SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2024
ORGANIZATION AND MANAGEMENT SERIES NO. 214

EUROPEAN PERSPECTIVE ON DIGITAL INDUSTRIAL SYMBIOSIS

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Purpose: The aim of the paper is to assess the current situation in European countries with regard to their needs for the implementation of Digital Industrial Symbiosis (DIS). It is also an identification of the ongoing European Commission projects that support the development of DIS.
Design/methodology/approach: The study employed secondary sources of information, including reliable websites, to analyze industrial symbiosis implementation across various European countries. Case studies of EU countries were selected based on their innovation levels as per the European Innovation Scoreboard. Unstructured interviews with representatives from several organizations, and review of several EU funded projects enabled to identify barriers and challenges to Digital Industrial Symbiosis development.
Findings: The study made it possible to assess the development of industrial symbiosis in selected European countries and their openness to implementing the concept of Digital Industrial Symbiosis. The role of EU programs in this process was also considered.
Research implications: The review can become the basis for exploring opportunities for international cooperation in the development of DIS platforms and for defining research guidelines in this area in the context of circular economy advancement.
Practical implications: Digital Industrial Symbiosis fosters cross-sector collaboration between industry, academia and policy makers, driving innovation and the creation of new business models, as well as supporting the EU's sustainability goals. Therefore, capacity building through EU-funded projects and policy development that ensures the integration of Industrial Symbiosis into standardization processes is crucial to equip entrepreneurs, SMEs and professionals with essential skills and digital tools to implement DIS.
Originality/value: The article presents a new concept for integrating stakeholder activities toward a circular economy - through Digital Industrial Symbiosis. Using mini case studies of European countries and EU projects, a broad European perspective on DIS challenges and needs is gained.
Keywords: industrial symbiosis, digitalization, Europe, European Commission programs.
Category of the paper: general review, case study.

1. Introduction

The concept of the circular economy, defined as an economic system that eliminates waste by reducing, reusing, and recycling products and materials, is gaining momentum among academics and policymakers (Lewicka et al., 2023). At the micro-level, companies can contribute to the circular economy by adopting innovative business models that focus on sharing resources, collaborating with stakeholders, and implementing cleaner production processes. Thus, the circular economy involves cooperation between actors in industrial networks, fostering symbiotic relationships that bring economic, social and environmental benefits (Lewicka, Zakrzewska-Bielawska, 2016).

Therefore, a key concept within the circular economy is Industrial Symbiosis (IS), which involves the collective use of under-used assets such as machinery, vehicles and storage space between companies, and the exchange of residual outputs such as materials, by-products and energy (Chertow, 2007; Ventura et al., 2023). This process benefits from the geographical proximity of companies, often located in eco-industrial parks and clusters, which enables the creation of a pro-environmental "innovation climate"" conducive to eco-innovation dynamics.

Nowadays, digitalization offers new opportunities to enhance IS, such as information and communication technologies (ICT) that enable monitoring and tracking material and energy flows through manufacturing processes. Digital Industrial Symbiosis (DIS) can lead to potential synergies by facilitating real-time information exchange between stakeholders. However, a lack of key IS-related services, low awareness of the availability of such solutions and insufficient involvement of potential users has limited the success of DIS (Kosmol, Leyh, 2021). Only limited research is being conducted to understand how digital technologies can help overcome barriers to the development of IS.

The European Commission has played an important role in promoting the circular economy through policies and action plans, and its influence can be crucial in making the DIS a reality. For example, the new 2020 Action Plan for a Cleaner, More Competitive Europe (CE Action Plan, 2020), which emphasizes sustainable product design and circularity in production across key value chains such as electronics, ICT and plastics, can also be a catalyst for advancing the Digital Industrial Symbiosis.

The main objective of this paper is to assess the current situation in European countries with regard to their needs for the implementation of Digital Industrial Symbiosis. It is also an identification of the ongoing European Commission projects that support the development of Digital Industrial Symbiosis.

2. The concept of Digital Industrial Symbiosis

The Industrial Symbiosis is a collaborative approach concerning physical exchange of materials, energy, and services among different firms: accordingly, wastes produced by a given firm are exploited as inputs by other firms. This methodology is able to generate remarkable environmental benefits, since it allows to reduce the amount of wastes disposed of in the landfill and the amount of primary inputs used by the industrial sector (Albino, Fraccascia, 2015).

Many technical solutions for waste and by-product material, water, and energy reuse between neighboring industries (so-called synergies) have been discovered and applied in the IS examples from all over the world (Akyazi et al., 2023). However, the potential for uptake of new synergies in the regions is often limited by a range of non-technical barriers (Krom et al., 2022). The latter include environmental regulation, lack of cooperation and trust between industries, economic barriers, and lack of information sharing (Lewicka et al., 2023). In addition, the growing complexity of the industrial processes and the pressing need for sustainable resource management require now a fast transition to a new Digital Industrial Symbiosis paradigm, by leveraging the unprecedented capabilities of digital technologies for tracking, analysing, and optimizing the flow of materials and energy across different industries, thus facilitating more effective symbiosis (Kosmol, Leyh, 2021).

Several definitions of IS exist, highlighting its complexity and diverse applications. According to Chertow (2007) the essence of IS lies in the exchange of resources between at least three different entities not primarily engaged in recycling. Lombardi and Laybourn (2012) described IS as a network fostering eco-innovation and long-term cultural change without requiring geographic proximity. Other authors framed IS within the context of transforming industrial systems into ecosystems through closed-loop thinking and material exchanges, requiring a collective approach and diverse organizational involvement (Mallawaarachchi et al., 2020).

As a response for the challenges of Industry 4.0 (Ventura et al., 2023), Digital Industrial Symbiosis (DIS) refers to collaborative and mutually profitable relationships between different industries and/or sectors to improve resource utilization and productivity based on business opportunities through digital platforms. It creates an interconnected industrial landscape where one company or sector uses underutilized resources such as: as waste, by-products, residues, energy, water, infrastructures, capacity, expertise, equipment, materials from another company or sector with the result of keeping resources in productive use for longer and for an economic profit (Scafà et al., 2020).

Despite the widely acknowledged benefits of IS, such as cheaper prices, job development, and less waste and pollution, its practical use has been restricted. Barriers include firms' commitments to sustainability, current environmental rules, community awareness, and a lack

of trust in industry collaboration. It may be assumed that digitalization will lead to the elimination of at least some communication barriers (Krom et al., 2022; Iyer, Sangwan, 2024).

Digital platforms can support IS by functioning as management tools and marketplaces for trading industrial waste and by-products, and ensure data confidentiality to alleviate concerns about sharing sensitive information (Krom et al., 2022).

Selected European countries are at varying stages of development in the field of industrial symbiosis. Particularly, Digital Industrial Symbiosis is being gradually, yet unevenly, advanced across EU nations (Järvenpää et al., 2021; Proszowska et al., 2023).

One of the most recognized examples of industrial symbiosis in practice is Kalundborg Symbiosis – a collaboration between nine public and private companies in Kalundborg, Denmark, established in 1972 (Kalundborg Symbiosis, 2024). It represents the world's first industrial symbiosis, utilizing a circular production approach. The core principle involves using one company's waste as a resource for another, benefiting both the environment and the economy. This partnership fosters local growth and supports the companies' CSR efforts and climate change mitigation strategies.

By exchanging materials, water, and energy, Kalundborg Symbiosis enhances resilience and economic benefits while reducing environmental impacts and costs. The goal is to continuously improve business practices, not just for mutual and environmental benefits.

While countries such as Denmark and the Netherlands lead the way with well-established frameworks and digital infrastructures supporting industrial symbiosis, other nations are still in the early phases of adopting these practices. This disparity highlights the need for tailored strategies and enhanced collaboration to ensure a more uniform progression towards sustainable and efficient resource management across the entire European Union.

Digital Industrial Symbiosis is largely driven by economic benefits achieved through mutually advantageous relations that lower costs, reduce risks, facilitate communication and ensure business sustainability. It is recognized as a catalyst for innovation. This approach offers benefits across economic, social, and environmental sustainability by leveraging technology to enhance the exchange of resources, information, and by-products between industries. It improves efficiency by enabling real-time data sharing and analysis, which helps identify potential synergies and optimize resource use. DIS facilitates faster and more accurate decision-making, reducing costs and minimizing waste. Additionally, digital platforms can broaden the network of participating organizations, increasing opportunities for collaboration and innovation. By integrating digital tools, Industrial Symbiosis can more effectively contribute to sustainability goals, reducing environmental impact and supporting the transition to a circular economy.

3. Research methodology

The study utilized secondary sources of information to conduct a comprehensive analysis of industrial symbiosis implementation across various European countries. In preparing this article, literature studies and reliable web pages about European Commission projects were used.

Through unstructured interviews with representatives of Chamber of Commerce and Industry Vratsa Sdruzhenie (Bulgaria); IURS - Institute for Sustainable Development of Settlements (Czech Republic), Confimi Industria Basilicata (Italy) it was possible to identify the barriers and challenges to IS development faced by different European countries. Interviews were conducted between December 2023 and June 2024.

Case studies of European countries and EU-funded projects were analyzed to understand the macro-level conditions fostering industrial symbiosis. Furthermore, statistical data from European databases were employed to assess the progress of industrial symbiosis initiatives across different countries.

Guided by the degree of innovation of European countries - on the basis of The European Innovation Scoreboard (EIS) report (European Innovation Scoreboard, 2024) - countries have been selected that represent varying degrees of innovation and, at the same time, implementation of the Digital Industrial Symbiosis.

The EIS provides a comparative assessment of the research and innovation performance of EU Member States and other European countries and distinguishes 4 groups of countries or regions: Innovation Leaders, Strong Innovators, Moderate Innovators, Emerging Innovators.

The following countries were selected for this review: Denmark and the Netherlands as Innovation Leaders; Austria and Norway (Strong Innovators); Greece, Czech Republic, and Italy (Moderate Innovators); Slovakia, Bulgaria and Poland as Emerging Innovators.

Using secondary sources, it was possible to summarize the current state of industrial symbiosis in these countries and to identify EU programs that support the introduction of DIS.

4. European landscape of Digital Industrial Symbiosis

The Industrial Symbiosis (IS) is one of the key tools identified by the European Commission to facilitate the progressive transition to a sustainable economic system based on a low carbon and resource-efficient economy. Such a concept in recent years has become a recognized approach for environmental improvements at the regional level.

The IS was incorporated into EU law in 2018, and Member States are now required to promote replicable practices. It is also a key component of the EU's Circular Economy Action Plan (CE Action Plan, 2020). Member States are invited to create the conditions for "facilitating Industrial Symbiosis by developing an industry-led reporting and certification system and enabling the implementation of industrial symbiosis".

This review examines the progress of various European countries in implementing industrial symbiosis as part of their circular economy strategies. Across Europe, countries exhibit different levels of advancement in adopting these practices, influenced by national policies, economic structures, and technological capabilities. This is even more evident when assessing the needs for DIS implementation. By comparing these efforts, we can identify best practices, highlight successful case studies, and understand the challenges faced in different contexts. This analysis aims to provide a comprehensive overview of the current landscape of Digital Industrial Symbiosis in Europe.

One of the European leaders in introducing the concept of Digital Industrial Symbiosis is Denmark; innovation index: 149.3 (European Innovation Scoreboard, 2024). With Kalundborg Symbiosis in Denmark being seen as the global pioneer project on industrial symbiosis, Denmark is working hard on bringing the IS also to smaller and more regional cooperation initiatives. Kalundborg is a collaboration between large to very large companies, showcasing how IS can be a competitive strategy, even after 50 years. However, extrapolating the learning to SME's and lesser developed regions of the country has been proven to be difficult.

In the Netherlands (innovation index: 138.3) (European Innovation Scoreboard, 2024), the local authorities are the primary body that is responsible for industrial symbiosis. There is a system for residents that allows recycling to happen more easily. However, businesses can use a helping hand with improving IS since it is less effort to dispose of waste materials rather than recycle them. There are subsidies available for SMEs relating to a circular economy but this is not enough. Several projects aim to equip the business community with knowledge related to Digital Industrial Symbiosis, but there are still more questions than answers on how to fully exploit the opportunities of DIS.

According to EIS Austria and Norway are "strong innovators", with the innovation indexes respectively 127.9 and 128.7 (European Innovation Scoreboard, 2024), what reflects their openness towards Industrial symbiosis.

The long-term goal of the Austrian government is to transform the Austrian economy and society into a comprehensive, sustainable circular economy by 2050. Financial support for circular economy projects and initiatives from public and private sources is therefore an important lever to accelerate the transformation. Under the EU's Recovery and Resilience Facility (RRF), Austria has applied for funding to support the following circular economy priorities for the period 2021-2026: waste prevention and resource conservation; collection quotas for plastic drinks packaging; and the construction and retrofitting of sorting facilities for

plastic packaging (Austrian CE Strategy, 2024). To achieve this, close collaboration between industrial partners, also within the Digital Industrial Symbiosis framework, is essential.

In Norway, industrial symbiosis is vital for reaching the country's ambitious climate goals. To transition to a supportive regulatory environment for industrial symbiosis, Norway needs updated regulations, industry initiatives, and new guidelines for residuals and by-products. Nevertheless, SMEs are seen as crucial actors in this transition, given their role in the Norwegian economy and innovation ecosystem, but they are mostly followers in the development.

Italy (innovation index: 98,6) (European Innovation Scoreboard, 2024) has been recognized for its innovative approach to IS, particularly through regional and national initiatives that integrate IS principles into industrial processes and policies. Recently, diverse networks and platforms have been established: it's the case, for instance, of ENEA (2024), which aims to facilitate the exchange of information, resources, and technologies among businesses to foster IS. However, while there has been significant progress, increasing awareness and participation among small and medium-sized enterprises (SMEs) remains a challenge and the Government is studying how to adapt the regulatory frameworks to deliver a more comfortable environment.

Similarly, the Czech Republic (innovation index: 98,7 (European Innovation Scoreboard, 2024) has shown commitment to industrial symbiosis through initiatives such as its National Waste Management Plan and adherence to EU Circular Economy directives. These efforts aim to optimize resource utilization and minimize waste generation. Additionally, research and innovation funding have supported projects focused on developing technologies and strategies for industrial symbiosis. Industry associations and collaborative initiatives play an important role in promoting symbiotic relationships among businesses, sharing best practices, and advocating for supportive policies. Government support, including incentives and assistance programs, further encourages industries to adopt practices that promote sustainability. Education and awareness campaigns raise awareness about the benefits of industrial symbiosis, fostering a culture of resource efficiency and collaboration. Together, these efforts demonstrate the Czech Republic's commitment to advancing industrial symbiosis and contributing to a more sustainable economy.

Despite the fact that Greece is recognized as a “moderate innovator” – innovation index: 85,3 (European Innovation Scoreboard, 2024), Digital Industrial Symbiosis may be easily introduced in the region. IS in Greece is explicitly referenced within the (Action Plans…, 2018; NNRRP, 2021). Certain regions include support to IS investments as part of their Regional Operational Programmes, e.g., the regions of Attiki and Western Greece. Significant examples of successful IS in Greece include the Volos Business Park in Thessaly, where cement and concrete-producing industries reduce the industry’s water footprint, or in Dytiki Ellada, where feedstuff-producing industries use the fish farming packaging industry’s waste. Also, Greece participates in a digital solid waste reuse platform involving Albania, Bulgaria, Cyprus and

Greece. Serious challenges for the continuing growth of IS in Greece include human capital and finance.

Slovakia is a classic example of an emerging innovator. According to EIS its innovation index is 71,6 (European Innovation Scoreboard, 2024). The Slovak Environmental Strategy (SR Strategy…, 2019) prioritizes the transition to a circular economy. Industrial symbiosis is also gaining momentum, with initiatives led by the Institute for Circular Economy (INCIEN) and Circular Slovakia. Both platforms aim to connect the public and the private actors and foster collaboration among industries to optimize resource usage, minimize waste, and develop new, circular business models. However, despite its potential, a lack of awareness is still observed in companies and industrial actors. In addition, IS development is still hampered by environmental, economic, technical, regulatory, organizational, social, and cultural barriers. These findings indicate problematic issues of industrial symbiosis implementation in Slovak Republic and represent the gaps that need to be addressed. Therefore, Slovakia urgently needs new impetus to re-establish its competitiveness in the digital age. The digitization projects must be driven by clear objectives to stay globally competitive, resilient and environmentally sustainable and to become part of a powerful innovation ecosystem (EXPANDI, 2024).

In Bulgaria (innovation index: 50,6) (European Innovation Scoreboard, 2024), industrial symbiosis initiatives are gaining momentum, exemplifying the principles of a circular economy. One notable example is the partnership between the Devnya Cement Plant and the nearby Svilosa pulp and paper mill. In this collaboration, waste materials from the pulp production process are used as alternative fuels and raw materials for cement production. This not only reduces waste and emissions but also lowers symbiosis is known and applied mainly by large enterprises from the processing industry. Bulgarian's industrial symbiosis integration shows a diverse approach to sustainable industrial practices through national strategies, EU projects, and local initiatives. One notable example is the partnership production costs for both companies. Another example is the collaboration in the Plovdiv region, where agricultural waste from local farms is converted into biogas, which in turn powers industrial operations and generates organic fertilizers. These initiatives demonstrates how strategic redevelopment can promote urban and industrial symbiosis, sustainable land use, and business investment without financial incentives, highlighting the importance of integrating IS into Bulgarian's economic and environmental strategy. Despite these efforts, DIS awareness and knowledge in corporations remain difficult.

It should be noted, that despite being evaluated as an emerging innovator (innovation index: 72,5) two Polish regions: Małopolskie and Warsaw (capital region) are graded as the moderate innovators, with innovation index respectively: 87,0 and 103,2 (European Innovation Scoreboard, 2024).

In Poland, there is a growing awareness of the importance of IS for increasing the economy's efficiency and implementing more dynamic pro-environmental solutions. Still, for a large percentage of Polish enterprises, especially the smaller ones, waste management is associated

only with complying with the legislative requirements regarding their treatment, transportation and recycling (Proszowska et al., 2024). There is not enough initiative regarding their utilization as a resource, as well as understanding of the benefits. The management of natural resources and industrial activities, waste generation and disposal, energy efficiency, demand on raw material for production are becoming urgent issues for our country. Individual good practices observed in Poland (e.g. green industrial parks) indicate a great potential for such solutions. At the same time, they show the need for organizational and financial support. Therefore, further research and projects developing industrial symbiosis are needed.

5. EU projects supporting the advancement of Digital Industrial Symbiosis

European Union programs, such as Horizon Europe or Erasmus Plus, actively support the implementation of industrial symbiosis principles. These initiatives provide substantial funding and resources to foster innovation, research, and collaboration among industries. By promoting eco-innovative practices and facilitating the sharing of resources, EU funding programs significantly contribute to the development of digital competencies and education in sustainable practices. Such programs foster a supportive environment for industrial symbiosis. In addition, these programs encourage partnerships between academia, industry, and policymakers, creating a conducive environment for developing and scaling industrial symbiosis projects. This support is crucial for advancing the circular economy and achieving the EU's sustainability goals.

5.1. Programs advancing Industrial Symbiosis

By strategically connecting companies from different industries, the Interreg Europe project BIS (BALTIC INDUSTRIAL SYMBIOSIS) promoted industrial symbiosis and helped boost eco-innovation. The project carried out nearly 40 business matchmaking events on local and transnational level. The events were ranging from one-to-one meetings between companies examining specific flow of resources (identified through the screening) to larger events considering broader fields of industrial symbioses. Transnational matchmaking granted regions with opportunities to identify companies from the neighboring countries that could help them to exploit the value of their resources more sustainably. Altogether more than 160 companies took part in the matchmaking events, some of them already signed agreements of collaboration. Besides, BIS succeeded not only in creating awareness of Industrial Symbiosis among a broad field of actors in the Baltic Sea region, but also in providing capacity building among supportive structures such as clusters and public authorities (BIS, 2019). Successful training programs were developed and implemented based on close cooperation with educational partners, and all training sessions were customized to each region (Screening Tool, 2021).

A survey conducted at regional level (2020-2021) as part of the project IN-SYMBIOSIS (Industrial Symbiosis efficiency for sustainable solutions in South Baltic area) showed a huge demand from industry to study and discuss scenarios of successful industrial symbiosis principles. During the process, it was found that in the field of industrial symbiosis there are no ready-made solutions, study visits are only isolated and rare, and there is a lack of sharing of experiences from good cases. There is a great need for partner-finding events, for training, for awareness-raising in this particular field of industrial symbiosis. Industries in the South Baltic region are able to switch to industrial symbiosis solutions more effectively, exchange good practices, find new business partners, increase skills, train staff, initiate new ideas for industrial symbiosis, if they are at least supported by regional experts in the field. Seed funding is needed to explore and structure the current state of knowledge in the field and to develop solutions to support cross-border cooperation in the exchange of experience and mutual cooperation in order to prepare a project concept to be used for the regular development of project proposals on the effectiveness of industrial symbiosis and the exchange of experience in the field (IN-SYMBIOSIS, 2024).

Through SYMBI project (Industrial SYMBIosis for Regional Sustainable Growth and a Resource Efficient Circular Economy) the Małopolskie Voivodeship has developed a methodology for collecting data on industrial symbiosis, the use of secondary raw materials and the circular economy at regional and national levels. In addition, a comparative analysis of public policies in the field of industrial symbiosis and CE for individual European Union (EU-28) countries was carried out, together with recommendations, e.g. on tax policy (abolishing VAT for products made from recycled materials, introducing tax breaks for companies applying industrial symbiosis). The added value of the project was to raise public awareness of the concept of industrial symbiosis and the circular economy and to promote public-private partnerships in pursuit of its implementation, as well as to encourage small and medium-sized enterprises to take advantage of synergies in the networking of separate economic sectors operating in this rapidly growing market (SYMBI, 2021).

Project RISERS (A Roadmap for Industrial Symbiosis Standardization for Efficient Resource Sharing) addresses developing a roadmap that defines areas, directions and proposes actions where standards are needed to advance industrial symbiosis with focus on priority resources and synergies demonstrating the highest symbiotic potential in Europe. Key activities of the RISERS project involve: identification of priority synergies between industries and sectors together with resources most relevant for industrial symbiosis, strengthening the links between R&I and standardization to valorize and integrate R&I results into IS standardization processes, cooperation with policy makers to develop policy frameworks in support of industrial symbiosis and engagement with standardization experts to develop a Standardization Roadmap for boosting IS impact complemented with guidelines for technical committees to address industrial symbiosis in standardization processes (RISERS, 2024). The project provides

a consensus on the core elements of industrial symbiosis to enable its identification and on good practice approaches to implementation across Europe and beyond.

5.2. Focus on digitalization in EU programs

Many EU funding programs support the transition to a smarter, more digitalised Europe. Below are some examples of projects whose main objectives coincide with the implementation of the DIS.

The project TRUE (Transparency of Learning Outcomes through Blockchain Technology) focuses on the university's use of Blockchain technology demonstrating how different sectors (ICT, rectories, administration, students, etc.) can benefit from this technology. The innovative force of TRUE relies on its targeted approach of blockchain deployment for higher education purposes, resulting in the use of such technological infrastructure to secure the circulation of verified learning transcripts, diplomas and academic credits, thus enhancing transparency between HEIs, students and third parties (TRUE, 2020).

The REFRAME project (Circular Economy Strategy Framework for Sustainable SMEs) creates a CE Transition Framework specifically for small and medium businesses in construction, manufacturing and crafts industry, to help them become friendlier to the environment. It provides the EU construction & manufacturing SMEs and micro-enterprises' employees and future employees with practical knowledge on implementing CE transition in their business. A step-by-step framework for SMEs and micro-enterprises shows them how to scale up by understanding, utilising and investing in a Circular Economy, how to manage resources more efficiently and be friendlier to the environment (REFRAME, 2021).

The project European Digital Innovation Hub EXPANDI 4.0 (EXPANDI 4.0 - EDIH) is oriented towards the digitization of industry – SMEs with a particular focus on manufacturing. EXPANDI 4.0 shall support companies, regional and national institutions and policy makers - in finding the adequate technological solutions for implementation of Industry 4.0. Besides understanding the underlying technologies such as IoT, Big Data, AR/VR, AI, ML, sensor systems, robotics, additive manufacturing, predictive smart maintenance, etc., the outcomes of the project support companies to stay globally competitive, resilient and environmentally sustainable and to develop competitive manufacturing skills of digital age (EXPANDI, 2024).

5.3. Programs developing DIS competences

Implementing the principles of Digital Industrial Symbiosis requires education at various levels, with a particular focus on entrepreneurs and SME owners. This multifaceted approach ensures that the benefits of resource sharing and digital innovation are fully understood and effectively applied. By providing targeted training and resources, businesses can leverage the power of digital technologies to optimize waste reduction, increase resource efficiency and foster collaborative networks. This education should encompass practical skills, strategic thinking, and an awareness of the economic and environmental advantages, ultimately driving

widespread adoption and success in sustainable practices across industries. The following are various EU projects that build the competencies needed to implement DIS.

The project TRANSITION (Foster Blockchain acquisition for entrepreneurs) aims to present the Blockchain technology to current and potential entrepreneurs and inspire them to adopt the technology in their business. Business hubs and incubators were also within the target group as they can further transfer the knowledge to their customers. The project‘s objective is to create and innovate teaching materials aimed at three crucial components of the entrepreneurial ecosystem: potential startup founders, entrepreneurial trainers/coaches working in business support organizations(accelerators, incubators, development agencies) and current entrepreneurs. These three categories need to be up to date with innovative technology trends and Blockchain is the tech revolution that most probably will change all the aspects of the business world forever (TRANSITION, 2019). Giving an integrated type of training to future entrepreneurs with general knowledge of the topic of Distributed Ledgers Technology along with entrepreneurial base competencies and the opportunities that this technology can open up for business making.

The I4U project (Industry 4.0 upskilling for SMEs) aims to develop a comprehensive set of educational programs and modules for digitalization of SMEs. The project will develop the concept for and implement 6 Upskilling Eco-systems which will bring together SMEs in labour intensive sectors with Vocational Education and Training (VET) Schools and High Education Institutions (HEIs) and other stakeholders involved in Digital transition/Industry 4.0 processes. The objective will be to build capacity on relevant digital competences and develop easy-to-access ICT training concepts by matching HEI/VET offers with SMEs upskilling needsTo support both collaboration within each Upskilling Eco-system and the access to training modules and knowledge about Industry 4.0, the project will develop the I4U Upskilling Eco-system Collaboration platform, which will enhance the cooperation between education and training, research, labour market, the public sector and the business sector to foster the adoption of common European digital competence frameworks (I4U, 2021).

5.4. Projects developing sustainable skills

Several Erasmus Plus projects support the development of digital capabilities and raising green awareness among scholars and students, based on the assumption that conscious students will soon enter adulthood, become entrepreneurs and employees who are informed about sustainable challenges and more open towards Digital Industrial Symbiosis networks.

The VR-WAMA project (Improve the Efficiency and the Attractiveness of Environmental Engineering and Waste Management Training with Game Based Virtual Reality) is a response to the continuing and urgent needs of the growing environmental engineering and waste management sectors to develop highly qualified VET students with great skills and competencies able to fulfil the sector needs for highly qualified and specialized professionals. Its objective is to enhance the students qualifications, expertise and skills and thus increase their

employability and assist them to make a career in the environmental engineering industry, especially in the context of Industrial Symbiosis. (VR-WAMA, 2019)

The GoGreen project (Using Augmented Reality Technology and Simulation-Based Training to Foster Green Economy) supports the professional development of the private sector stakeholders and entrepreneurs and those willing to effectively support Green Economy through the development of a tailored green curriculum based on augmented reality technology, simulation training and an innovative Massive Open Online Course. The project aims at redefining disciplinary programs and educational methods through cooperation between the different institutions of education and providing theoretical-methodological schemes which are innovative and closer to the analyzed realities as well as virtuous models of action which will enhance environmental issues (GoGreen, 2022).

RAISE (Raising environmental knowledge & awareness through an innovative virtual environment) devised a 3D Virtual World Learning Environment which engages students/teachers, through transformative education to develop the knowledge, skills and attitudes to live more sustainably, change patterns of consumption and production, embrace healthier lifestyles and contribute – both individually and collectively – to the transformation of our societies and the promotion of Industrial Symbiosis. Through learning, students and learners of all ages can find solutions to challenges of today and the future. The 3D Virtual World Learning Environment". will engage students/teachers, through transformative education to develop the knowledge, skills and attitudes to live more sustainably, change patterns of consumption and production, embrace healthier lifestyles and contribute – both individually and collectively – to the transformation of our societies. Environmental education for sustainable futures could increasingly engage students in public life and participation, helping them to face socio-ecological crises caused by human activity (RAISE, 2022).

The project BESIDE (Blockchain use cases in digital finance) aims to present the Blockchain technology and how it can be beneficial to the financial providers (banks, insurance companies, etc.). In addition, the project aims to support the digital transformation of the vocational education and training sector by making the course and its resources for ongoing professional development, all the while adhering to the EU policies. The objectives and results of the BESIDE project align with the priorities of digital transformation and vocational education and training. The BESIDE project is designed to assist financial sector professionals in staying current with the latest developments and technologies in the industry, with a focus on the application of Blockchain technology in digital financial services, all in line with the objectives of the European digital policy (BESIDES, 2022).

Erasmus Plus project ETCASE (Education Towards Circular And Sustainable Economy) aims to drive this change from the grassroots level by educating the next generation. By raising awareness and inspiring young people about sustainability, the project lays the foundation for a society and economy that harmonize with nature. Using innovative teaching methods and

hands-on activities, ETCASE demonstrates that sustainability is enjoyable and a collective responsibility. Today's students are viewed as tomorrow's changemakers. Through a collaborative international effort involving higher education institutions (HEIs) and NGOs, the project will implement innovative activities that include research, practical actions, and educational materials. The project's goal is to transform educational schemes by providing research-based guidelines, innovative instructional resources, and comprehensive teacher training to inspire and empower the next generation in circular economy practices (ETCASE, 2023).

The overall objective of the project REBUILT (ReEngineering BUsIness under cLimaTe crisis) is to develop and cultivate an effective innovation ecosystem of Higher Education Institutions, Business Communities and Research Institutions that contributes towards achieving an urgent environmental turning point. The specific objectives of the REBUILT project include: improvement of the match between curricula of Higher Education Institutes and human capital needs of businesses; development of future-oriented curriculum for Higher Education students and professionals; development of skills strategy and a low carbon transition action plan; raise awareness about environmental and climate-change challenges (REBUILT, 2024).

As the above overview shows, many projects funded by the European Commission directly or indirectly support the advancement of Digital Industrial Symbiosis. Many EU projects are dedicated to raising awareness about the circular economy and industrial symbiosis. These initiatives aim to develop competencies among young adults and entrepreneurs, which will ultimately facilitate the broader implementation of Digital Industrial Symbiosis across Europe. Through educational programs, workshops, and collaborative research, these projects strive to equip participants with the necessary skills and knowledge to integrate sustainable practices into their businesses and communities. By fostering a deeper understanding of the circular economy principles and the benefits of industrial symbiosis, these EU initiatives are laying the groundwork for a more sustainable and resource-efficient future, promoting innovation and cooperation among different sectors and stakeholders across the continent.

6. Conclusions

Industrial Symbiosis (IS) can contribute to achieving a win-win situation between industry and environment for local and regional circular economies. It can often create economic, environmental, and social benefits, which assists in promoting local and regional sustainable development through the collaboration and the synergistic possibilities offered by geographic proximity. However, both creation and operation of IS remain complex and dynamic processes, which requires continuous improvement.

The circular economy aims to eliminate waste through innovative business models and cooperation among industries, supported by digital platforms and regulatory frameworks. Therefore DIS may play a vital role in this system, but practical implementation faces numerous barriers. Continued research and strategic initiatives are essential to overcome these challenges and realize the full potential of a circular economy.

A review of the situation in various EU countries has been conducted to highlight the diversity in the field of industrial symbiosis across Europe. This examination reveals notable differences in how countries adopt and implement industrial symbiosis practices, with some nations displaying advanced and well-established systems, while others are still in the developmental stages. By illustrating these disparities, the review offers a comprehensive insight into the current state of industrial symbiosis in Europe, underscoring the need for customized strategies and collaborative efforts to enhance the adoption of sustainable practices across the region.

While Nordic countries have been pioneers in adopting national strategies and regional initiatives to promote IS, many other countries with less developed industrial sectors or those facing economic challenges didn't not prioritize it or allocated public investments in industries that offer quick returns on investment over those requiring long-term strategy and collaboration. Industrial Symbiosis is a relatively new challenge, not clearly integrated into the regional development strategies or into academic curriculum and training courses: this means that symbiotic mechanisms are unlikely to be initiated from the bottom without the push and support of both public funding and expert players who can act as promoters and coordinators of such a complex process (Akyazi et al., 2023).

The European Commission actively supports the implementation of industrial symbiosis through Horizon Europe or Interreg programs, providing funding and resources to foster innovation, research, and collaboration among industries. These initiatives promote eco-innovative practices and facilitate resource sharing, contributing to the development of digital competencies and sustainable education. Projects like BIS, IN-SYMBIOSIS, SYMBI, and RISERS have demonstrated the benefits of industrial symbiosis, such as reducing carbon emissions, preserving critical resources, and ensuring business sustainability, while also highlighting the need for continued partner-finding events, training, and awareness-raising activities. With regard to the advancement of DIS, projects like TRUE or REFRAME illustrate the EU's commitment to enhancing digital capabilities and fostering a circular economy. These initiatives demonstrate the EU's holistic approach to integrating digital and sustainable practices.

Furthermore, Erasmus Plus projects emphasize developing digital and green skills among students, entrepreneurs, and professionals. These projects aim to cultivate a new generation of informed individuals capable of driving sustainable change and implementing industrial symbiosis principles.

Overall, EU-funded projects significantly contribute to advancing Digital Industrial Symbiosis by promoting education, innovation, and collaboration. By equipping participants with the necessary skills and knowledge, these initiatives are laying the groundwork for a more sustainable and resource-efficient future, fostering cooperation among various sectors and stakeholders across Europe. This general review may serve as a basis for exploring possible opportunities for international cooperation in the development of Digital Industrial Symbiosis platforms and for defining research guidelines in this area in the context of promoting the circular economy.

Acknowledgements

The author would like to express her gratitude to the partners at EXEOLAB (Italy) for their assistance during the collection of information on the needs of individual European countries in the context of DIS.

References

1. European Commission (2020). *A new Circular Economy Action Plan for a cleaner and more competitive Europe*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/, 30.05.2024.
2. *Action Plans. for Circular Economy*. *Greece* (2018). Retrieved from: https://circulareconomy.europa.eu/platform/en/strategies/greeces-action-plan-circular-economy, 16.06.2024.
3. Akyazi, T., Goti, A., Bayón, F., Kohlgrüber, M., Schröder, A. (2023). Identifying the skills requirements related to industrial symbiosis and energy efficiency for the European process industry. *Environmental Sciences Europe*, *No. 35(1),* 54.
4. Albino, V, Fraccascia, L. (2015). The industrial symbiosis approach: A classification of business models. *Procedia Environmental Science, Engineering and Management, No. 2(3)*, pp. 217-223.
5. BESIDES (2022). *Blockchain use cases in digital finance.* Retrieved from: https://besideproject.eu/, 16.06.2024.
6. BIS (2019). *Baltic Industrial Symbiosis*. Retrieved from: https://interreg-baltic.eu/project/bis/, 16.06.2024.
7. Chertow, M.R. (2007). "Uncovering" industrial symbiosis. *Journal of industrial Ecology*, *11*(1), pp. 11-30. https://doi.org/10.1162/jiec.2007.1110

8. ETCASE (2023). *Education Towards Circular And Sustainable Economy.* Retrieved from: https://circular-economy.education/, 16.06.2024.
9. ENEA (2024). Retrieved from: http://www.industrialsymbiosis.it/, 16.06.2024.
10. *European Innovation Scoreboard* (2024). Retrieved from: https://research-and-innovation.ec.europa.eu/statistics/performance-indicators/european-innovation-scoreboard_en, 16.06.2024.
11. EXPANDI (2024). *European Digital Innovation Hub EXPANDI 4.0*. Retrieved from: https://www.expandi40.sk/, 16.06.2024.
12. GoGreen (2022). *Using Augmented Reality Technology and Simulation-Based Training to Foster Green Economy*. Retrieved from: https://go-green.pixel-online.org/, 16.06.2024.
13. I4U (2021). *Industry 4.0 upskilling for SMEs.* Retrieved from: https://i4u-project.eu/, 16.06.2024.
14. IN-SYMBIOSIS (2024.07.02). *Industrial Symbiosis efficiency for sustainable solutions in South Baltic area*. Retrieved from: https://southbaltic.eu/-/industrial-symbiosis-efficiency-for-sustainable-solutions-in-south-baltic-area. 16.06.2024.
15. Järvenpää, A.M., Salminen, V., Kantola, J. (2021). Industrial symbiosis, circular economy and Industry 4.0–a case study in Finland. *Management and Production Engineering Review*, *14*(4), pp. 111-121.
16. *Kalundborg Symbiosis*. Retrieved from: https://www.symbiosis.dk/en/, 16.06.2024.
17. Kosmol, L., Leyh, C. (2021). *A conceptual design for Digital Industrial Symbiosis ecosystems. In The Next Wave of Sociotechnical Design*. 16th International Conference on Design Science Research in Information Systems and Technology, DESRIST 2021. Proceedings 16, pp. 362-374. Kristiansand, Norway: Springer International Publishing.
18. Krom, P., Piscicelli, L., Frenken, K. (2022). Digital platforms for industrial symbiosis. *Journal of Innovation Economics & Management*, *I124-XXVI*.
19. Lewicka, D., Zakrzewska-Bielawska, A. (2016), Rola zaufania w relacyjnej orientacji przedsiębiorstwa. In: G. Osbert-Pociecha, S. Nowosielski (eds.), *Meandry teorii i praktyki zarządzania*. Wrocław: Wydawnictwo UE we Wrocławiu.
20. Lewicka, D., Krot, K., Petryshyn, L., Rehmann, H.U. (2023). Relationship between institutional trust, intraorganisational collaboration and commitment to strategic business development. *Scientific Papers of Silesian University of Technology*. *Organization & Management, no. 186*, pp. 317-328.
21. Lewicka, D., Zarębska, J., Batko, R., Tarczydło, B., Woźniak, M., Cichoń, D., Pec, M. (2023). *Circular Economy in the European Union: Organisational Practice and Future Directions in Germany, Poland and Spain.* London/New York: Taylor & Francis.
22. Lombardi, D.R., Laybourn, P. (2012). Redefining industrial symbiosis: Crossing academic–practitioner boundaries. *Journal of Industrial Ecology*, *16*(1), pp. 28-37.
23. Mallawaarachchi, H., Sandanayake, Y., Karunasena, G., Liu, C. (2020). Unveiling the conceptual development of industrial symbiosis: Bibliometric analysis. *Journal of Cleaner Production*, *258*, 120618.

24. NNRRP (2021). *The National Recovery and Resilience Plan "Greece 2.0"*. Retrieved from: https://commission.europa.eu/business-economy-euro/economic-recovery/recovery-and-resilience-facility/country-pages/greeces-recovery-and-resilience-plan_en, 16.06.2024.
25. Proszowska, A., Prymon-Ryś, E., Dubel, A., Kondak, A., Wilk, A. (2024). *Sustainable marketing and the circular economy in Poland: key concepts and strategies*. London/ New York: Routledge.
26. RAISE (2022). *Raising environmental knowledge & awareness through an innovative virtual environment.* Retrieved from: https://raise-environment.eu/, 16.06.2024.
27. REBUILT (2024). *ReEngineering BUsIness under cLimaTe crisis.* Retrieved from: https://rebuilt-project.eu/, 16.06.2024.
28. REFRAME (2021). *Circular Economy Strategy Framework for Sustainable SMEs*. Retrieved from: https://reframe-project.eu/, 16.06.2024.
29. RISERS (2024). *A Roadmap for Industrial Symbiosis Standardisation for Efficient Resource Sharing.* Retrieved from: https://risers-project.eu/, 7.07.2024.
30. Scafà, M., Marconi, M., Germani, M. (2020). A critical review of symbiosis approaches in the context of Industry 4.0. *Journal of Computational Design and Engineering*, *No. 7(3),* pp. 269-278.
31. Screening Tool (2021). *Screening Tool for Industrial Symbiosis Facilitators.* Retrieved from: https://symbiosecenter.dk/screening-tool-for-industrial-symbiosis-facilitators/, 7.07.2024.
32. SR Strategy... (2019). *Strategy of the Environmental Policy of the Slovak Republic until 2030.* Retrieved from: https://www.minzp.sk/, 7.07.2024.
33. SYMBI (2021). *Industrial Symbiosis for a Resource Efficient Economy*. Retrieved from: https://projects2014-2020.interregeurope.eu/symbi/, 7.07.2024.
34. Federal Ministry Republic of Austria (2022). *The Austrian Circular Economy Strategy*. Retrieved from: https://www.bmk.gv.at/en/topics/climate-environment/waste-resource-management/ces.html, 30.05.2024.
35. TRANSITION (2019). *Foster Blockchain acquisition for entrepreneurs*. Retrieved from: https://www.transition-project.eu/, 7.07.2024.
36. TRUE (2020). *Transparency of Learning Outcomes through Blockchain Technology*. Retrieved from: https://trueproject.eu/, 7.07.2024.
37. Ventura, V., Bortolini, M., Galizia, F.G. (2023). *Industrial symbiosis and industry 4.0: literature review and research steps toward sustainability.* International Conference on Sustainable Design and Manufacturing, Proceedings. Singapore: Springer, pp. 361-369.
38. VR-WAMA (2019). *Improve the Efficiency and the Attractiveness of Environmental Engineering and Waste Management Training with Game Based Virtual Reality*. Retrieved from: https://vr-wama.etcenter.eu/index.php/en/about-project, 7.07.2024.