurring patterns and gaps in the existing educational provision. It was not intended to provide a formal comparative evaluation of their pedagogical quality, learning outcomes or longer-term impact, which would require direct participation in or systematic evaluation of the courses. A subsequent evaluation could address these aspects through pilot application, learner and educator feedback, and assessment of learning outcomes for selected resources.

Finally, the proposed learning framework represents an evidence-informed conceptual basis that has not yet been formally validated or tested through pilot implementation. Its practical application and validation with relevant stakeholder groups represent appropriate next steps for further work within LIAISE COST Action.

9. Conclusions and Future Directions

This report examined the existing landscape of learning and training related to Industrial Symbiosis and used the findings to develop a conceptual framework for future learning within the LIAISE network. The analysis combined the mapping of existing learning resources and higher education provision with the assessment of knowledge areas and competencies considered relevant for Industrial Symbiosis education and capacity building.

The mapping results show that Industrial Symbiosis learning is currently dispersed across different educational formats and is frequently embedded within broader areas such as Circular Economy, sustainable production, resource efficiency, and waste management. At the same time, more specialised Industrial Symbiosis knowledge and some analytical foundations, including Material Flow Analysis and Industrial Ecology, are less consistently represented. The competency assessment further indicates that effective Industrial Symbiosis learning requires a combination of complementary competencies rather than a single dominant area. In particular, the findings highlight the importance of connecting Circular Economy principles with Industrial Symbiosis, together with analytical and resource-related competencies, innovation, collaboration, interdisciplinary understanding, and other supporting capabilities.

These findings provided the basis for the development of the LIAISE conceptual framework for future learning. Rather than proposing a single curriculum or standardised training programme, the framework provides a common reference for structuring Industrial Symbiosis learning across different educational and professional contexts. Its competency-based, interdisciplinary, practical, and adaptable orientation allows learning providers to select and organise relevant knowledge, competencies, learning activities, and resources according to their specific learners and institutional environments.

The framework also provides a basis for connecting existing and future learning resources and for supporting greater compatibility and transferability across institutions and countries. Its potential alignment with wider European approaches to competence-based and sustainability-oriented learning, together with the possibility of linking it to existing skills and competency classifications, can further support its reuse and adaptation beyond the immediate LIAISE network.

The report also identified opportunities for further development through digitalisation and AI/ML-supported approaches. Existing competency frameworks, learning resources and digital technologies provide a potential basis for further exploring an open-source AI/ML-based platform for broad skills assessment. Such a platform could, subject to further methodological and technical investigation, support competency profiling, identification of skills gaps and connections between assessment results and relevant learning opportunities. Its development would require further consideration of data availability, assessment methodology, interoperability, transparency, human oversight, and other governance requirements.

Overall, the work presented in this report establishes a foundation for a more coherent, competency-oriented, and transferable approach to Industrial Symbiosis learning. The framework is intended as a living reference that can be further tested, refined, and enriched through future LIAISE activities, collaboration with educational and professional stakeholders, and the experience gained from applying it in different contexts. Its wider value will depend on its ability to support the development, adaptation and exchange of learning opportunities that strengthen the knowledge and competencies required for the broader implementation of Industrial Symbiosis.

Appendix 1. Selected Examples of Industrial Symbiosis Training and Learning Resources

This appendix presents selected examples of existing training and learning resources identified through the mapping of industrial symbiosis education and training provision. The examples were selected to illustrate the diversity of formats, target groups, learning levels, and approaches currently used to develop knowledge and competencies related to industrial symbiosis. The selection is illustrative rather than exhaustive.

SUS0310 – Industrial Symbiosis

steeluniversity

Provider / project: Steel university
Type of resource: Online course
Target group: Students
Level: Introductory
Delivery format: Self-paced
Geographic scope: International
Key characteristics: Short-term training; limited scalability
Source: [SUS0310 – Industrial Symbiosis](#)

SUS0310 – Industrial Symbiosis is a short online course developed by steel university, the learning and training programme of the World Steel Association. The course has an estimated duration of three hours and introduces the principles and practices of industrial symbiosis, with a focus on applications in the cement, ceramics, and steel sectors. The learning objectives include understanding the main benefits and challenges of industrial symbiosis, describing current practices and material, thermal, and electrical energy synergies, and comparing traditional industrial practices with symbiotic approaches to identify opportunities for improvement and innovation. The course therefore provides a concise, sector-oriented introduction to industrial symbiosis, combining general concepts with examples from specific industrial sectors.

Industrial Symbiosis and Eco-Industrial Parks Development Training Course



Provider / project: Upskill Development Centre
Type of resource: Online course
Target group: All
Level: Intermediate
Delivery format: Online
Geographic scope: International
Key characteristics: Practical / case-based; Tool-oriented
Source: [Industrial Symbiosis and Eco-Industrial Parks Development Training Course](#)

The Industrial Symbiosis and Eco-Industrial Parks Development Training Course is a five-day professional training programme focusing on the technical and strategic aspects of industrial symbiosis and eco-industrial park (EIP) development. The course covers the principles and evolution of IS and EIPs, circular economy and resource efficiency, industrial metabolism and resource-flow assessment, identification and mapping of industrial synergies, EIP design and infrastructure planning, cleaner production, governance and regulatory frameworks, financing, stakeholder engagement, and sustainability monitoring and reporting. Tools such as GIS, material flow analysis and digital platforms are introduced to support the identification and management of symbiotic opportunities. The training combines theoretical content with practical activities, group discussions, and global case studies. Its distinctive feature is the broad scope of IS implementation, bringing together technical, analytical, financial, policy, governance, and stakeholder-related aspects within a single professional training programme.

INSIGHT Industrial Symbiosis Facilitator Training



Provider / project: INSIGHT Consortium
(Erasmus+ project)

Type of resource: Online course

Target group: All

Level: Intermediate

Delivery format: Online

Geographic scope: International

Key characteristics: Interdisciplinary

Source: [INSIGHT Industrial Symbiosis
Facilitator Training – e-learning platform](#)

The INSIGHT Industrial Symbiosis Facilitator Training is an online learning programme developed within an Erasmus+ project with the specific aim of developing a new professional profile, the Industrial Symbiosis Facilitator. The training is designed for a range of target groups involved in regional and local economic development, including regional development agencies, technology centres, clusters, local and regional administrations, and technology parks. The e-learning course comprises five modules, with each module concluding with a knowledge assessment test. Its distinctive feature is the explicit focus on the professional role of an industrial symbiosis facilitator, rather than on general awareness of industrial symbiosis. The programme is therefore particularly relevant to capacity building for actors expected to support the development of industrial symbiosis within specific territories and among relevant organisations.

Capacity Building for Industrial Symbiosis



Provider / project: International Synergies

Type of resource: Other

Target group: Industry / practitioners

Level: Advanced

Delivery format: Self-paced

Geographic scope: International

Key characteristics: Practical / case-based

Source: [Capacity Building for Industrial Symbiosis – International Synergies](#)

Capacity Building for Industrial Symbiosis by International Synergies focuses on developing the practical capabilities required to identify, develop, and implement industrial symbiosis opportunities. The training is designed for industrial symbiosis facilitators, companies, public authorities, and other stakeholders involved in economic and regional development. Depending on the target group, the training combines presentations, guided exercises, interactive activities, and self-guided learning. Content includes resource mapping, identification and prioritisation of resource-reuse opportunities, engagement of companies in industrial symbiosis networks, and facilitation of potential resource exchanges. The approach is strongly practice-oriented and draws on International Synergies' experience in implementing industrial symbiosis programmes and supporting stakeholders in real-world contexts. A distinctive feature is its emphasis on translating industrial symbiosis concepts into practical action, particularly by developing the capabilities needed to identify and progress resource-reuse opportunities. The resource therefore represents a practice-oriented approach to capacity building for industrial and institutional stakeholders involved in implementing industrial symbiosis.

INSET Toolkit and Training Modules



Provider / project: INSET Consortium
(Erasmus+ project)

Type of resource: Toolkit / guideline

Target group: All

Level: Advanced

Delivery format: Online

Geographic scope: EU-level

Key characteristics: Practical / case-based;
Theoretical; Interdisciplinary; Short-term
training

Source: [INSET Resources – Training](#)

The INSET project provides a digital training toolkit aimed at supporting capacity building for Industrial Symbiosis among enterprises, innovation agents and Vocational Education and Training (VET) providers. The project addresses knowledge gaps and skills need that can hinder the

implementation of IS and emphasises management and transversal skills needed to facilitate collaboration. Its capacity-building approach is complemented by resources addressing IS networking and cooperation among relevant stakeholders. The IS Networking Session Handbook provides practical guidance for organising networking sessions aimed at supporting interaction and cooperation around Industrial Symbiosis. The broader INSET approach also includes an open-access Observatory on IS and policy-oriented activities addressing regulatory frameworks, training opportunities, and barriers to implementation. The resource is therefore positioned within a broader capacity-building approach that combines training, networking, awareness raising and support for the development of IS-enabling skills.

CATALYST Resource Hub and Training Package



Provider / project: National Center for Sustainable Production and Consumption (CNPCD)

Type of resource: Toolkit

Target group: All

Level: Intermediate

Delivery format: Online

Geographic scope: International

Key characteristics: Practical / case-based; Interdisciplinary

Source: [CATALYST Resource Hub](#)

The CATALYST Resource Hub is a collection of training and documentary resources developed within the CATALYST project, focusing on circular economy and industrial symbiosis in relation to industrial parks. The training resources cover several aspects of industrial symbiosis, including an introduction to circular economy and industrial symbiosis, energy, water and resource flows, circular economy and industrial symbiosis in different industries, mapping tools for industrial symbiosis, and facilitating industrial symbiosis. The collection also includes resources specifically addressing eco-industrial parks. Materials are available in English, Romanian and Norwegian. The hub provides a structured set of learning resources covering both conceptual aspects of industrial symbiosis and practical topics such as resource-flow mapping and facilitation. Its distinctive feature is the combination of general industrial symbiosis topics with resources addressing eco-industrial parks and specific tools for mapping and facilitating industrial symbiosis.

Smart Circular Economy: From Industrial Symbiosis to Future Supply Chains



Provider / project: FREiNDS
Type of resource: Online course
Target group: All
Level: Intermediate
Delivery format: Online
Geographic scope: International
Key characteristics: Project-based;
 Interdisciplinary; Practical / case-based; Tool-
 oriented
Source: [Smart Circular Economy: From
 Industrial Symbiosis to Future Supply Chains](#)

Smart Circular Economy: From Industrial Symbiosis to Future Supply Chains is an online course that places industrial symbiosis within the broader context of circular economy and future-oriented supply chains. The course combines conceptual learning with practical and project-based activities, addressing the relationships between industrial symbiosis, resource efficiency, circular economy, digitalisation, and supply-chain transformation. Its interdisciplinary approach brings together analytical, digital, and business perspectives, while practical cases and tools support the application of concepts to real-world challenges. A distinctive feature of the course is its broader systems perspective: rather than treating industrial symbiosis as an isolated mechanism for resource exchange, it connects IS with changes in supply chains and the development of smart circular production and business systems. The course also incorporates industry-integrated challenges and competence-based assessment, following a learning sequence from modules and quizzes through real case work to a final test and integrated competence.

Circular and Green Economy



Provider / project: University Politehnica
 Timișoara
Type of resource: Master's programme
Target group: Students
Level: Advanced
Delivery format: On-site
Geographic scope: National
Key characteristics: Theoretical
Source: [MEng Circular and Green Economy](#)

The Circular and Green Economy programme is intended for master's students and integrates Industrial Symbiosis within broader learning on circular economy transition. The curriculum connects IS with resource efficiency, cleaner production, life-cycle assessment, sustainable business models, environmental legislation, decarbonisation, and ESG risk management. Industrial Symbiosis is addressed through a dedicated course and supported by professional practice. The programme combines engineering, environmental management, and business perspectives, enabling students

to analyse resource use and develop technical and organisational solutions for circular industrial systems.

Industrial Symbiosis to Build Sustainable and Competitive Systems



Provider / project: AIDIMME
Type of resource: Other – video podcast
Target group: All
Level: Intermediate
Delivery format: On-site
Geographic scope: National
Key characteristics: Interdisciplinary; case-based
Source: [Industrial Symbiosis to Build Sustainable and Competitive Systems](#)

The video podcast explains the role of the Valencian Community Industrial Symbiosis Observatory in identifying opportunities, conducting assessments, developing collective strategies, and monitoring symbiosis initiatives. The material also addresses the difficulties companies face when translating circular economy principles into practice. Its distinctive feature is the use of a concrete regional case to demonstrate how cooperation and resource exchange can simultaneously reduce environmental impacts and support industrial competitiveness.

Apply Industrial Symbiosis in Your Company: Presentation of the Valencian Community Industrial Symbiosis Portal



Provider / project: AIDIMME
Type of resource: Training / workshop
Target group: Industry / practitioners
Level: Introductory
Delivery format: On-site
Geographic scope: National
Key characteristics: Project-based
Source: [Apply Industrial Symbiosis in Your Company](#)

This short online workshop presented the SYMBINET project and its prototype for supporting Industrial Symbiosis among companies in the Valencian Community. It explained how resources no longer useful to one company could be used in the processes of another. The programme included sector-specific demonstrators and indicators for assessing the sustainability of symbiotic activities. Its distinctive feature is the presentation of practical tools that translate the concept of Industrial Symbiosis into potential applications within industrial companies.

First Annual Meeting of the Valencian Community Industrial Symbiosis Observatory (OSICV): Industrial Symbiosis and Territory



Provider / project: AIDIMME
Type of resource: Training / workshop
Target group: Industry / practitioners
Level: Introductory
Delivery format: On-site/hybrid
Geographic scope: National
Key characteristics: Project-based
Source: [First Annual Meeting: Industrial Symbiosis and Territory](#)

The first annual OSICV meeting provided industry practitioners and other stakeholders with an introduction to Industrial Symbiosis from a territorial perspective. Participants were introduced to the initial findings of a diagnostic study on Industrial Symbiosis in Valencian industry and to practical experience from an established territorial initiative. Through these examples, the event illustrated the role of local organisations, cooperation between stakeholders and territorial conditions in supporting Industrial Symbiosis. Its distinctive feature is the combination of research findings and practical cases to strengthen participants' understanding of how Industrial Symbiosis initiatives can be developed at the regional and local levels.

Circular Economy Specialist



Provider / project: AIDIMME
Type of resource: Other (professional training course)
Target group: Industry / practitioners
Level: Intermediate
Delivery format: On-site
Geographic scope: National
Key characteristics: Theoretical
Source: [Circular Economy Specialist](#)

The Circular Economy Specialist course provides professionals with knowledge and tools for integrating Circular Economy and sustainability into business operations. Its content covers Circular Economy strategies, environmental risk assessment, Industrial Symbiosis, ecodesign, Life Cycle Assessment, carbon foot printing, ecolabelling, corporate social responsibility and sustainability reporting. Participants are also introduced to methods for identifying organisational strengths and weaknesses and developing a company-level Circular Economy action plan. Industrial Symbiosis is therefore addressed as one component of a broader professional training programme on sustainable business management.

Industrial Symbiosis, End-of-Waste Status and By-products: Creating Value from a Company's Underutilised Resources



Provider / project: AIDIMME
Type of resource: Training / workshop
Target group: Industry / practitioners
Level: Intermediate
Delivery format: Online/On-site
Geographic scope: National
Key characteristics: Theoretical
Source: [Industrial Symbiosis, End-of-Waste Status and By-products](#)

This course introduces industry practitioners to Industrial Symbiosis, the legal framework governing its implementation and the use of underutilised company resources. It covers waste legislation, end-of-waste, and by-product considerations, together with practical examples of Industrial Symbiosis developed by companies in the Valencian Community. Participants are also introduced to Simbylay, AIDIMME's Industrial Symbiosis platform for identifying potentially useful resources. Its distinctive feature is the connection between regulatory knowledge, practical company cases and a digital tool supporting the identification of resource-exchange opportunities.

Third Annual Meeting of the Valencian Community Industrial Symbiosis Observatory



Provider / project: IVACE
Type of resource: Training / workshop
Target group: Industry / practitioners
Level: Intermediate
Delivery format: Online
Geographic scope: National
Key characteristics: Project-based
Source: [Third Annual Meeting of the Valencian Community Industrial Symbiosis Observatory](#)

The third annual OSICV meeting provided industry practitioners and other stakeholders with an overview of recent Industrial Symbiosis developments in the Valencian Community. The programme presented the development of OSICV activities, the European Circular Cities and Regions Initiative, Industrial Symbiosis demonstrators and a regional catalogue of good practices. Through practical company cases, participants learned how cooperation between organisations can transform waste streams, resources and energy into new opportunities while improving environmental and economic performance. Its distinctive feature is the combination of regional project results, practical business examples, and wider European Circular Economy initiatives.

İzmir Resource Efficiency Center



**İzmir
Kaynak Verimliliği
Merkezi**

Provider / project: İZKA
Type of resource: Other (capacity-building and business support centre)
Target group: Industry / practitioners
Level: Advanced
Delivery format: On-site
Geographic scope: International
Key characteristics: Project-based
Source: [İzmir Resource Efficiency Center](#)

The İzmir Resource Efficiency Center supports industrial and agricultural companies through tailored training, consultancy and guidance in green transformation, resource efficiency, clean energy, carbon management, and digital transformation. Its Industrial Symbiosis activities combine training and capacity building with cleaner production assessments, Life Cycle Assessment, and technical support for companies. The Center also operates ECOCYCLE, a digital platform through which companies can identify potential matches, exchange waste and by-products, and monitor the environmental and economic benefits of resource exchanges. Its distinctive feature is the integration of learning and capacity building with company-level needs assessment, technical consultancy, and a practical digital platform for implementing Industrial Symbiosis.

Symbiosis Training Program



**Kalundborg
SYMBIOSIS**

Provider / project: Kalundborg Symbiosis / SACI project
Type of resource: Online course
Target group: Industry / practitioners
Level: Intermediate
Delivery format: Online / on-site
Geographic scope: International
Key characteristics: Interdisciplinary; practical / case-based
Source: [Symbiosis Training Program](#)

The Symbiosis Training Program was developed as part of the SACI project to provide participants with knowledge, practical insights and tools for Industrial Symbiosis and the green transition. The programme combines online training, a master class in Kalundborg and online case-sharing sessions. Its content addresses facilitation, the role of municipalities, technical screening, policy, energy and side-stream mapping, communication, and partnership development. Cases from Denmark, Norway, Brazil, and the United States connect Industrial Symbiosis concepts with practical experience from different industrial and geographical contexts.

Introduction to Industrial Symbiosis



Provider / project: Kalundborg Symbiosis / SACI project

Type of resource: Online course

Target group: Industry / practitioners; facilitators

Level: Intermediate

Delivery format: Online

Geographic scope: EU-level

Key characteristics: Practical / case-based; tool-oriented

Source: [MAESTRI Training Courses](#)

Introduction to Industrial Symbiosis is one of five self-contained micro-training courses within the MAESTRI Total Efficiency Manager 4.0 training programme. The programme is intended for the industrial community and other stakeholders interested in applying MAESTRI tools and methods within their professional contexts. The Industrial Symbiosis course is positioned alongside modules on IoT, eco-efficiency and Lean Management, connecting Industrial Symbiosis with an integrated approach to improving environmental and economic performance in process industries. Participants access the learning materials online, complete a quiz and may request a certificate of attendance without prior enrolment.

Training on Industrial Symbiosis for Small and Medium Enterprises



Provider / project: Kalundborg Symbiosis / SACI project

Type of resource: Training/workshop

Target group: Industry / practitioners

Level: Introductory

Delivery format: On-site

Geographic scope: National

Key characteristics: Theoretical

Source: [Training on Industrial Symbiosis for Small and Medium Enterprises](#)

This training introduces small and medium-sized enterprises to the principles of Circular Economy and Industrial Symbiosis and explains how Industrial Symbiosis differs from conventional recycling and waste management. Participants examine cooperation models, resource-use synergies, and international examples relevant to Montenegro. Practical activities include mapping company resource flows, identifying losses and by-products and exploring opportunities for resource exchange, shared infrastructure and knowledge sharing through an interactive World Café session. The training also addresses implementation barriers, facilitation, trust-building and available support for pilot Industrial Symbiosis projects.

Appendix 2. Survey on Industrial Symbiosis Content and Training Programs in Higher Education

The aim of this survey is to support the development of the deliverable **D3.1 – Report on Existing Training and Future Learning Framework related to Industrial Symbiosis** within COST Action CA22110

The survey seeks to collect information on the current presence of Industrial Symbiosis (IS) content and related sustainability topics in higher education courses, curricula, and training programs. Participation in this survey is voluntary and anonymous. The collected data will be used solely for research and reporting purposes within LIAISE, and the results will be presented in aggregate form.

General Information

1. Country _____
2. Type of institution:
 - University
 - Research institute
 - Vocational education and training (VET) provider
 - Private training provider
 - Other: _____
4. Your role within the institution:
 - Academic staff
 - Researcher
 - Programme coordinator
 - Administrative staff
 - Trainer/educator
 - Other: _____

Presence of Industrial Symbiosis-Related Content

5. Does your institution include topics related to Industrial Symbiosis (IS) or closely related concepts in its educational or training activities?
 - Yes
 - No
 - Not sure
6. In which forms are these topics included? (multiple answers possible)
 - Dedicated course on Industrial Symbiosis
 - Module/unit within another course

- Circular Economy course including IS topics.
- Industrial Ecology course
- Professional training programme
- Workshop/seminar
- Summer school
- Project-based learning activities
- Research activities connected to teaching
- Other: _____

7. At which educational level are these topics offered?

- Bachelor level
- Master level
- PhD level
- Lifelong learning / professional education
- Vocational education and training (VET)
- Informal training
- Other: _____

8. How extensively is Industrial Symbiosis covered within the curriculum??

- Mentioned briefly
- One lecture/session
- One module/unit
- Multiple modules
- Dedicated full course/programme.

9. Which target groups are primarily addressed in the course/training?

- Undergraduate engineering students
- Environmental science students
- Business and economics students
- Public policy and administration students
- Postgraduate researchers
- Industry professionals
- Public sector practitioners
- Interdisciplinary groups
- Other: _____

Knowledge and Skills Areas

9. Which knowledge areas are addressed through these courses or activities? (multiple answers possible)
- Principles of Circular Economy
 - Industrial Symbiosis concepts

- Resource efficiency
- Sustainable production systems
- Waste management and valorisation.
- Industrial ecology
- Environmental management
- Material flow analysis
- Life-cycle assessment (LCA)
- Policy and regulation
- Business models and innovation
- Digital technologies/data management
- Other: _____

10. How relevant are the following skills and competencies for effective Industrial Symbiosis implementation?

	Not relevant	Slightly relevant	Moderately relevant	Relevant	Highly relevant
Systems thinking					
Analytical and problem-solving skills					
Data analysis and interpretation					
Resource management and flow analysis					
Collaboration and networking					
Communication skills					
Technical and process engineering skills					
Project management					
Strategic decision-making					
Sustainability assessment					
Circular economy integration					
Innovation and entrepreneurship					
Interdisciplinary thinking					
Digital and data-driven skills					
Other: _____					

Challenges and Gaps

12. What are the main barriers to integrating Industrial Symbiosis topics into curricula or training programmes? (multiple answers possible)

- Lack of expertise
- Lack of teaching materials
- Limited institutional support
- Lack of funding
- Limited stakeholder interest
- Insufficient interdisciplinary collaboration
- Lack of practical examples/case studies
- Curriculum overload
- Other: _____

13. Are there plans to expand or introduce Industrial Symbiosis-related educational activities in the future?

- Yes
- No
- Maybe

Additional Information

14. Please provide links or references to relevant courses, syllabi, training materials, or platforms (if available): (open-ended)

15. Additional comments or suggestions: (open-ended)

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