

Towards the advancement of Circular Economy via Digital Industrial Symbiosis

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Abstract

This paper highlights Industrial Symbiosis (IS) as crucial for Europe's Circular Economy transition, emphasized by the European Green Deal and EU law since 2018. IS enables sustainable resource use by exchanging materials, energy, and services among industries, reducing waste and enhancing efficiency. Despite proven synergies, barriers like regulation, economics, and trust hinder uptake. Responding to growing industrial complexity and sustainability needs, the study explores Digital Industrial Symbiosis (DIS) using digital tools to optimize collaboration. Surveys and interviews from European countries reveal operational challenges and competence gaps among IS managers. The study develops comprehensive curricula tailored for higher education institutions and vocational training aimed at preparing the IS managers equipped with the skills and knowledge to implement digital and AI solutions. These innovations support green entrepreneurship and the EU's sustainability goals for a circular economy.

Keywords: Circular Economy, Industrial Symbiosis, Artificial Intelligence, Curriculum Development

1. INTRODUCTION

The transition towards a circular economy (CE) is a cornerstone of sustainable development in Europe, as stated in the European Green Deal. 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 low carbon and resource-efficient economy.

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 [1]. This concept in recent years has become a recognized approach for environmental improvements at the regional level. In 2021 the European Commission launched the Circular Economy Action Plan asking the Members States to put in place all the pre-conditions for “facilitating IS by developing an industry-led reporting and certification system and enabling the implementation of industrial symbiosis” [2].

Industrial Symbiosis is a collaborative approach concerning physical exchange of materials, energy, and services among different firms: accordingly, waste produced by a given firm is exploited as input by other firms. This methodology is able to generate remarkable environmental benefits, since it allows to reduce the amount of waste disposed of in the landfill and the amount of primary inputs used by the industrial sector [3].

2. PROBLEM STATEMENT

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 [4]. However, the potential for uptake of new synergies in the regions is often limited by a range of (non) technical barriers. The latter includes environmental regulation, lack of cooperation and trust between industries, economic barriers, and lack of information sharing [5,6]. Further, the increasing complexity of industrial processes and the increasing demand for sustainable resource management make a rapid shift toward a new DIS paradigm essential [7,8]. This paradigm leverages advanced digital technologies to monitor, analyze, and optimize the flow of materials and energy across diverse industries, fostering more efficient collaboration and sustainable resource utilization [9]. This study focuses on developing solutions to overcome the challenges towards the DIS shift.

3. METHODOLOGY

The research process employed a mixed-method approach, combining quantitative and qualitative techniques. At the same time, survey research was carried out in the partner countries. The study provides a comprehensive analysis of empirical data collected through two principal methods: a structured survey and a series of semi-structured interviews. *Figure 1* depicts mixed approach used in this research.

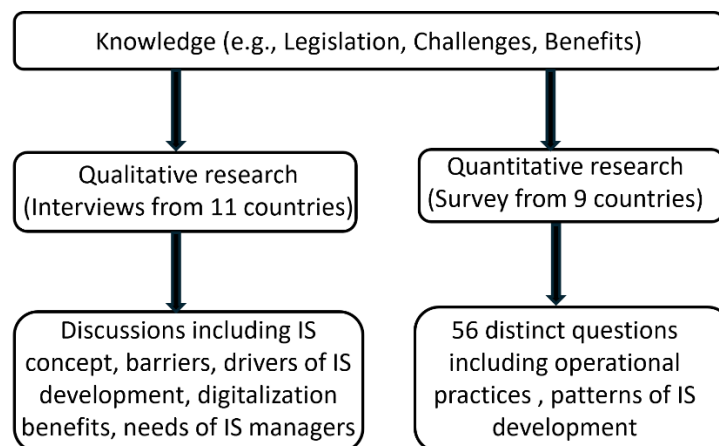


Figure 1: An overview of mixed-method research activities.

The structured survey was designed to examine the current state, operational practices, and development patterns of IS and comprised 56 distinct questions which captured a broad spectrum of information pertinent to industrial symbiosis, ranging from fundamental operational aspects and collaborative structures to subjective perceptions of benefits, trust dynamics, and internal organizational integration. The survey generated a robust dataset encompassing responses from companies operating in nine European countries. To ensure the relevance and validity of the findings, the sample population was deliberately limited to organizations actively engaged in IS initiatives at the time of data collection.

Interviews were conducted with representatives of companies practicing industrial symbiosis as well as with academic experts, trainers, and consultants involved in disseminating knowledge on IS. The interviews covered several topics related to IS including the understanding of the concept of IS, the barriers and drivers of its development, the benefits of digitalizing in IS as perceived by informants, current training offerings, the training needs of IS managers and the curricular content needed to professionalize the IS management profession.

3.1. Curriculum Development

This research systematically identifies, categorizes, and analyzes the dominant trends, recurring challenges, and notable benefits associated with the adoption and execution of IS practices across diverse European industrial contexts. Based on the research results, the main competence gaps (e.g. lack of knowledge about IS, lack of skills in mapping material flows, lack of practices in managing inter-organizational cooperation) were defined for professional roles (e.g. IS Manager, IS Operator).

Considering the requirements of fulfilling the competences gap, two curricula are development, one for university students (higher education Institutions - HEIs) and one for vocational education and training (VET). The curriculum takes into account the learning outcomes, training and education needs of higher education and vocational students so that they can act as symbiotic technology managers after graduation. Each curriculum has seven modules, and each module has its own syllabus. The seven modules and their syllabuses are defined based on the training needs identified for a new professional in IS.

Thus, seven syllabuses for seven HEIs modules and seven VET modules are developed. Learning outcomes of each syllabus were formulated in three categories 1) Knowledge (e.g. knowledge of CE/IS terminology), ii) Skills (e.g. use of flow mapping tools) and iii) Competences/Autonomy and responsibility (e.g. independent observation and reporting). It ensures that a new professional (IS manager) gains required knowledge and skills for using AI-solutions, digital tools for sustainable business models.

4. SUMMARY

This piece of work conducted a mixed research approach for identifying challenges and competencies gaps for new professionals in the digital industrial symbiosis. Considering the requirements to fulfill the lacking knowledge and skills, curricula are developed for courses in HEIs and VET. The competences developed after going through these curriculum supports IS managers managing the resources using advanced digital technology. It contributes to advancing the circular economy through the innovative Digital Industrial Symbiosis paradigm, aiming to foster sustainable growth by integrating innovative training programs, and innovative digital solutions/tools for knowledge exchange and industrial symbiosis practices. It emphasizes collaboration among European Small and Medium-sized Enterprise, educational institutions, and key stakeholders to enhance skills and opportunities in the green economy, by leveraging cutting-

edge technologies. As a part of this initiative, curricula are developed for HEIs and VET which promote green entrepreneurship and labor market opportunities for IS Managers.

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