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Industrial matchmaking: A self-assessment and planning framework and a roadmap approach for industrial symbiosis

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ABSTRACT

Industrial symbiosis plays an important role in reducing greenhouse gas emissions and optimizing resource efficiency within industrial systems. This study introduces a comprehensive methodology to facilitate the transition from the conceptualization of industrial symbiosis initiatives to their practical implementation, focusing on a roadmap process and an innovative self-assessment and planning tool. The research explores the question: *How can a newly introduced methodology and the roadmap methodology contribute to the effective planning and deployment of industrial symbiosis activities, particularly in terms of stakeholder engagement and alignment of shared goals?* The roadmap methodology enables the identification of potential synergies among industrial actors by guiding them through the strategic planning required to foster collaboration, resource exchange, and environmental sustainability. The self-assessment and planning tool further supports this process by offering a framework for evaluating current system performance and outlining future actions, focusing on industrial symbiosis, industrial–urban symbiosis, and the circular economy. This integrated approach, developed as part of the CORALIS and H4C Europe project, is designed to ensure that industrial symbiosis ecosystems can effectively align their objectives with shared goals, minimise risks, and maximise the symbiotic benefits. Through a case study and practical applications, this study illustrates how these tools contribute to developing actionable plans for sustainable industrial collaboration.

1. Introduction

Industrial symbiosis (IS) is a key concept that contributes to the reduction of greenhouse gas (GHG) emissions in the industrial sector and raw materials, energy, and water used through the physical exchange of materials, energy, water, and by-products [1–3]. All these concepts are aligned with the core of the circular economy (CE), which moves from a linear model of consumption to a circular model in which resources are kept within the cycle for a longer period. The definition of IS in the European Committee for Standardization in 2018 is as follows: "*Industrial symbiosis is the use by one company or sector of underutilised resources broadly defined (including waste, by-products, residues, energy, water, logistics, capacity, expertise, equipment and materials) from another, with the result of keeping resources in productive use for longer*" [4,p. 5]. In industrial symbiosis, different stakeholders collaborate to exchange waste and by-products to achieve mutual benefits [3]. Additionally, by facilitating the exchange of materials and energy among various processes and sectors, the IS activities are recognised as a strategy that improves resource efficiency, decreases waste output, and lowers GHG emissions [5].

To achieve successful symbiosis, several aspects must be considered as they can directly influence the performance of IS activities. In the planning phase, one key challenge is coordinating collaborative actions among stakeholders. A major difficulty lies in aligning the objectives of different stakeholders, each with its own priorities, operational procedures, and different degrees of familiarity with IS practices [6]. As highlighted in previous studies [8], companies are often reluctant to engage in synergistic collaborations due to limited awareness of the industrial symbiosis mechanism, concerns over data confidentiality, and uncertainties regarding the economic viability and associated risks of IS

Abbreviations: CCRI, Circular Cities and Regions Initiative; CE, Circular Economy; GHG, Green House Gas Emissions; IS, Industrial Symbiosis; I-US, Industrial-Urban Symbiosis; IT, Information Technology; KPI, Key Performance Indicator; LCA, Life Cycle Assessment; RTO, Research and Technology Organisations; SA&PT, Self-assessment and planning tool; SMART, Specific Measurable Achievable Reasonable Time-bound; SME, Small and Medium Enterprise.

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[7]. These factors complicate the building of trust and collaboration, which are necessary for coordinated resource sharing and the creation of mutually advantageous strategies [8]. Moreover, this type of ecosystem entails social complexity as the networks of interaction constantly evolve [9]. In this context, aligning strategies becomes crucial for a smooth deployment of the activities.

In recent years, numerous studies have focused on supporting IS activities through the development of various methodologies and tools. The literature presents a broad spectrum of qualitative and quantitative approaches addressing different challenges, from identifying IS creation opportunities to evaluating its performance [10]. Among these efforts, a review of IS-related tools conducted highlights the role of information technology (IT) solutions in supporting IS activities. Their analysis further reveals that existing tools can be categorised into five main functions: synergy identification, symbiosis assessment, barrier removal, implementation, and follow-up [11].

Despite advancements in methodologies and tools to support IS activities, certain aspects remain underexplored. As noted in the literature, most tools focus on performance evaluation, while discussions on tools specifically designed for managing participants and stakeholders appear to be less developed [10]. This gap underscores the need for methodologies that not only assess the feasibility and benefits of IS but also facilitate the engagement and coordination of stakeholders throughout the IS process. In this context, the roadmap methodology emerges as a structured approach that can help address these challenges.

Roadmaps have been widely applied in technology and policy planning to define strategic pathways, align stakeholders, and facilitate the stepwise implementation of complex initiatives [12]. Applying a roadmap framework to IS could provide a structured means to anticipate barriers, align objectives, and define actionable steps for effective symbiosis deployment. Additionally, under this context roadmaps assist identify potential synergies between industrial actors by mapping opportunities for resource exchange, such as the transfer of waste, by-products, and energy. In doing so, it allows stakeholders to assess the technical and economic viability of such exchanges, evaluate regulatory or environmental constraints, and prioritise actions based on their expected impact on resource efficiency and GHG emission reduction. This step-by-step approach fosters better coordination and collaboration among diverse entities and helps ensure that resources are directed toward the most impactful symbiotic activities [7].

It is important to note that the effectiveness of stakeholder involvement does not necessarily depend on the number of stakeholders involved, but rather on the relevance and influence of the selected stakeholders in the given context. What matters is not how many stakeholder categories are included, but whether those that are relevant to the specific objectives and maturity of a symbiosis process are integrated in a meaningful way. The roadmap method is designed to enable the flexible involvement of stakeholders that are essential to a particular development phase. While in principle it allows for a broader involvement in later phases, its scalability in practice, especially in terms of aligning the interests of different stakeholders, needs to be further tested in a multi-stakeholder environment.

Building on these insights, the roadmap methodology offers a structured framework for addressing the challenges of engaging and aligning stakeholders in collaborative activities. Accordingly, this study explores the application of the roadmap methodology within an IS environment, alongside a new self-assessment and planning tool (SA&PT) designed to assist users in defining future actions on key topics related to IS, industrial–urban symbiosis (I-US), and CE. This study seeks to answer the following research question: How can a newly introduced methodology and the roadmap methodology contribute to the effective planning and deployment of industrial symbiosis activities, particularly in terms of stakeholder engagement and alignment of shared goals?

To answer this question, two complementary methodologies are presented and evaluated—a novel self-assessment and planning approach and the roadmap methodology tailored for IS ecosystems. By analysing their contributions to the planning of IS activities, the study aims to assess their effectiveness in facilitating stakeholder coordination and establishing strategic implementation pathways. Through a comparative assessment, this research offers insights into how different methodological frameworks can support the structured development of IS initiatives, ultimately enhancing stakeholder engagement and aligning shared goals. Additionally, the manuscript compares both methodologies, exploring their strengths, limitations, and synergies.

The remainder of this paper is organised as follows: Section 2 delves into the theoretical foundations of the methodologies discussed, namely roadmapping and SA&PT. Section 3 outlines the methodology behind each approach. Section 4 covers the application of both methodologies in a real-case scenario, while Section 5 presents a discussion that includes a newly proposed method, which combines these tools for ecosystem improvement. Finally, Section 6 concludes with a summary of key findings and recommendations for future improvement work.

2. Literature review and theoretical basis of the methodologies

2.1. Selection of Roadmapping as a strategic planning approach

As already mentioned in the introduction, there are different approaches that can be chosen to support the implementation of industrial symbiosis. The decision to use a roadmap method to implement industrial symbiosis can be justified by analysing the existing IS-related tools. The literature shows that current approaches to support IS activities include the five main functions of synergy identification, symbiosis assessment, barrier removal, implementation and follow-up [11]. While these tools address specific challenges, there is a lack of an overarching, strategic planning method that enables a long-term and coordinated implementation of IS. A roadmap offers the opportunity to combine these tools and thereby achieve their cumulative benefits.

The identification of potential synergies makes it possible to record material and energy flows and highlight possible industrial links. However, they are usually limited to a snapshot and do not offer any perspective for developing synergies in the long term and putting them into practice [13]. In contrast, a roadmap offers the opportunity to identify not only existing but also future synergy potential and to transfer this into a structured implementation plan.

Industrial symbioses are often evaluated using methods such as Life Cycle Assessment (LCA) or techno-economic analyses that quantify environmental and economic effects. While these tools provide valuable information, they are often not integrated into a comprehensive planning perspective [14]. A roadmap can close this gap by placing assessment results in a temporal context and providing clear development paths for companies and stakeholders.

Another key problem in the implementation of IS are institutional, technical and economic barriers. While some tools aim to identify regulatory barriers or facilitate co-operation, a holistic approach that involves all relevant actors over a longer period of time is lacking [15]. Roadmaps provide a structured framework for involving key stakeholders at an early stage, anticipating obstacles and developing targeted measures that gradually lead to the successful implementation of IS. The involvement of key players is one of the central aspects addressed in this paper. The actual implementation of industrial symbiosis requires close coordination between companies and other stakeholders. Many existing tools focus on specific aspects of implementation, such as technical feasibility or business optimisation. However, they do not take into account the development of synergies over longer periods of time [16]. A roadmap can serve as a guide here, providing companies with a clear direction and at the same time offering sufficient flexibility to adapt to changing conditions.

It can then be said that a roadmap provides a structured strategy for systematic future planning, for developing long-term planning of an industrial symbiosis solution and for fostering collaboration between the actors involved.

Different stakeholders with sometimes divergent interests are involved in IS projects. A roadmap allows these different actors to be integrated into the planning process at an early stage so that their respective goals and requirements are taken into account. It enables a clear definition of roles and responsibilities, which facilitates communication and coordination between those involved. In addition, the roadmap contributes to transparency by creating a common strategic direction and promoting long-term commitments between the stakeholders.

2.2. Roadmap

A concrete analysis of existing literature on the concept of roadmapping shows its development from a simple planning tool to an instrument of strategic corporate planning [17]. The model has continued to evolve and is now used in various areas such as technology development, product planning and innovation management. Before roadmapping was recognised in science and academic literature, its use was limited to internal applications within organisations. Technology roadmapping was first used by Motorola in the 1960s/70s as a forecasting and planning tool to enable a forward-looking assessment of technological progress. Over the years and from the beginning of the 21st century, this roadmapping established itself as an international standard for strategic planning in various sectors of the economy. Roadmaps were increasingly integrated into more comprehensive strategic planning processes that took into account business, social and political aspects as well as technological ones. The type of planning is often backward-looking, first defining the end goal and then identifying the necessary steps. This can be visualised in various ways, including tables, timelines and Gantt charts [18]. Due to its simplicity, flexibility and usefulness, roadmapping has been adopted and modified in various organisational contexts in different industries and countries [19]. Clive Kerr and Robert Phaal, who are recognised as experts in the field of technology roadmapping, have made a particular contribution to this. Their extensive research and publications have contributed significantly to the development and dissemination of roadmapping methods. In their publication 'Roadmapping and Roadmaps: Definition and Underpinning Concepts', Kerr and Phaal [20] define a roadmap as a "structured visual chronology of strategic intentions". The standardization of such roadmaps ensures that everyone involved has a common view of the project's progress, which facilitates collaboration and coordination within teams and between different departments.

2.2.1. Industrial Symbiosis

Industrial symbiosis refers to co-operation between companies that are actually separate, in which waste or by-products from one company are used as resources for another [21]. This concept promotes the exchange of materials, energy, water, infratructure and by-products to achieve environmental and economic benefits. The main benefits include reducing resource consumption, minimising waste and lowering operating costs by sharing infrastructure and services. The importance of industrial symbiosis lies in its ability to transform linear production processes into circular systems, thereby reducing environmental impact and increasing resource efficiency. This contributes significantly to the promotion of a sustainable economy.

Despite the obvious benefits, industrial symbiosis is not yet a widespread practice for building sustainable industries for different reasons. The processes to build a symbiotic relationship are complex, the opportunities are often outside of one sector and require the involvement of many stakeholders [22,23]. To create win-win situations and incentivise industrial symbiosis, industry and policy makers need a solid framework that is applicable to different industrial settings. It should ensure that the terms and principles of industrial symbiosis are commonly agreed and understood by stakeholders, that resources are interchangeable between industries and industrial sectors, that systems, practices and processes are compatible and interoperable and comply with legal requirements, that the relevant data and information formats and technical solutions are available, and that R&I results are integrated.

2.2.2. Roadmapping in IS

The use of roadmapping to implement industrial symbiosis is still at an early stage of development. While roadmapping is widely used in areas such as technology development and innovation management, there is a lack of standardised processes and established methods in the context of IS. Some initiatives, such as the Swedish project to develop a roadmap for industrial symbiosis [24], aim to identify key components and measures to promote the development of IS. Nevertheless, there is a lack of comprehensive, standardised approaches that support the broad implementation of IS.

Experience to date [24,25] shows that the implementation of IS is challenging due to the complexity of the processes and the need to involve numerous stakeholders. The development of symbiotic relationships often requires cross-sector cooperation, which makes implementation more difficult [21]. There is also a lack of clear, standardised methods to help companies implement IS effectively. Many projects are based on individual approaches that are not easily transferable to other contexts. Therefore, there is a need for further research in order to develop uniform frameworks and best practices that facilitate and standardise the implementation of IS. These findings highlight a key research gap, as there is currently no structured, standardised process for the systematic introduction and implementation of IS. While classic roadmaps serve as effective tools for planning, strategy development and decision-making in other areas, such an approach has not yet been comprehensively developed or documented for IS. A standardised roadmapping process for IS could therefore make an important contribution by providing a procedure for companies and regions. By defining steps, resources and relevant stakeholders, an IS roadmap could facilitate implementation and reduce uncertainty. It could also serve as a decision-making tool to provide companies with a long-term perspective and encourage investment in symbiotic models.

To address this gap, our aim is to establish a generalised roadmap for IS by analysing and synthesising data from multiple real-world cases.

2.2.3. Benefits and challenges of roadmapping in IS

As already mentioned, the roadmap is an application that is particularly widespread in technology development and offers numerous advantages. It serves as a strategic planning tool that supports companies in linking short and long-term goals with specific technological solutions. This facilitates the alignment of technology developments with overarching business goals and promotes a common innovation strategy [26–28].

As the existing literature has shown, one of the main benefits of using the roadmap is the visualisation of development strategies. Roadmaps provide a clear and visual representation of the path from the current state of the art to the desired future state. This makes it easier to gain an overview of the development processes and to plan strategically (Keer and Phaal 2015). It was also frequently mentioned that providing a common framework improves communication between different departments and teams. They stimulate discussions about future developments and thus promote a shared vision [20]. A clearly defined roadmap helps to target resources by prioritising technology projects and ensuring that investments are aligned with the company's long-term goals [20].

Although roadmaps are successfully used in technology development, there are also challenges that are frequently addressed. Particularly in a potential application in industrial symbioses, gaps can still be recognised that make an application less than ideal. The success of IS initiatives depends heavily on the active involvement of various stakeholders. However, traditional roadmapping approaches often do not sufficiently take into account the need to involve all relevant stakeholders and harmonise their different interests. IS requires collaboration between different industries, which makes it difficult to harmonise goals and timelines. Traditional roadmaps are often not designed to reflect these intersectoral dynamics [29]. IS projects are often influenced by variable factors such as market changes, regulatory adjustments and technological advances. Rigid roadmapping methods can struggle to take these uncertainties into account.

To meet the specific requirements of Industrial Symbiosis, it is essential to adapt traditional roadmapping approaches. This requires the development of more flexible and participative methods that take into account both the complexity and dynamics of IS projects and ensure the effective involvement of all relevant stakeholders.

In this context, we aim to link the benefits identified in the literature with the existing challenges and gaps in practical application. On this basis, we are developing our own roadmap strategy for Industrial Symbiosis. In view of the complexity of IS activities, where harmonising the goals and interests of different stakeholders is a challenge, the roadmapping process serves as an essential tool. It helps to align the system toward common goals, minimise risks and make the best possible use of the benefits of symbiotic relationships.

2.3. SA&PT

The SA&PT tool was conceptualised and developed during the EU projects H4C Europe[1] and CORALIS.[2] However, this manuscript presents, for the first time, a detailed description and scientific evaluation of the tool, assessing its effectiveness in stakeholder engagement and goal alignment within industrial symbiosis ecosystems. This new tool was designed to facilitate the assessment of the current state of an IS case while also serving as a dynamic instrument to guide users in improving IS management and strategically planning future actions. The SA&PT covers all the relevant elements that facilitators are expected to consider when preparing for the subsequent steps in the deployment of IS, I-US, or CE activities, and it aims to identify improvement actions based on IS-related topics.

Several tools designed to support companies in the IS process have been identified in the literature. For example, an applied assessment tool has been developed to help companies evaluate their potential for developing and implementing IS scenarios [30]. This structured tool is composed of three modules: company identification, current state assessment, and implementation potential [30]. A key aspect of this methodology is its approach to evaluating the current state of a company. It does so by addressing specific thematic areas through a set of targeted questions, which are answered using a three-level scale: “yes,” “no,” and “yes, with some modifications”. Each response is assigned a score, allowing for a structured and quantifiable assessment of the company's readiness for IS implementation.

In regards with the transitioning to a CE, other kind of tools can be found in the literature too. The key among these are the *Circular Cities and Regions Initiative (CCRI) methodology* and the *CCRI Self-Assessment Tool*, introduced by the European Commission as part of the EU Circular Economy Action Plan 2020 [31]. These tools provide support to different target audiences, such as regional and local councils, European cities and regions, industry representatives, research and technological organisations, and societies. These tools help users understand the current situation in their ecosystems, assess strategies, set targets, and monitor key performance indicators (KPIs) for the implementation of circular systemic solutions.

Another notable tool is the circular benchmarking tool, designed to assess and compare CE performance across regions using six indicators and a qualitative-quantitative maturity level scale [32].

The SA&PT was developed considering existing methodologies while addressing critical gaps that remained unfulfilled. Rather than providing users with specific solutions, the SA&PT identifies key areas with the greatest potential for improvement. Instead of quantitatively assessing the maturity level of an IS case, it helps users pinpoint which areas require further development. These identified elements serve as the foundation for defining subsequent steps in the planning phase of the tool, enabling users to outline concrete actions and establish implementation timelines.

To achieve this, the methodology behind the SA&PT integrates core principles from IS, I-US and CE. As a first step, a screening process was conducted to identify key elements necessary for assessing the state of IS cases. The selected core elements—referred to as indicators—offer a qualitative approach to evaluating IS performance, focusing on aspects crucial for advancing IS activities. The indicators include technical, economic, management, social, legal, and environmental aspects to cover all dimensions of such activities.

2.3.1. Indicators related to IS, I-US and/or CE

To identify the core elements of IS—those essential for measure the enhancement and maturation of these ecosystems—a comprehensive review of indicators from literature was conducted. This review focused on key concepts related to IS, I-US, and conforming the basis for explaining the SA&PT methodology.

The indicators review was conducted, focusing on scientific papers, documents, and relevant methodologies, considering both quantitative and qualitative indicators. From all the literature viewed is highlighted the European Commission's CE monitoring framework which introduces 10 key indicators, divided into four subcategories: production and consumption, waste management, secondary raw materials, and competitiveness and innovation, which are crucial for measuring circular economies across Europe [33]. Additionally, in regards with CE indicators, another study focused on identified CE indicators for European cities across various fields such as environment, economy, social factors, material flows, and recycling [34]. Also, the European Green Deal aims for a climate-neutral CE, and progress is monitored through the Eco-Innovation Index, a composite of 12 unweighted indicators covering eco-innovation inputs, activities, outputs, resource efficiency, and socio-economic outcomes [35,36].

In regards with IS, Valenzuela-Venegas et al. classify 249 sustainability indicators for eco-industrial parks, addressing social, environmental, and economic dimensions [37]. Regarding I-US, Ruiz-Puente (2021) identifies eco-efficiency indicators based on a guide from the World Business Council for Sustainable Development, covering industry, municipality, and I-US levels, including aspects like waste management, pollution, and socio-economic metrics [38,39].

The literature review laid the groundwork for selecting the indicators employed in the methodology used to develop the SA&PT.

Table 1 presents the categories into which these indicators are grouped according to the authors referenced.

A comprehensive review of over 250 indicators from various sources was conducted. This review allowed us to identify recurring themes and common dimensions that underpin IS evaluation. Sources included established frameworks in IS, I-US, CE and sustainability assessments. Through this review, several categories of indicators emerged, allowing as by grouping the initial set into broader thematic categories. With the objective of selecting the indicators most relevant to ecosystem improvement following the principles of IS, I-US, and CE, a set of six indicators it was selected. These indicators are intended to guide industrial and urban–industrial ecosystems in areas that should be prioritised.

The resulting six indicators encompass key dimensions and provide a set of qualitative rather than quantitative indicators. As is indicated by several authors, “*indicators are useful tools to assess conditions and trends (even in relation to specific goals and targets)*” according Gallopin (1996)

[1] H4C Europe stands for “Building a European Community of Practice of Hubs for Circularity” (Grant agreement ID: 101058416)

[2] CORALIS stands for “Creation Of new value chain Relations through novel Approaches facilitating Long-term Industrial Symbiosis.” (Grant agreement ID: 958337)

Table 1
Literature review on indicators related to the concept of IS, I-US and CE.

Indicator groups	Ref.
Production and consumption Waste management Secondary raw materials Competitiveness and innovation	European Commission, 2018
Environmental Economic Social Consumption Enabling metrics Material flows Waste Reuse and recycling Secondary raw materials Competitiveness and innovation	(Feiferytė-Skirienė & Stasiškienė, 2021)
Eco-innovation inputs Eco-innovation activities Eco-innovation outputs Resource efficiency outcomes Socio-economic outcomes	Eco-Innovation scoreboard and the Eco-innovation index (European Comission, 2022)
Environmental Economic Social	Valenzuela-Venegas et al. 2016
Industry and municipality (applicable) Applicable to the whole UIS Industry (exclusive) Municipality (exclusive)	Ruiz-Puente, 2021

[40] and Fraccasia (2020) [41]. In this context, the set of indicators encompasses at least these six groups, covering the key thematic areas that an IS ecosystem must advance.

A brief description of each indicator is provided below

1- Enabling assets: This indicator is based on the industrial ecosystem approach of utilising and identifying assets for the exchange and flow of mass and energy. These enabling assets support the integration of members through shared frameworks, common risk-mitigation strategies, and digitalisation.
2- Primary raw materials, energy, and water: This indicator considers the flows within industrial collaborations, encompassing primary raw materials, various forms of water (urban wastewater, industrial wastewater, treated water, and water for cooling purposes), energy (thermal and electrical), and waste energy. These flows are considered both within industrial collaboration and in terms of the inputs and outputs from industrial collaboration.
3- Environmental: The environmental impacts of industrial collaboration have been assessed using various actions and strategies. It measures, controls, reduces, modifies, and integrates these actions to evaluate their environmental impact. This evaluation focused on several key areas, such as CO_2 emissions, GHG emissions, other air emissions, and the quality and compliance of wastewater discharge.
4- Solid waste regulatory management: This indicator considers the flow of secondary raw materials, municipal solid waste, and industrial solid waste. These flows are considered both within industrial collaboration and in terms of the inputs and outputs from industrial collaboration.
5- Managerial: This indicator is an initiative to support members and operations undertaken by an industrial ecosystem.
6- Competitiveness includes all activities related to the promotion and reinforcement of ongoing initiatives to improve the local, European, and global competitiveness of industrial collaborative ecosystems.

The selection of indicators has been made taking into account, according to the literature, all relevant aspects in the activities carried out in IS ecosystems (technical and non-technical). Therefore, this set fulfil conditions that make them suitable to cover IS, I-US and CE aspects. The indicators are intended to guide all areas that an IS ecosystem should prioritise. Rather than utilising a scoring scale for comparing their performance, the set of indicators is beneficial for offering an overview of all relevant aspects for implementing activities.

3. Research design and tool application

In response to the need for industrial collaboration ecosystems to have tools and methodologies that can help define shared objectives among participants and strengthen stakeholder engagement two different approaches are presented. The research design of this study is based on a qualitative case study design that explores the application of the roadmapping process and the application of the SA&PT tool as a methodological approach for the planning of the implementation of industrial symbioses. Qualitative case studies are an established research design for investigating complex, real-world phenomena, especially in the field of sustainable industrial development [42,43]. The roadmapping approach is used as a strategic planning tool to identify long-term synergies between companies and to actively involve relevant stakeholders in the implementation process.

The empirical basis of this study is based on a research project in which the roadmapping process was used to develop industrial symbiosis. Specifically, a case study (Use Case A) was conducted focussing on a regional IS initiative in Austria between a chemical company and a steel producer. The aim of this initiative is to utilise renewable hydrogen as an energy carrier and raw material in order to gradually replace fossil fuels in production and thus significantly reduce CO_2 emissions. Comparable approaches have been described in the literature, particularly in the context of European research projects investigating industrial symbioses to reduce greenhouse gas emissions through hydrogen technologies (CORALIS project 2021).

The case study analysed the development of an industrial symbiosis for renewable hydrogen between the companies involved. The roadmapping process serves as a strategic planning tool that divides the development process into several phases and involves relevant stakeholders in the process from the outset. Additionally, the SA&PT is used within the same ecosystems to assist the facilitator in planning the next steps, taking into account actions focused on the key elements of IS, I-US, and CE.

3.1. Roadmap process

The roadmap developed for implementing industrial symbioses is based on a structured approach that systematises the planning, implementation and evaluation of these collaborations. It serves as a methodological tool for identifying and realising synergy potential between companies and was tested as part of the case study. The roadmapping process is divided into four central phases, which are run through along a time axis and enable strategic implementation.

Four steps were developed to structure the roadmapping process (see Fig. 1).

I. Analysing the current situation
II. Defining visions and goals for IS implementation
III. Identifying key steps and measures
IV. Integrating success factors and conducting risk assessment

The first phase, analysing the current situation, forms the basis for identifying potential industrial synergies. This step involves a comprehensive assessment of the existing framework conditions, including industrial processes, resource utilisation and environmental challenges. To this end, qualitative interviews were conducted with relevant stakeholders to ensure stakeholder involvement right from the start. A particular focus was placed on identifying relevant challenges and

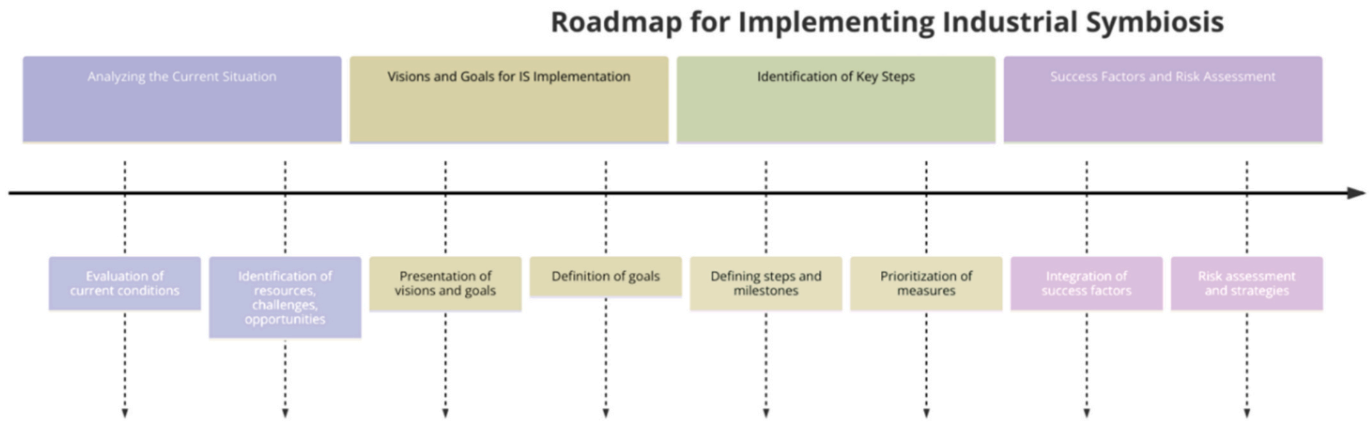

Fig. 1. Basic guideline on roadmaps for implementation of industrial symbiosis. Source: Energieinstitut an der JKU Linz. Own illustration.

opportunities in order to gain a holistic understanding of the economic, technical and regulatory starting position.

Building on these findings, the second phase follows, in which visions and goals for the implementation of industrial symbioses are defined. This step serves to define a strategic direction and establish a common objective among the stakeholders involved. Long-term visions were developed in stakeholder workshops to ensure broad acceptance and alignment. Specific, measurable goals were then formulated to serve as milestones for further planning.

The third phase focussed on identifying the key measures to enable targeted implementation of the roadmap, which were derived from the opportunities and barriers identified and the recommendations for action derived from them. Central steps and milestones were initially defined to ensure a structured sequence of measures. The measures were prioritised on the basis of a stakeholder survey, which focused on the relevance and feasibility of individual measures.

In the fourth and final phase, success factors are integrated, and a risk assessment is carried out to ensure long-term stable implementation. Key factors that favour successful implementation were identified. At the same time, a comprehensive risk assessment was carried out in order to address potential uncertainties, such as regulatory risks or economic fluctuations, at an early stage. The importance of these steps was also assessed by the relevant stakeholders.

This methodically structured roadmap represents a strategic approach to implementing industrial symbioses by combining a well-founded analysis of the initial situation with a clear definition of objectives, structured measures and proactive risk management. Realistic and scalable implementation is made possible through iterative adaptation to changing framework conditions and close collaboration with relevant stakeholders. This methodology was implemented and documented in practice using use case A. This approach was supplemented by the use of the SA&PT tool. This is described below, while the following chapter discusses the results and evaluates the methodologies.

3.2. *SA&PT: Description of the tool*

The new methodology presented in this article, SA&PT, is used to explore the usefulness of this type of tool in the planning phase of IS activities. Based on a case study, the tool was applied to Use Case A, and user feedback from those who tested the tool was evaluated.

The following section provides a detailed description of how SA&PT works and its main components.

3.2.1. *Description of the tool*

Since the terminology used in the SA&PT may be subject to varied interpretations, Table 2 summarises the specific definitions employed for two elements.

Table 2
Key concepts in SA&PT methodology.

Terminology	Definition
Facilitator	Individuals or teams capable of coordinating and mobilising resources (public, private, or both) to support ecosystems in achieving large-scale industrial symbiosis, industrial-urban symbiosis, and circular economy initiatives in various ways. These facilitators are recognised by their ecosystem as key references in defining collaborative initiatives that benefit all the members they oversee, coordinate, or guide.
Industrial collaboration ecosystems	Referring to the ecosystem that involves industries, research and technological organisations, SMEs, public authorities, and, in some cases, urban areas such as regions or cities. In this ecosystem, collaboration activities occur between its members, carried out through IS, I-US, or CE-related activities.

The SA&PT was developed to support industrial collaboration ecosystems throughout the maturation process of collaborative activities. The target audience are facilitators, of industrial collaboration ecosystems, the tool encompasses all elements that should be considered to advance further in the next step to a mature and strengthened ecosystem.

An innovative aspect of the SA&PT is its dual function: assessing the current state of the ecosystem and collaboratively planning next steps with the users. The tool enables users to assess whether the ecosystem is implementing actions aligned with key elements of IS, I-US, and CE. And also, helps users define the next steps in a clear, simple, and integrated manner. Fig. 2 shows the key features of each section of the SA&PT. The subsequent sections provide a detailed description of the content, scope, and expected outcomes of each part of the tool.

3.2.1.1. Section 1: Structure. The first section collects key data on industrial collaboration ecosystems to understand the environment in which the ecosystem operates. General information on the ecosystem is gathered, including data on the location, urban, and economic context of the area where industrial collaboration is located, as well as questions about the industrial activities performed by the members of the ecosystem.

In addition, Section 1 includes an analysis of policies affecting the ecosystem, with the objective of enabling users to identify which policies at the European, national, and regional levels currently limit ecosystem activities and classify them according to whether they are more or less restrictive.

Finally, Section 1 provides an analysis of members via a description of member types (governmental or non-governmental organisation) and the completion of a brief questionnaire. Table 3 presents the information required to complete Section 1.

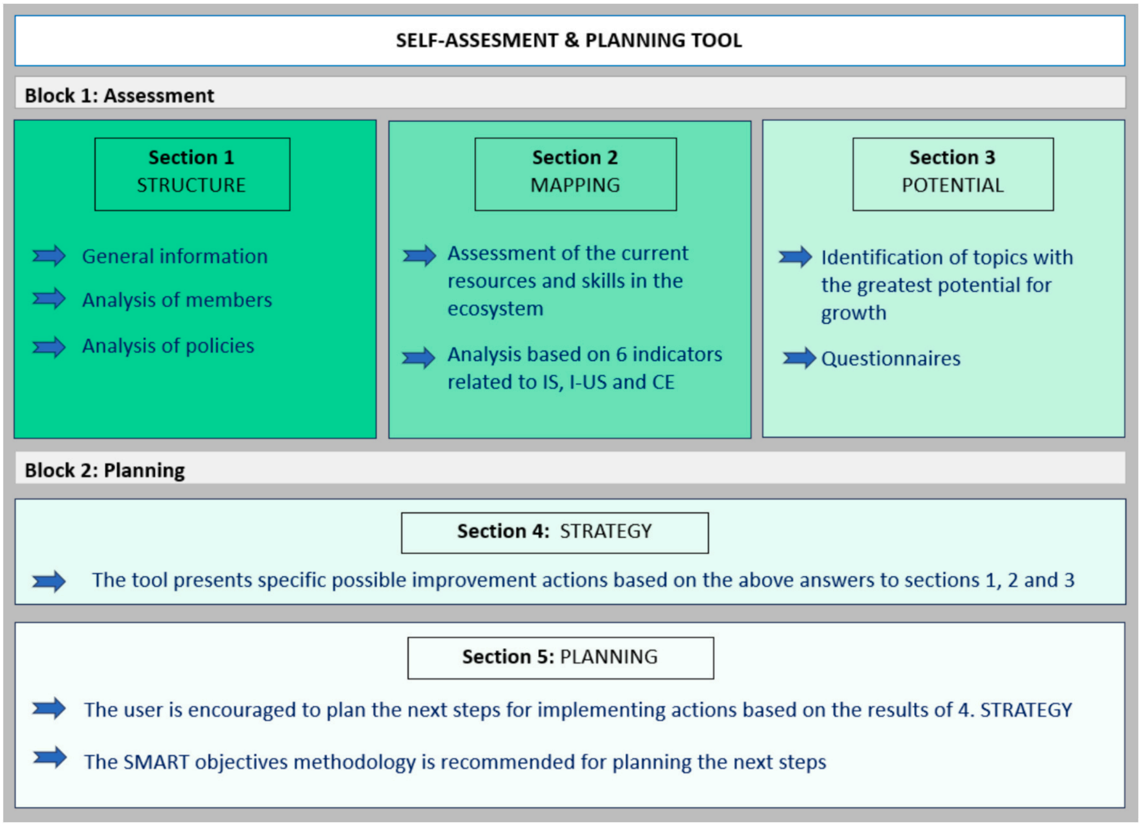

Fig. 2. Self-assessment and planning Tool – Structure by sections. Source: CIRCE.

The information collected in this section is useful for recording essential details about the ecosystem and serves as an effective way to gather general information from the facilitator.

3.2.1.2. Section 2: Mapping. The mapping section evaluates ecosystem activities based on the set of six key indicators aligned with IS, I-US, and CE concepts. Each indicator is broken down into smaller components (topics and sub-topics), capturing different aspects of the ecosystem's development. Users assess these sub-topics (smaller components of each indicator) to determine whether relevant actions are being implemented, ranking them on a 1 to 5 scale as outlined in Table 4.

The complete list of indicators, along with their detailed components (topics and subtopics), is presented in Table 5.

3.2.1.3. Section 3: Potential. The Potential section identifies areas within the ecosystem with the highest growth potential, focusing on industrial collaboration where few actions have been implemented so far. Based on the mapping responses users access questionnaires designed to further explore underrepresented topics.

The questionnaire is structured by topics and classified as mandatory or optional. Topics in which more than half of the subtopics are rated below 4 (in the mapping section) are considered mandatory, requiring further assessment. In cases where the mapping section indicates that most subtopics already have significant actions in place, the questionnaire remains optional. The questionnaire is multi-level, including yes/no and multiple-choice questions, with each level suggested based on previous answers. The full questionnaire is in Annex I.

3.2.1.4. Section 4: Strategy. In Section 4, the tool moves to the planning phase, guiding users in making decisions that will help the ecosystem mature in the key elements considered important for developing IS, I-US, and CE activities. At this stage, the tool recommends actions that should be implemented to improve the topics assessed in the previous sections. The recommended actions are based on the negative responses in Section 3. These actions are not specific to the ecosystem but provide a general idea of possible actions to be implemented.

3.2.1.5. Section 5: Planning. The last section of the tool aims to assist the user in developing an action plan to execute the actions outlined in Section 4 (strategy). An action plan is created by the user for each action suggested in Strategy, following the S.M.A.R.T. objectives methodology to plan the next moves [44,45] see Table 6.

Thus, by completing all sections of the tool, users will ultimately have a set of defined actions to strengthen and improve specific aspects of IS activities. Throughout this process, the recommendations generated by the tool will guide the users.

4. Results

To illustrate the application of these methods, a case study based on a current project is described. The roadmap method was developed and applied in the Horizon 2020 project CORALIS and the SA&PT Tool was conceptualised and developed during the EU projects H4C Europe and CORALIS. The ecosystem of industrial collaboration studied is in Austria, where symbiotic possibilities involving two partners—a chemical company and a steel company—for the production, import, and utilisation of renewable hydrogen are under investigation. This case study involves a theoretical assessment of the technical options for IS at different technology readiness levels.

The IS case study (hereafter referred to as Use Case A) provides a compelling example of how the roadmap methodology can be applied to foster collaboration between industries in a regionally focused initiative. Additionally, the SA&PT is applied in Use Case A. This case study focuses on a key industrial hub home to several energy-intensive industries, including steel and chemical manufacturing. This case is part of a broader project (Horizon 2020 CORALIS), which aims to enhance IS

Table 3
List of data to be filled in Section 1 - STRCUTRE.

	Information to be completed by the user	Technical objective
General information		
Ecosystem localisation	• NUTS 1 region • NUTS 2 region • NUTS 3 region	Analysis of the geographical context
Urban context	• Local population size	Analysis of the urban context
Economic context	• Gross Domestic Product (€)	Characterisation of the economic activities of the region
Members of the ecosystem	• Industrial sectors in the ecosystem	Definition of the industrial activities
Policies affecting the ecosystem		
Policy analysis	• Description of the policies • Scope (European, national, regional) • Importance for the ecosystem (low, medium, high)	Identify the policies that impact current and future activities within the industrial collaboration ecosystem
Analysis of members		
Brief questionnaire	• Does any of the industrial members work in the same business field? • Do the authorities of the region integrate the nearby industrial sites in their strategies for promoting circularity and industrial-urban interactions? • Do the ecosystem have a high concentration of industrial companies?	Understand the ecosystem context related to member interaction
Member's description	• Type of organisation: - Governmental or non-governmental) - Industry, RTO, SME, Financial institutions, etc.	Categorise each member according to their activities

Table 4
Description of the ranking in the MAPPING section.

Level	Description
1	No actions are implemented yet
2	Very few actions are implemented
3	Some actions are implemented
4	Lots of actions are implemented
5	Fundamental for the performance of the ecosystems

through the exchange of resources, energy, and by-products among companies to promote CE principles and reduce environmental impacts.

4.1. Roadmap implementation

4.1.1. Context and approach

One of the primaries focuses of Use Case A is the production, import, and utilisation of renewable hydrogen. These projects aim to reduce the region's reliance on fossil fuels by leveraging hydrogen as a clean energy carrier, which aligns with both the sustainability goals of local industries and broader European Union climate targets.

Hydrogen presents unique opportunities for IS. Hydrogen can be produced through various renewable methods, such as electrolysis using renewable energy, and once produced, it can serve as both a feedstock and an energy source for nearby industries. For instance, in this case, symbiotic possibilities were identified between a large steel producer and a chemical company, both of which can benefit from integrating hydrogen into their production processes. This collaboration could significantly reduce CO_2 emissions by replacing conventional fossil fuel-based inputs with renewable hydrogen.

4.1.2. Selection of stakeholders

The stakeholders for this roadmap approach were selected carefully to ensure a focused and effective collaboration. The decision was made to concentrate exclusively on two key industrial partners, supported by a scientific organisation. This focused selection was essential because the roadmap aimed to build a strong cooperation between these two companies. Both industrial partners were directly involved in the implementation of the industrial symbiosis initiative, making their participation critical for defining technical feasibility, infrastructure needs, and economic viability. This was because the primary aim of the roadmap was to establish and strengthen the cooperation between these two industrial partners. It was critical to have both companies directly at the table to jointly define visions, infrastructure needs, and technological requirements.

The scientific organisation acted as a neutral supporter, providing a research-based and objective perspective that helped maintain an equal and structured decision-making process. By limiting the stakeholder group to these core participants, it was possible to ensure clear communication, fast decision-making, and a strong alignment of goals. Including a broader range of stakeholders, such as representatives from policy, civil society, or academia, was not considered necessary at this early stage, as the priority was to establish a solid technical and economic foundation between the two industrial partners.

However, in future projects or other IS initiatives, it may indeed be beneficial and even necessary to involve a broader range of stakeholder categories to address additional social, regulatory, or academic perspectives.

4.1.3. Implementation phase

The implementation of the roadmap for industrial symbioses in Use Case A took place in several successive phases, which were based on the methodological structure of the roadmapping methodology. The aim was to enable the use of renewable hydrogen between a steel producer and a chemical company in an Austrian region through strategic planning and targeted measures.

The first step was to analyse the current situation in order to identify the initial conditions and potential synergies between the companies involved. To this end, qualitative interviews were conducted with relevant stakeholders who provided insights into industrial processes, resource utilisation and regulatory framework conditions. Particular attention was paid to the technical and economic challenges of hydrogen integration, such as the availability of green hydrogen, the necessary infrastructure and the long-term economic viability of the project. This analysis formed the basis for the strategic direction of further measures.

Building on this, visions and goals for the industrial symbiosis were defined in the second phase. A long-term vision for industrial symbiosis was developed in workshops with the relevant stakeholders. The main objectives included reducing CO_2 emissions by replacing fossil fuels, creating a stable hydrogen market and ensuring the economic competitiveness of the companies involved.

In the third phase, the focus was on identifying and prioritising the key measures for implementing the roadmap. From the expert interviews conducted in advance, the knowledge from the literature and the knowledge built up in the project, both opportunities and possibilities of industrial symbiosis as well as challenges and problematic areas were filtered out. Initial recommendations for action could then be derived from the identified aspects, which could prove essential for the future implementation of industrial symbiosis (see Table 7).

Specific fields of action were identified, including the joint procurement of green hydrogen, the development of a hydrogen infrastructure and the optimisation of process integration between the steel and chemical industries. One important aspect was the development of an electricity and gas purchasing pool to reduce costs and ensure

Table 5
List of indicators, topics and subtopics.

Indicator	Topic	Subtopic	Indicator	Topic	Subtopic
ENABLING ASSETS	Digitalisation	Data exchange	SOLID WASTE MANAGMENT	Secondary raw materials	Waste categorisation
		Digitalisation of process design			Waste exchange
		Digitalisation of industrial plants			Valorisation technologies in use
		Software services			Special treatment of hazardous waste
		Digitalisation of processes and supply chain			Recycling rates
		Real-time systems			Regions-industry involvement
	Plant, Properties, Inf., and Equipment Assets	Share framework	MANAGERIAL	Facilitator	Incubation activities for members
		Functionality			Training activities
PRIMARY RAW MATERIALS, ENERGY AND WATER	Primary raw materials and circularity	Materials exchange			Benefits monitoring
		Supply and demand			Supporting innovative projects
		Feedstock		Legal and ethical	Regional regulations
		Technologies			Legal service/expert
		Waste materials			Responsibility policy
		Reused/recycled materials			Impacts of the hub
		Quality		Communication	Internal communication
	Water	Sources			External communication
		Water exchange		Governance structure	Basis of the governance structure
		Natural sources			Meetings
		Quality - Water			Governance renewal
		Valorisation of water			New members voting system
		End of water	COMPETITIVENESS	Finance	Investment framework
		Wastewater			Revenues of members
	Energy	Energy demand		Global competitiveness	Market analysis
		Energy exchange			Status of the strategy
		Renewable energy			Alignment with regions
		Technologies			Mission and vision
		Waste energy			Hub expansion
		Energy efficiency awareness		Social awareness	New employment
		Fuels			Job creation monitoring
ENVIRONMENTAL	Emissions	Monitor CO2 emissions			Dissemination
		Reduction technologies			Research
		Capture technologies			Patents creation
		Other emissions monitoring			Training of employees
		Sectors emissions			Engagement of educational entities

Table 6
Methodology S.M.A.R.T. objectives.

Variable	Description
SMART	Define a specific challenges and action to improving the ecosystem.
MEASURABLE	Define milestones or concrete progress on targeted challenges and actions.
ACTIONABLE	Verify if the ecosystem can actually do something to achieve these improvements
REASONABLE	Within the scope of the available resources: define how much resources (what members, funds, equipment, etc.) would be required to achieve the improvements.
TIMELY	Feasible within acceptable timeframe: Define a reasonable timeline to achieve the improvements.

security of supply. Technological solutions for connecting electrolysers to a joint hydrogen pipeline were also developed. These measures were taken to a stakeholder workshop in order to ensure their involvement and active participation. The respective subject areas, which resulted from the opportunities and possibilities, barriers and challenges as well as from the recommendations for action, were prioritised by the stakeholders there in order to get a picture of where the respective priority areas lie.

Subsequently, and in parallel, possible success factors and risks were included in the fourth phase in order to ensure the long-term implementation of the measures. Strategies and measures were developed that could be important for the implementation of industrial symbiosis. These resulted from the previous three phases and were also included in the stakeholder dialogue. These measures were put into a time frame by the stakeholders.

The graphic (see Fig. 3) shows a roadmap for the realisation of an industrial symbiosis with hydrogen from 2024 to 2030. It shows various fields of action, including financing, technological innovation, stakeholder engagement, communication, sustainability and regulatory framework conditions.

Specific measures that will be implemented over several years are listed for each field of action. The bars visualise the planned timeframe for each measure and their sequence. The roadmap illustrates how technological developments, financial incentives, cooperation and regulatory adjustments will be coordinated over time in order to establish a sustainable hydrogen economy. This graphic represents the final result of the ongoing roadmapping process. It is the first point of reference to fulfil the previously created vision. However, the roadmap is subject to constant change and should therefore be regularly adapted and adjusted.

4.1.4. Evaluation of the roadmap approach

The implementation of industrial symbiosis requires a structured and well-coordinated approach that integrates technological innovation,

Table 7
Merging the opportunities and problem areas into recommendations for action. Results from the stakeholder workshops.

Chances→	Recommendations for action	←Problem areas
Early participation in the market creates competitive advantages	Regular workshops and transparent communication for stakeholder integration.	Different expectations of stakeholders, especially from the public
Continuation of existing co-operations strengthens implementation	Define clear responsibilities and governance structures	Difficulties in interdisciplinary coordination
Public funding instruments support implementation	Early identification and use of suitable funding programmes	Uncertain or insufficient funding
Electricity & gas purchasing pool reduces costs	Development of joint procurement strategies to reduce costs	High costs for green hydrogen and uncertainty about long-term financing models
Utilisation of CO_2 as a raw material offers synergy potential	Gradual implementation with pilot projects to minimise risk	Integration of new processes and technologies into existing structures is complex
Development of hydrogen import routes and pipelines strengthens security of supply	Establishing joint infrastructure and concluding long-term supply contracts	Low production capacity and limited availability of green hydrogen
Support from local authorities for hydrogen projects	Early cooperation with political decision-makers to clarify regulatory issues	Unclear legal framework and legal uncertainties
Integration into the 'Hydrogen Valley Upper Austria' facilitates knowledge exchange	Development of standardised business models and contract structures. Cooperation in a Hydrogen Valley or a Hydrogen Import Alliance.	Complexity of billing and responsibilities in co-operations
Increasing public awareness of hydrogen technologies	Proactive information campaigns and citizen dialogues to increase acceptance	Unknown attitudes and concerns of citizens and lack of acceptance
Heat supply to cities improves energy utilisation	Establish monitoring and evaluation systems to track progress	Risk of delays in implementation

economic feasibility, stakeholder collaboration, and regulatory alignment. The roadmap approach presented in this study was designed to address the key challenges of IS implementation, including the lack of standardised procedures, the alignment of goals across diverse stakeholders, and the facilitation of stakeholder engagement. This chapter evaluates the effectiveness of the roadmap approach by assessing its capacity to address these challenges and comparing it to traditional roadmapping methodologies.

One of the core strengths of the roadmap approach is its comprehensive stakeholder integration throughout the entire process. Unlike traditional technology-driven roadmaps, which often involve stakeholders only in later stages, this approach prioritises early and continuous engagement.

The roadmap was structured to ensure that relevant stakeholders were involved from the visioning phase onward. This was achieved through continuous stakeholder workshops, interviews in the very beginning and regular alignment meetings. This structured involvement not only increased stakeholder commitment but also mitigated potential conflicts arising from misaligned interests.

Traditional IS projects often face hurdles due to stakeholder restraint, and unclear governance structures (Hossain et al. 2024, Yazan et al. 2020). Furthermore, one of the first challenges identified in this study was the difficulty of aligning the objectives of stakeholders within an IS. Different priorities from different stakeholders often lead to fragmented decision-making and delays in implementation. The roadmap approach effectively addressed this problem by promoting structured coordination mechanisms.

In conclusion, the roadmap methodology has emerged as a strategic planning tool that provides a clear framework for defining common goals, identifying synergies and mapping out the steps required for the successful implementation of IS. This approach is designed to ensure that the stakeholders within an IS are aligned toward common goals. The roadmap facilitates structured joint planning and helps stakeholders to prioritise, allocate resources and anticipate challenges.

4.2. SA&PT implementation

The SA&PT was applied to Use Case A, providing a detailed assessment of the current status of IS initiatives. SA&PT focused on mapping existing resources and competencies within the region and identifying areas with high potential for improvement.

According to Section 2 of the tool, the results of the mapping section are presented in Fig. 4 which shows the average value assigned to each topic, based on whether actions related to the respective topic have been implemented.

Analysis of the results from the mapping section reveals that the topics *Emissions to Air*, *Energy*, and *Global Competitiveness* exhibit the highest average number of actions implemented. Although these topics remain important, they are not currently emphasised as priorities. By contrast, topics with lower ratings reflect areas in which actions are limited or not yet implemented. These lower-rated topics should be considered in the SA&PT to guide the development of an action plan aimed at improving the performance of a complex industrial ecosystem.

Water, for example, received the lowest rating among all topics. Although water management is crucial for any industrial facility, it is not the primary focus of IS activities in this context and will therefore not be the subject of further analysis. Instead, attention is directed toward other topics with similarly low scores, such as *Digitalisation* and *Secondary Raw Materials*, which have emerged as key areas of interest.

For the topics with the lowest values, the *Potential* section conducts a thorough analysis through a series of questionnaires structured in levels, progressing from general aspects to specific details. Consequently, this section assists the user in identifying improvement actions, which are reflected in the *Strategy* section. After completing the questionnaires, the *Strategy* section highlights the areas where the ecosystem should concentrate as these are critical for advancing in IS, I-US, and CE activities. This section also recommends general actions to address less developed topics and promote ecosystem enhancement.

The primary outcomes of the tool are the actions proposed by the users; however, the tool provides the necessary framework to guide users and help them focus on elements intrinsically related to the development of industrial collaboration activities. Table 8 summarises the topics with the lowest scores in the mapping section, the results of the strategy section (based on the user's responses in the potential section), and the outcomes from the planning section, which is the most valuable part. In this section, the user defines clear objectives to address weaker areas using the S.M.A.R.T. methodology, which involves specifying each goal as a concrete action and determining how to measure it, the time required, and necessary resources.

The SA&PT has proven effective in helping users design the next steps by directing them toward the highest-priority topics based on their current activities. The tool can be used either by a facilitator for a quick, time-efficient initial assessment of the next steps or through a more detailed approach, bringing together key representatives from the industrial collaboration ecosystem to collaboratively evaluate and establish actions and objectives.

4.2.1. Evaluation of the SA&PT approach

With the aim of evaluated how can a newly introduced methodology (SA&PT) contribute to the effective planning and deployment of industrial symbiosis activities it was performed an interview with the users

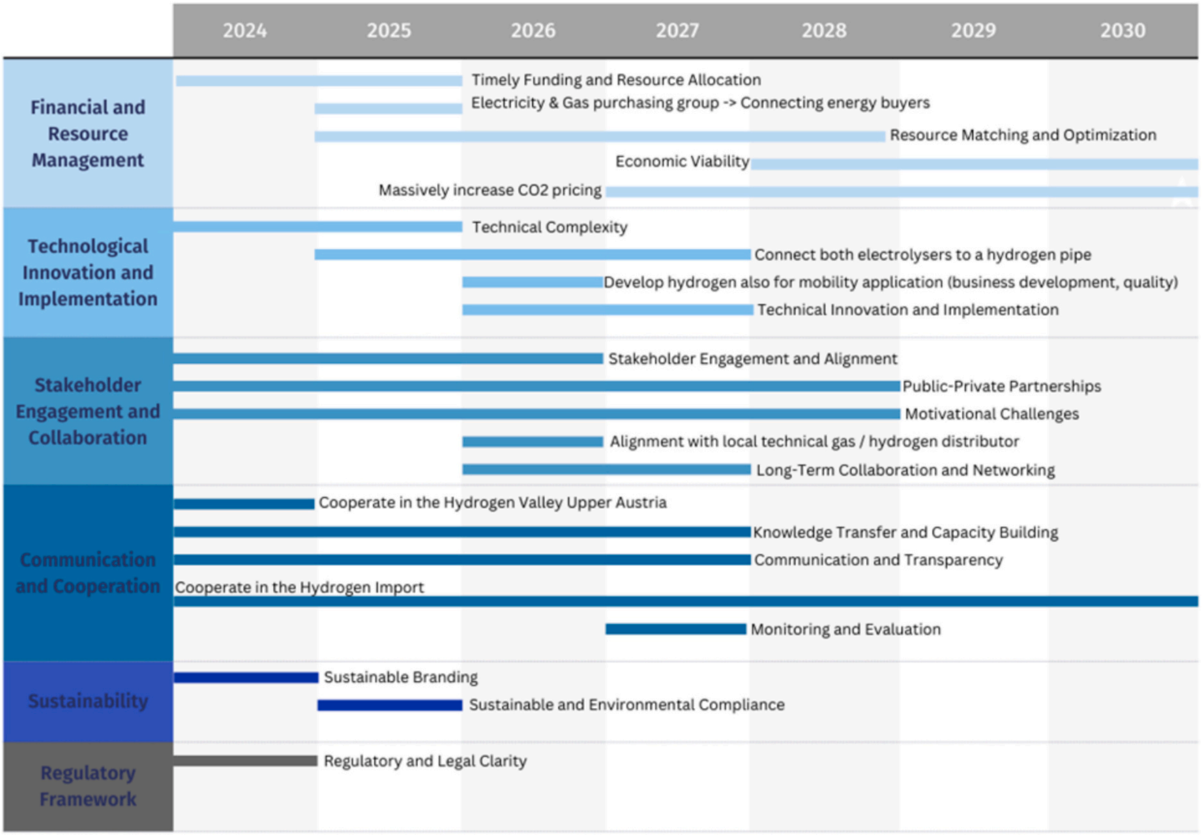

Fig. 3. Visualisation of the roadmap. Own illustration. Source: Energieinstitut an der JKU Linz.

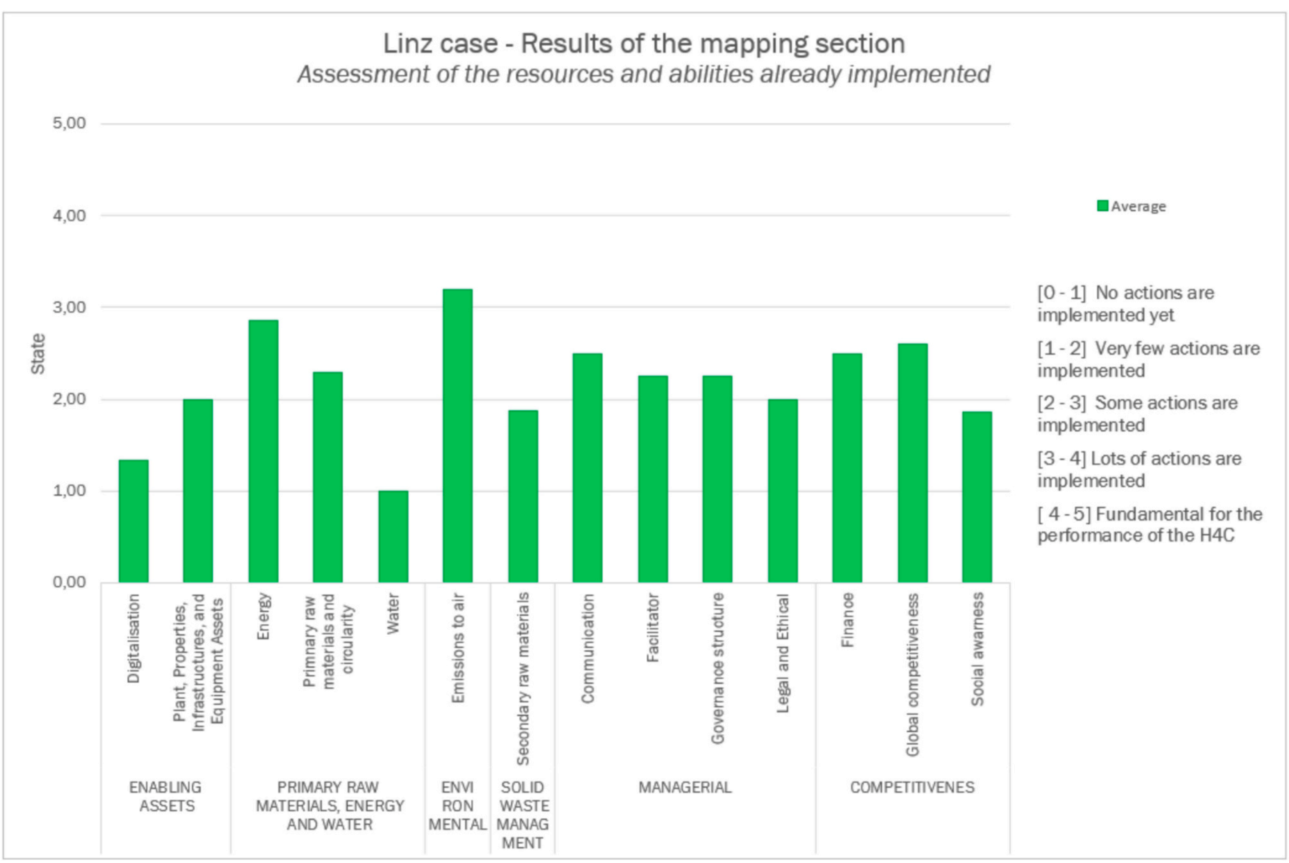

Fig. 4. Result of the mapping section SA&PT – Use-case A. Source: CIRCE.

Table 8
Results of the strategy and planning section SA&PT-Use-case A.

Priority Topic	*Strategy section* Action suggested by the tool	*Planning section* Objective proposed by the facilitator
Digitalisation	Incorporate digital systems for data collection, storage, and information extraction from members within the industrial collaboration ecosystem to ensure resource availability.	S: Implement a digital system for data collection among members. M: Achieve 80 % member participation within 6 months. A: Utilise existing technological resources. R: Allocate IT support. T: Complete the implementation in 24 months.
Secondary raw materials	Promote the exchange of by-products within the industrial collaboration ecosystem (by-products refer to solid waste that requires no further processing)	S: Establish a platform for by-product exchange. M: Reach 60 % participation in by-product exchange within 12 months. A: Collaborate with members for platform development. R: Allocate resources for platform development. T: Launch the platform in 18 months.

of the tool to collect their feedback regarding the usefulness of the methodology tested.

The SA&PT has been designed to support any industrial and/or industrial-urban environment, regardless of its situation, maturity level, composition, or expectations. Considering this, the tool was developed to accommodate different scenarios and user profiles, representing a variety of cases. To ensure its applicability, the tool was tested in existing demonstration cases within the framework of two EU projects (CORALIS and H4C EUROPE). Feedback was gathered from five IS demonstrator cases, in addition to the one presented in this article. These cases represent various levels of IS implementation. Case B focused on deploying IS solutions in the chemical, minerals, and water sectors, while Case C addressed IS initiatives within the pulp & paper, horticulture, and energy sectors. Case D involved IS applications in the steel, cast iron, and aluminium industries. Additionally, two cases were identified as being in the planning phase, representing different levels of maturity: Case E, related to the steel and energy sectors, and Case F, associated with the petrochemical sector. Furthermore, the tool was tested by two industrial parks, Case G and Case H, both actively engaged in IS activities [46,47].

The procedure used to gather feedback from users who tested the tool initially involved individual meetings with the facilitator of each use case. In the first meeting, the key features of the tool, its objectives, and usage instructions were explained. Afterwards, participants were given a one-week timeframe to complete the tool. Finally, a follow-up meeting was scheduled to discuss individual comments and feedback, focusing on three main topics:

- "How useful did you find the self-assessment process in evaluating the current state of the ecosystem?"
- "What aspects need improvement?"
- "Effectiveness of the tool in stakeholder engagement and alignment of objectives."

In general, most of the feedback received indicates that the tool is useful for considering broader aspects of IS implementation that might otherwise be insufficiently addressed. Additionally, users responsible for completing the SA&PT often required data they were initially unaware of, highlighting the importance of coordination and collaboration with relevant stakeholders. In this regard, the tool has proven to strengthen communication among partners and enhance stakeholder engagement by encouraging information sharing and structured discussions.

Regarding time requirements, facilitators across the case studies agreed that the tool can be time-consuming, as conducting a thorough analysis requires gathering information from multiple partners. One facilitator suggested that the tool should include a downloadable file containing recommendations and guidelines to support users in completing the planning section collaboratively with their partners. Another key insight raised by facilitators was the challenge of establishing a common vision in IS cases. In many instances, reaching a shared strategic direction is not straightforward. However, the tool proved valuable in initiating discussions around these aspects, helping stakeholders align their objectives and work toward a collective IS strategy.

4.3. Synergies between both methodologies

Considering the scope of each methodology and aiming to maximise the key features of each of one, a new approach that integrates both methodologies is proposed to enhance the planning and implementation of IS. This new model integrates the strengths of both the SA&PT and roadmap process to leverage their respective advantages. The model is designed to guide users through the planning process of future activities, offering the necessary assistance in detailing the steps to follow and evaluating the key elements that such ecosystems require. By incorporating the most important aspects of both the roadmapping process and SA&PT, an improved methodology is presented.

This new methodology focuses on defining a clear and well-defined action plan for an industrial collaborative ecosystem. This model is not a methodology that can be used only by the facilitator; it must be completed by the facilitator in company with the stakeholders involved in the ecosystem of industrial collaboration. The steps to be followed are presented in Table 9, integrating elements from both the roadmap methodology and the SA&PT. The combination of these approaches provides a holistic perspective on the necessary steps to further develop activities involving industrial collaboration, such as IS, I-US, and/or CE.

Step 1, the *preparatory phase*, involves activities related to understand ecosystem interactions, reflecting its vision, aspirations and industrial challenges. It includes market analysis to identify economic opportunities and assess competitiveness aspects. Further, the preparatory phase takes advantage of social, technological, economic, environmental, political analysis to identify external factors that can impact the ecosystem. Alternatively, in-depth interviews with field experts are effective in extracting detailed insights into the specific challenges and opportunities faced by ecosystem members. Finally, general information about the ecosystem, its members industrial activities and relevant policies is collected. This phase lays the foundation and framework of the ecosystem, led by the facilitator with support from members as needed.

Step 2 is the *identification phase*, which involves recognising the opportunities and possibilities presented by the activities in the ecosystem as well as the problems and challenges. This is done through workshops that bring together all relevant stakeholders in the ecosystem. In addition, the facilitator will be responsible for identifying elements related to IS, I-US, and CE that still have room for improvement, using the mapping section of the SA&PT. The identified elements are brought into the workshop for discussion with the members.

In Step 3 (*assessment*), the elements identified in the previous step are assessed. The chances, opportunities, problems, and challenges are assessed and ranked. In parallel, the facilitator completes the potential section of the SA&PT, in which the user accesses a series of questionnaires to further explore topics that have not been extensively covered in the ecosystem. The results of this step provide a clear picture of the elements that require further ecosystem development. These elements either capitalise on opportunities or address existing problems. Additionally, it highlights topics that have not yet been fully developed, but

Table 9
New model applied step by step, interaction of both methodologies. Source. CIRCE.

1	2	3	4	5
PREPARATORY PHASE	IDENTIFICATION	ASSESSMENT	PROPOSAL FOR ACTION	ACTION PLAN
o Vision of the ecosystem o Market analysis o Expert interviews o General information o Member's analysis o Policy analysis	o Relevant chance and opportunities o Challenges and problems areas o Topics with limited action related to IS, I-US and CE	o Chance and Opportunities o Challenges and Problems o Topics with limited actions deployed	o Actions aimed at overcoming the identified problems and making the most of the opportunities o General actions recommended by the Strategy section of SA&PT	o Prioritization and time schedule of the actions selected o S.M.A.R.T. objectives for each action selected

are relevant to IS, I-US, and/or CE.

The central element of this new model is Step 4, the ***Proposal for Actions***, in which the recommended actions for implementation are documented. A Workshop is organised among all participants of the IS ecosystem, and a list of proposed actions is created to address the identified challenges and maximise opportunities. Additionally, general actions are suggested and discussed in the same workshop (corresponds to the Strategy section of the SA&PT). Although these actions are not tailored to a specific ecosystem, they offer a broad perspective on potential initiatives for addressing issues with the highest growth potential.

Finally, in Step 5 (*action plan*), actions are prioritised in a discussion led by the facilitator with all members involved in the ecosystem. The actions will be ranked and prioritised over a time schedule, and for each action, a detailed plan will be indicated based on the S.M.A.R.T objectives methodology. Therefore, for each selected action, a specific milestone is indicated, and it is necessary to verify if the ecosystem can do so, define the resources needed (partners, funds, and equipment), and the time of implementation. Thus, this new methodology provides a comprehensive approach for developing a detailed action plan for a collaborative ecosystem with IS.

One of the main strengths of the dual approach is its ability to foster stakeholder engagement and collaboration. Through its emphasis on workshops and collaborative vision sessions, the roadmap methodology offers the possibility that all relevant actors including industries, local governments, and research institutions contribute to the planning process. This can help align individual goals with broader sustainability objectives and encourages stakeholders to take ownership of IS initiatives—a factor that is crucial for long-term success.

Further, the SA&PT complements the roadmap by providing a detailed assessment framework that allows ecosystems to monitor progress, identify gaps, and prioritise future actions. By focusing on indicators the SA&PT assists facilitators to evaluate their current IS activities and plan improvements. The iterative nature of both methodologies ensures that the planning process remains dynamic, with the flexibility to adapt to new information, technological advancements, and regulatory changes.

5. Discussion

This article presents two methodologies that can be used in the planning phase of IS activities. On one hand, the roadmap methodology serves as a strategic tool that aligns shared goals and provides a long-term perspective for IS implementation. On the other hand, the SA&PT methodology offers a structured framework for self-assessment and planning, helping stakeholders identify critical areas for improvement in IS activities. Both methodologies were exemplified in Use Case A to evaluate to what extent their application enhances stakeholder engagement and contributes to establishing shared goals. The roadmap methodology proved to be particularly relevant for stakeholder engagement, as different partners were involved from the visioning phase onward. This was achieved through continuous stakeholder workshops, early-stage interviews, and regular alignment meetings. This structured involvement not only increased stakeholder commitment but also mitigated potential conflicts arising from misaligned interests. In regards with the SA&PT the user who evaluate the tool facilitates broader discussions on IS implementation, strengthens communication among partners, and encourages collaboration by prompting information sharing and structured discussions. Users often discover the need for additional data, emphasising the tool's role in fostering coordination with relevant stakeholders to ensure a comprehensive analysis. While establishing a common vision can be challenging, the tool helps initiate discussions, align objectives, and support the development of a collective IS strategy.

Considering the results of applying both methodologies, some interesting conclusions emerge. The use of these two different methodologies led to distinct yet complementary outcomes regarding the next steps. While the roadmap outlines actions to be developed across six thematic axes—Financial and Resource Management, Technological Innovation and Implementation, Stakeholder Engagement and Collaboration, Communication and Cooperation, Sustainability, and Regulatory Framework—the SA&PT focuses on providing a framework for developing actions related to the themes of Digitalisation and Secondary Raw Materials.

For all these reasons, the synergy that can emerge between these two approaches (presented in Section 4.3) is particularly interesting. By combining both methodologies, the outcomes can be more comprehensive, covering a wider range of aspects from multiple perspectives. Future research should focus on validating the third approach, which involves applying this synergy in a real-world case.

Future iterations and applications of the roadmap methodology could explore the engagement of wider stakeholder groups including policy makers, civil society, and academia, to test the applicability of the methodology in more complex, multi-actor environments.

5.1. Limitations and strengths

When selecting an appropriate methodology, it is important to note the limitations and strengths of each. The roadmapping process is recommended during the initial phase of an IS project, as it helps define the next steps. Conversely, the SA&PT can be applied throughout all stages of the project as it serves as a verification method to ensure that activities are aligned with the most relevant topics for IS, I-US, and the CE. In cases where these topics are not sufficiently addressed, the tool helps plan corrective actions in these areas.

Each methodology also has specific time and process limitations. The roadmap development process requires sufficient time to organise workshops with stakeholders and facilitate discussions on various issues, while the SA&PT providing users with a general overview of key topics and necessary actions in approximately two hours (in the case that the facilitator has sufficient data from all members). Both methodologies effectively support collaborative industrial ecosystems by helping to plan the next steps and setting common objectives. Notably, the SA&PT can also be used to enrich the roadmapping process, leveraging the discussions that arise during workshops and the specific guidelines provided by the tool regarding critical topics that require attention.

However, several challenges remain unaddressed. The successful implementation of a roadmap is highly dependent on stakeholder commitment. As observed in IS systems, a lack of sustained engagement can hinder progress, particularly during the long-term stages of implementation. Therefore, mechanisms that maintain active participation throughout the process, such as continuous workshops and periodic reviews, are essential to maintain momentum.

It must be clearly stated that the ability of the roadmap methodology to comprehensively integrate the stakeholders in use case A was only realised in a more simple version, as the process was intentionally narrowed to two industrial stakeholders and a scientific partner to ensure a focused and manageable collaboration. This specific focus reflects the initial area of application and does not rule out a broader applicability of the methodology. However, the potential of the method to include other stakeholder groups beyond the current use case has not yet been empirically tested in the future.

Another challenge is the resource-intensive nature of developing and maintaining both a roadmap and the SA&PT. The initial phases, particularly stakeholder workshops and situational assessments, require considerable time and effort to gather data, analyse resources, and evaluate potential synergies. This process can be further complicated by technological barriers or regulatory uncertainties that may delay action planning. In our case study, for example, the initial stakeholder workshops required considerable effort to collect and consolidate data on resource flows, production processes and potential symbiotic exchange relationships. These issues highlight the importance of a supportive policy framework and adequate funding mechanisms to ensure that IS systems can achieve sustainability goals without undue delay.

Finally, although the roadmap and the SA&PT are powerful planning tools, there remains a need for ongoing evaluations and feedback mechanisms to track their effectiveness over time. Continuous monitoring and the inclusion of adaptive feedback loops are necessary to ensure that the objectives remain relevant and adjust as the ecosystem evolves. The integration of advanced digital platforms for real-time data collection and performance tracking could enhance the capacity of the roadmap to adapt and respond to external factors such as market shifts or environmental challenges.

Despite these challenges, the notable strengths of the dual approach are its scalability and adaptability. The roadmap methodology and the SA&PT are designed to be flexible, allowing IS ecosystems of various sizes and complexities to tailor the process to their unique needs. This adaptability enables industrial ecosystems to respond dynamically to changing circumstances and provides a framework that can be replicated across different regions and industries. Moreover, the collaborative nature of the methodology fosters innovation by bringing together diverse experts and perspectives, which can lead to creative solutions and breakthroughs in resource efficiency, energy management, and waste reduction. Ultimately, this approach provides IS systems with the tools needed to navigate complex sustainability challenges while empowering them to achieve long-term impactful results.

6. Conclusions

The methodology presented in this study offers a comprehensive and adaptable approach to IS planning, addressing both strategic vision and practical implementation. The roadmap methodology, with its structured framework for collaboration and long-term planning, provides a clear pathway for aligning diverse stakeholders toward shared sustainability goals. By integrating workshops and stakeholder engagements at multiple stages, the roadmap ensures that all actors are actively involved in shaping the future of there IS system. The roadmap methodology acts as a guiding framework for strategic planning, offering a structured approach to defining shared objectives, identifying potential synergies, and outlining the necessary steps for the effective implementation of IS. By fostering alignment among diverse stakeholders within the IS ecosystem, this approach encourages a common direction while promoting collaboration. Additionally, the roadmap supports structured decision-making, helping stakeholders to set priorities, allocate resources efficiently, and proactively address potential challenges.

The SA&PT serves as a critical complement to the roadmap by enabling the ongoing assessment and refinement of IS initiatives. Through a detailed analysis of the key indicators related to resource efficiency, environmental impact, and technological readiness, the SA&PT provides a valuable tool for facilitators to monitor progress and plan future actions. Together, these tools create a robust iterative process that helps IS ecosystems navigate the complexities of resource sharing, regulatory compliance, and stakeholder coordination.

However, successful application of this methodology requires continuous engagement, adequate funding, and a supportive policy environment. The challenges of aligning stakeholder goals, overcoming regulatory hurdles, and maintaining long-term commitment are meaningful, but can be mitigated through clear communication, transparent action plans, and strong partnerships between industry, government, and the public sector.

This dual approach offers a scalable model for IS planning that can be adapted to various contexts. As industrial ecosystems increasingly seek to embrace CE principles and reduce their environmental footprints, the roadmap and the SA&PT methodology provide practical and effective strategies for achieving sustainable industrial collaboration. Future research could explore the integration of digital tools and real-time monitoring technologies to enhance the adaptability and responsiveness of IS roadmaps further, ensuring that they remain relevant in rapidly changing technological and regulatory environments.

CRediT authorship contribution statement

Melanie Knoebl: Writing – review & editing, Writing – original draft, Visualization, Methodology, Conceptualization. **Lucía Ventura:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Conceptualization. **Johannes Lindorfer:** Writing – review & editing, Writing – original draft, Supervision, Methodology. **Ignacio Martín Jimenez:** Writing – review & editing, Methodology.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Annex 1.

TOPIC: DIGITALISATION		Answers
Level 1: Data for resource availability		
Q1.	Are digital systems for data collection, data storage, and member information extraction system used within the analysed industrial collaboration ecosystem to provide insights on resource availability?	Yes / No / No yet, but strategies are ongoing
Q2.	What types of data are collected within the analysed industrial collaboration ecosystem?	Energy data / Water data / Raw materials data / By-products data / Waste materials data / Investments data / Strategies data / More than one
Level 2: Platforms and databases for resource flexibility and accelerate synergies		
Q3.	Are platforms and databases used to increase resource flexibility and accelerate synergies between members of the analysed industrial collaboration ecosystem?	Yes / No
Q4.	Is there a platform for data exchange between members of the industrial collaboration ecosystem?	Energy management system / Water management system /Investments/ Civil works/ Strategies/Permits / More than one
Level 3: Real-time decision support systems for resource flexibility and accelerate synergies.		
Q5.	Are real-time decision support systems used to improve resource flexibility and accelerate synergies between members of the industrial collaboration ecosystem under study?	Yes / No
Q6.	Are exchange, matchmaking, participation, and living labs integrated into a common platform to monitor and improve IS/I-US/CE practices within the analysed industrial collaboration ecosystem and to identify future members?	Yes / No

TOPIC: PLANT/PROPERTIES/ INFRASTRUCTURES/EQUIPMENT ASSETS		Answers
Level 1: Shared common assets		
Q1.	Is there sharing of common assets such as waste treatment plants, public utility infrastructures, equipment, land, logistics infrastructure, and computer networks among the members of the industrial collaboration ecosystem?	Yes / Among industries / Among industries and cities (urban environments) / No
Level 2: Identification of different types of assets		
Q2.	In the industrial collaboration ecosystem under study, what type of "Feeding assets" do members share? (Feeding assets are understood as assets that facilitate the integration of the principal raw materials into the ecosystem, i.e., energy, materials, and water)	Solid waste treatment plants / Wastewater treatment plants / Utilities, such as water, electricity, steam, etc. / Renewable energy infrastructures / More than one
Q3.	What type of "Operational assets" do the ecosystem's members share? (Operational assets are understood as assets that facilitate the exchange of energy, materials, and water)	Warehouses / Landfills/ Heavy machinery/ Mid-weight machinery/ Light machinery/ Heavy transport/ Mid-weight transport/ Light transport / More than one
Q4.	What type of "Transversal assets" do the ecosystem's members share? (Transversal assets are understood as assets that facilitate the day-to-day work and the integration of members within the ecosystem)	Digital networks / Office buildings / IT equipment's / More than one
Q5.	Does the industrial collaboration ecosystem have policies or agreements in place for the end-of-use of existing plant, property, and equipment assets (shared among the members) that enable practical recirculation?	Yes, all assets are covered by asset recirculation policies or agreements / Yes, we have asset recirculation policies or agreements, but not for all assets / Work is ongoing to create asset recirculation policies or agreements for some all assets / No, there are no asset recirculation policies or agreements in place
Level 3: Assets for future members		
Q6.	Does the industrial collaboration offer industrial site leasing to future members? (This should include office buildings, laboratories and pilot plant facilities, warehouses, land area, modern industrial infrastructure/utilities, etc.)	Yes, please indicate which one… / No

TOPIC: PRIMARY RAW MATERIALS AND CIRCULARITY		Answers
Level 1: Measurements of virgin materials in the industrial collaboration ecosystem		
Q1.	Does the industrial collaboration ecosystem measure the quantity of virgin materials used or processed? (Virgin materials are understood as imported natural resources extracted, excluding imports of waste for recycling)	Yes / No
Q2.	What percentage of raw materials used in the industrial collaboration ecosystem are virgin materials?	0–30 % / 31 % – 60 % / 61 % – 100 %
Level 2: Identification of virgin materials that could be replaced by recycled materials		
Q3.	Have virgin materials been identified within the analysed industrial collaboration ecosystem that could be replaced by recycled materials?	Yes, the industrial collaboration ecosystem, characterises virgin feedstocks and promote recyclability / Partially, the industrial collaboration ecosystem does not have total access to feedstock data within industrial companies / No, industrial companies handle their own feedstocks individually.
Q4.	Has the use of common suppliers of virgin materials among members of the industrial collaboration ecosystem been facilitated? (Common suppliers tend to reduce raw material prices)	Yes / No

TOPIC: ENERGY		Answers
Level 1: Monitor energy demand		
Q1.	Is the energy demand of the industrial collaboration ecosystem members monitored?	Yes / No
Q2.	From which type of members does the ecosystem monitor energy demand?	Industry and cities / Only industry / Only cities / Others

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TOPIC: ENERGY		Answers
Level 2: Monitor waste energy		
Q3.	Is the waste energy of the ecosystem members monitored?	Yes / No
Level 3: Facilitate the exchange of energy		
Q4.	Does the ecosystem facilitate the exchange of energy among its members?	Yes / No
Q5.	Who are the members involved in energy exchange?	Industry - Industry/ Industry- cities / Only cites / Others
Q6.	What type of energy is exchanged within the ecosystem?	Electrical energy (from fossil fuels) / Electrical energy (from renewable sources) /Thermal energy /Waste energy (mainly thermal energy) / Others
Q7.	What infrastructures or technologies are used or shared among members involved in energy exchange?	District heating network / Co-generation plants / Electrical storage / Incineration plant fuelled by municipal solid waste / On-roof photovoltaic and solar thermal plants / Wind turbine installation / Low-grade industrial waste heat recovery (heat pump-Rankine cycle) / More than one
Level 4: Facilitate the exchange of fuels		
Q8.	Does the ecosystem facilitate fuel exchange among members? (e.g., hydrogen, biomethane, biomass, solid waste, plastic waste)	Yes / No
Q9.	What types of materials or energy vectors are exchanged?	Low-carbon fuels (hydrogen, biomethane) / Biomass / Solid waste/ Plastic waste/ None of the above / More than one /
Level 5: Produce and consume renewable energy * (Mandatory to answer regardless of previous levels)		
Q10.	Does the ecosystem produce renewable energy?	Yes / No
Q11.	Does the ecosystem consume renewable energy?	Yes / No
Q12.	What renewable energy conversion technologies are implemented within the ecosystem?	Wind turbines / PV systems / Biomass gasification units / BESS / Biogas CHP-boiler / Others / More than one

TOPIC: WATER		Answers
Level 1: Monitor water demand		
Q1.	Is the water demand of the industrial collaboration ecosystem members monitored?	Yes / No
Q2.	Which of the following water sources are used among members in the ecosystem?	Groundwater sources (rivers, lakes)/ Seawater / Precipitation / Cascading use of water (direct use of untreated wastewater in an environmentally safe manner) / Internally recirculated water / non-potable water from freshwater areas that are not classified as water-stressed, or seawater / More than one /None of the above / Data not available
Q3.	From which type of members does the ecosystem monitor water demand?	Industry and cities / Only industry / Only cities / Others
Level 2: Recycling of wastewater generated in the ecosystem		
Q4.	Does the ecosystem monitor wastewater among its members?	Yes / No
Q5.	How do members reuse the wastewater generated within the ecosystem?	For reuse elsewhere (e.g., in symbiosis or cascading systems) / Recharge local aquifers/ groundwater / Replenish rivers/lakes/wetlands / Local societal purposes (e.g., drinking water supply) / Back to a saltwater body / None of the above / Others
Level 3: Facilitate the exchange of both fresh water and wastewater among the members of the ecosystem		
Q6.	Does the ecosystem facilitate the exchange of wastewater among its members?	Yes / No
Q7.	Who are the members involved in water exchange?	Industry-industry / Industry-cities / Only cities / Others
Q8.	Do the members of the ecosystem share and use the same wastewater treatment plants?	Yes, industries and cities / Partially, only among industries / Partially, only among cities / No
Level 4: Valorisation of water		
Q9.	To what extent does the ecosystem have plants in place to extract surplus nutrients, metals, chemicals, heat, and similar valuable resources before discharging the water used in its processes, operations, and cities?	Processes in place for most of the water used in operations and relevant resources / Processes in place for some of the water used in operations, or for some of the relevant resources / Not yet
Q10.	Are most of the extracted resources subsequently recirculated (e.g., as fertilizer, through heat exchange)?	Yes / No

TOPIC: EMISSIONS		Answers
Section 1: CO2 emissions		
Level 1: Monitor CO2 emissions		
Q1.	Are the CO2 emissions of all members of the studied industrial collaboration ecosystem monitored?	Yes / No
Level 2: Monitor CO2 emissions per member and from the ecosystem itself		
Q2.	Does the ecosystem distinguish and measure individual emissions (from each member) and shared emissions (from the ecosystem itself) to create solutions for those intensive-emitter members?	Yes, and define strategies with those intensive-emitters members / No, the hub does not have access to own-emissions data, only the general emissions of the hub itself
Level 3: Implement actions/technologies for reducing CO2 emissions?		
Q3.	Does the ecosystem implement actions or technologies to reduce CO2 emissions?	Yes / No
Q4.	To what extent is the ecosystem implementing actions or technologies to reduce CO2 emissions among its members? (Select which technologies have been promoted by the ecosystem)	Oxycombustion (cement, lime, glass sectors) / Substitute of fossil fuels with renewable energy sources / CO2 hydrogenation for methanol production (chemicals, steel, refining, power generation) / CO2 fermentation for ethanol production / Electrification / Others

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TOPIC: EMISSIONS		Answers
Level 4: Implement CO2 capture and storage/utilisation technologies		
Q5.	Does the ecosystem implement CO2 capture, storage, and utilisation (CCS/CCU) technologies?	Yes / No
Q6.	To what extent is the ecosystem implementing CCS/CCU technologies? (Select which technologies have been implemented within the ecosystem)	Calcium looping CCS (cement, minerals, power plants) / CO2 scrubbing (minerals) / Direct separation CCS (Cement, minerals) / Combined steam methane reforming and CCS (Refining sector) / Blast furnace top-gas recycling (Steel sector) / Carbonation of steel slag (cement) / Mineral CO2 for carbonates production (minerals, chemical sectors) / Advanced carbonation technology for gravel substitution
Level 5: Reporting system at ecosystem level in terms of environmental performance		
Q7.	Is there a reporting system at the ecosystem level in terms of environmental performance?	Yes / No
Section 2: Emissions to air		
Level 1: Monitor sector-specific emissions		
Q8.	Does the ecosystem monitor sector-specific emissions such as NH3, NOx, SOx, CH4?	Yes / No
Q9.	Which molecules does the ecosystem monitor?	NH3 / NOX / SOX / CH4 / Others
Level 2: Implement actions/technologies for reducing sector-specific emissions?		
Q10.	Is the ecosystem implementing any actions or technologies to reduce sector-specific emissions?	Yes, we ecosystem has implemented its own actions / Partially, we are participating in projects around this topic / No, each industrial company has implemented their own technologies
Section 3: Emissions to water		
Q11.	Does the ecosystem monitor sector-specific emissions such as NH3, NOx, SOx, CH4 for all its members?	Yes / No
Q12.	Which molecules does the ecosystem monitor?	Yes, all industrial companies emissions licenses are centralised and it speeds up the paperwork / Partially, some industrial companies are not considered / No, there is not any centralisation of that information

TOPIC: SECONDARY RAW MATERIALS		Answers
Level 1: Identification of actions related to the exchange of waste		
Q1.	Does the industrial collaboration ecosystem measure, quantify, and categorise its solid waste into the following types (based on the European List of Waste: Urban solid waste / Industrial waste / Plastic waste / Paper and cardboard waste / Hazardous and non-hazardous waste)?	Yes /No / If No, specify….
Q2.	What percentage of the ecosystem's total solid waste ends up in landfill? (Select the range of solid waste sent to landfill)	0–25 % of the total solid waste / 26–50 % of the total solid waste /51–100 % of the total solid waste
Q3.	What percentage of the ecosystem's total solid waste ends up in incineration without energy recovery?	0–25 % / 26–50 % / 51–75 % / 76–100 %
Q4.	Does the ecosystem use special procedures for hazardous substances removed before treatment?	Yes / No
Q5.	Does the ecosystem promote the transformation of hazardous waste from its industrial members to enhance its value? (For example, waste oils and solvents)	Yes / No
Level 2: Promotion of the exchange of end-of-waste		
Q6.	Does the ecosystem promote the exchange of by-products within its operations? (By-products are solid waste that has not undergone further processing)	Yes / No
Q7.	Who are the members involved in the by-product exchange?	Industry-industry / Industry-cities / Only cities
Q8.	What is the ratio of by-products (used as raw material) exchanged in the ecosystem in relation to the total raw material used?	0–25 % / 26–50 % / 51–75 % / 76–100 %
Q9.	Does the ecosystem have a municipal/industrial recycling rate?	Yes / No
Q10.	Are logistics companies involved in these exchanges?	Yes, and they are members of the hub / Yes, but they are not members of the hub / No, each industry and/or city manages the exchangers
Q11.	Who monitors the exchanges within the ecosystem?	The hub representative (or working group in charge within the hub) / The main beneficial industry / The main beneficial government
Q12.	Which processing technologies are used in the ecosystem? (Select from the list)	Gasification / PET recycling plants / Pyrolysis / Production of intermediate fuels / Others
Q13.	Does the ecosystem apply a circular material usage rate? (Contribution of recycled and reused materials to overall material demand)	Yes / No
Level 3: Creation of waste prevention programs		
Q14.	Does the ecosystem collaborate with authorities in the creation of waste prevention programs?	Yes, the hub collaborates in the development of the plans / Partially, the hub collaborates in the revision / No, the industrial ecosystem does not collaborate in such programs

TOPIC: FACILITATOR		Answers
Level 1: Offering activities/tools		
Q1.	Does the industrial collaboration ecosystem offer industrial incubator activities (e.g., support, capital, networks, and physical adaptation) to develop ideas?	Yes / No
Q2.	Does the ecosystem offer incubator activities to new members of the industrial collaboration ecosystem?	Yes / No
Q3.	Does the ecosystem promote training activities, such as training courses, coordination among members, exchange of experiences and best practices among partners and external representatives, etc.?	Yes / No

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TOPIC: FACILITATOR		Answers
Q4.	To what extent are tools and metrics in place to support innovative projects within the ecosystem? (Tools such as design guidelines, material selection tools, proof of concept tools)	Already in place / Partially in place, for some innovation projects / Not in place
Level 2: Identification of benefits		
Q5.	What are the main benefits that can be obtained with the implementation of the industrial collaboration ecosystem? (Select from the list)	Increase of the competitiveness / Increase of the sustainability / Mutual cooperation, extension of business area / Increase of the overall energy efficiency / Reduction in waste and disposal costs / Creation of new business / Generation of revenue from higher-value by-products and waste streams / Costs sharing / Other

TOPIC: LEGAL AND ETHICAL		Answers
Section 1: Regional regulations		
Q1.	Are the legal terms for logistics and transportation of materials, such as primary/secondary raw materials, waste, and wastewater, established within the analysed industrial collaboration ecosystem?	Yes / No
Q2.	Are the legal terms for waste treatment and exchange known within the ecosystem?	Yes / No
Q3.	Is the ecosystem compliant with the legal and regulatory framework for developing circularity aspects?	Yes, we have legal instruments / No, but we are aware that the normative is on-going / No, any normative identified
Q4.	Is the ecosystem aware of any upcoming regulatory changes in the region that may encourage the search for alternatives	Yes / No
Section 2: Legal service		
Q5.	Is there an *internal* entity providing legal services or expertise within the ecosystem?	Yes / No
Q6.	Does an *external* entity provide legal services or expertise to the ecosystem?	Yes / No
Q7.	Is there security policy support within the ecosystem to ensure the proper implementation of regional policies for safeguarding the region?	Yes / No
Q8.	Is there environmental policy support within the ecosystem to ensure the proper implementation of regional policies on the environmental impact of activities?	Yes / No
Q9.	Does the ecosystem provide regulatory support for the circularity of by-products, solid waste, and secondary raw materials between industries and cities?	Yes / No
Section 3: Ethics		
Q10.	Is there a social responsibility policy that all members of the ecosystem have signed?	Yes / No
Q11.	Does the ecosystem's responsibility policy include gender equality, corporate responsibility, goal representation, environmental behavior, etc.?	Yes / No
Q12.	Does the ecosystem's activity contribute to reducing the local environmental impact in cities?	Yes / No
Q13.	Does the ecosystem support natural processes, such as enhancing soil health and biodiversity?	Yes / No
Q14.	To what extent is the ecosystem aligned with the Sustainable Development Goals? (Select from the list below)	No Poverty / Zero Hunger / Good Health and Well-being / Quality Education / Gender Equality / Clean Water and Sanitation / Affordable and Clean Energy / Decent Work and Economic Growth / Industry, Innovation and Infrastructure / Reduced Inequality / Sustainable Cities and Communities / Responsible Consumption and Production / Climate Action / Life Below Water / Life on Land / Peace and Justice Strong Institutions / Partnerships to achieve the Goal

TOPIC: COMMUNICATION		Answers
Section 1: Internal communication		
Q1.	Does the industrial collaboration ecosystem regularly engage in communication activities among its members?	Yes / No
Q2.	How extensively are the ecosystem's strategies, initiatives, examples, opportunities, and implementation plans communicated internally?	Internal case examples communicated via intranet, newsletters, campaigns, etc. / Internal feedback channels / Employee, community, or committee platforms / Open challenges, such as business plan pitching, accessible to all members / Other methods
Section 2: External communication		
Q3.	Does the ecosystem regularly engage in communication activities within the community where it operates?	Yes / No
Q4.	Are the ecosystem's achievements shared with the region through open events and with diverse audiences of interest?	Yes / No
Q5.	Are there campaigns or outreach channels to communicate the ecosystem's benefits and role in its region or local area?	Yes / No

TOPIC: GOVERNANCE STRUCTURE		Answers
Level 1: Governance basis		
Q1.	Is there a Declaration of Interest (DoI) that formalizes the intent to cooperate within the framework of the industrial collaboration ecosystem?	Yes / No
Q2.	Is there a regular governance committee that includes community leaders, stakeholders, and ecosystem members?	Yes / No
Q3.	Does the governance structure establish working groups, an annual calendar of meetings, decision-making processes, and milestones?	Yes / No
Level 2: Governance renewal		
Q4.	Is there a rotating governance system to facilitate leadership changes?	Yes / No
Q5.	Is there a voting system for governance renewal?	Yes / No

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TOPIC: GOVERNANCE STRUCTURE		Answers
Q6.	How frequently is governance renewed?	Yearly / Biannual / Triannual / More than three years
Q7.	Is the approval process for new ecosystem members and the associated voting system clearly defined?	Yes / No

TOPIC: FINANCE		Answers
Section 1: Finance		
Q1.	Does the industrial collaboration ecosystem have a co-investment framework involving European, national, regional, and industrial funds?	Yes / No
Q2.	Does the European Commission support the ecosystem's activities through project funding?	Yes, we participate actively in innovation actions projects as demonstrators / Yes, we participate in coordination and support actions projects / Yes, we participate in research and innovation actions projects
Q3.	Does the regional government represented in the ecosystem invest to support the development of breakthrough technologies through innovative research?	Yes / No
Q4.	Which public entities participate in the ecosystem's investment model?	City's government / Country's government / European Commission / More than one / Other (please specify)
Q5.	Which private entities participate in the ecosystem's investment model?	Internal member with fees / External private entities / No one, we base our operation model just in public funding / More than one / Other
Q6.	Does the ecosystem have a financial plan to support its management activities?	Yes, and the hub uses a fee's system / Yes, and the hub uses public fundings /Other (specify)

TOPIC: GLOBAL COMPETITIVENESS		Answers
Section 1: Global questions		
Q1.	Are there any ongoing initiatives related to innovative technologies, processes, business models, or social innovation that the industrial collaboration ecosystem can engage in with external entities?	Yes / No
Q2.	Is the integration of nearby urban areas into the ecosystem under consideration?	Yes / No
Q3.	To what extent does the ecosystem engage with cities and policymakers to support its strategies and activities?	No interactions planned / Ad-hoc interactions (e.g., informing policymakers about the hub's strategies) / Regular engagement through meetings and interactions / Ongoing engagement with existing results to attract new members to the ecosystem
Section 2: Strategies		
Q4.	Does the ecosystem have a common mission and vision?	Yes / No
Q5.	Has the ecosystem set specific goals and targets (e.g., CO2 reduction by 2030, reduction targets for water/energy/material use) with timelines in its strategy?	Yes / No
Q6.	Are the ecosystem's goals integrated and aligned with local and regional priorities?	Yes / No

TOPIC: SOCIAL AWARENESS		Answers
Section 1: Jobs creation		
Q1.	Does the collaborative industrial ecosystem pay special attention to human resources to complement its technical perspective?	Yes / No
Q2.	Does the ecosystem implement any of the following hiring initiatives?	Recruitment event / Links with local employment agencies / Connections with regional or local employment government bodies
Section 2: Knowledge creation		
Q3.	Does the ecosystem provide practical knowledge on circularity actions between cities, industries, and within industries?	Yes / No
Q4.	Does the ecosystem produce research and position papers on sustainability, industrial symbiosis, and the circular economy?	Yes / No
Q5.	Has any innovative technology been patented and implemented within the ecosystem?	Yes / No
Section 3: Skills		
Q6.	Does the ecosystem encourage educational institutions to incorporate circular economy (CE), industrial-urban symbiosis (I-US), and industrial symbiosis (IS) into their curricula?	Yes / No
Q7.	Does the ecosystem promote education and skill development through courses on energy/ resource efficiency, circularity between cities and industries, waste management, etc.?	Yes / No
Q8.	How is training provided within the ecosystem?	General training courses / Training on specific topics in the industrial sector / Job training (mentorships, trainee programs, apprenticeships)

Data availability

The data that has been used is confidential.

References

[1] M.R. Chertow, Industrial Symbiosis: literature and taxonomy, Annu. Rev. Energy Environ. 25 (1) (2000) 313–337, https://doi.org/10.1146/annurev.energy.25.1.313. Bd.. Nr.

[2] L. Sun u. a., Eco-benefits assessment on urban industrial symbiosis based on material flows analysis and emergy evaluation approach: a case of Liuzhou city, China, Resour. Conserv. Recycl. 119 (2017) 78–88, https://doi.org/10.1016/j.resconrec.2016.06.007.

[3] T. Domenech, R. Bleischwitz, A. Doranova, D. Panayotopoulos, L. Roman, Mapping industrial Symbiosis development in Europe_ typologies of networks, characteristics, performance and contribution to the circular economy, Resour. Conserv. Recycl. 141 (2019) 76–98, https://doi.org/10.1016/j.resconrec.2018.09.016.

[4] CEN, Industrial Symbiosis: Core elements and implementation approaches. Workshop Agreement, 2018. Dez. CWA 17354:2018 E.

[5] H. Li, L. Sun, L. Dong, K. Fang, R. Jingzheng, Eco-benefits assessment on urban industrial symbiosis based on material flows analysis and emergy evaluation approach: a case of Liuzhou city, China, Resour. Conserv. Recycl. 119 (2017) 78–88, https://doi.org/10.1016/j.resconrec.2016.06.007.

[6] M.A. Butturi und, R. Gamberini, Urban–industrial symbiosis to support sustainable energy transition, Int. J. Energy Prod. Manag. 5 (4) (2020) 355–366, https://doi.org/10.2495/EQ-V5-N4-355-366. Bd.. Nr.

[7] A. Neves, R. Godina, S.G. Azevedo, C. Pimentel, J.C.O. Matias, The potential of industrial Symbiosis: case analysis and Main drivers and barriers to its implementation, Sustainability 11, Nr. 24 (2019) 7095. Dez, https://doi.org/10.3390/su11247095.

[8] E. Faria, A. Caldeira-Pires, C. Barreto, Social, economic, and institutional configurations of the industrial Symbiosis process: a comparative analysis of the literature and a proposed theoretical and analytical framework, Sustainability 13, Nr. 13 (2021) 7123. Juni, https://doi.org/10.3390/su13137123.
[9] M. Morales und, A. Diemer, Industrial Symbiosis Dynamics, a Strategy to Accomplish Complex Analysis: The Dunkirk Case Study, Sustainability (2019), https://doi.org/10.3390/su11071971. Bd. 11, Nr. 7, S. 1971.
[10] Z. Yeo, D. Masi, J.S.C. Low, Y.T. Ng, P.S. Tan, S. Barnes, Tools for promoting industrial symbiosis: a systematic review, J. Ind. Ecol. 23 (5) (2019) 1087–1108, https://doi.org/10.1111/jiec.12846. Bd.. Nr.
[11] A.S. Maqbool, F. Mendez Alva, G. Van Eetvelde, An assessment of European information technology tools to support industrial Symbiosis, Sustainability 11, Nr. 1 (2018) S. 131. Bd.. Dez. https://doi.org/10.3390/su11010131.
[12] M.C.S.D. Abreu, D. Ceglia, On the implementation of a circular economy: the role of institutional capacity-building through industrial symbiosis, Resour. Conserv. Recycl. 138 (2018) 99–109, https://doi.org/10.1016/j.resconrec.2018.07.001.
[13] C. Makropoulos, N.-A. Kritikos, C. Pantazis, Matchmaking for industrial symbiosis: a digital tool for the identification, quantification and optimisation of symbiotic potential in industrial ecosystems, Front. Chem. Eng. 6 (2024) 1363888. Bd.. Juni, https://doi.org/10.3389/fceng.2024.1363888.
[14] Z. Liu, D.W. Hansen, Z. Chen, Leveraging digital twins to support industrial Symbiosis networks: a case study in the Norwegian wood supply chain collaboration, Sustainability 15, Nr. 3 (2023) S. 2647, https://doi.org/10.3390/su15032647.
[15] G.B. Grant, T.P. Seager, G. Massard, L. Nies, Information and communication Technology for Industrial Symbiosis, J. Ind. Ecol. 14, Nr. 5 (2010) 740–753. Bd.. Okt, https://doi.org/10.1111/j.1530-9290.2010.00273.x.
[16] L. Castellet-Viciano, V. Hernández-Chover, Á. Bellver-Domingo, F. Hernández-Sancho, Industrial Symbiosis: a mechanism to guarantee the implementation of circular economy practices, Sustainability 14, Nr. 23 (2022) S. 15872, https://doi.org/10.3390/su142315872.
[17] M. Nippa, F. Labriola, Roadmapping als integrative Planungsmethode im Rahmen eines situationsgerechten Time-to-Market Management, in: M.G. Möhrle und R., Hrsg Isenmann (Eds.), Technologie-Roadmapping, 2008, pp. 297–324, https://doi.org/10.1007/978-3-540-74755-0_15. Berlin, Heidelberg: Springer Berlin Heidelberg.
[18] M.P. Loginov, V.P. Ivanitsky, M.S. Maramygin, V.A. Tatyann, Roadmaps classification, Int. J. Eng. Technol. 7 (4.7) (2018) 91–96, https://doi.org/10.14419/ijet.v7i4.7.20522. Bd.. Nr.
[19] S. Vinayavekhin, R. Phaal, T. Thanamaitreejit, und, K. Asatani, Emerging trends in roadmapping research: a bibliometric literature review, Technol. Anal. Strateg. Manag. 35, Nr. 5 (2023) 558–572. Bd.. Mai, https://doi.org/10.1080/09537325.2021.1979210.
[20] C. Kerr und, R. Phaal, Roadmapping and roadmaps: definition and underpinning concepts, IEEE Trans. Eng. Manag. 69 (1) (2022) 6–16, https://doi.org/10.1109/TEM.2021.3096012. Bd.. Nr.
[21] A. Neves, R. Godina, S.G. Azevedo, J.C.O. Matias, A comprehensive review of industrial symbiosis, J. Clean. Prod. 247 (2020) S. 119113, https://doi.org/10.1016/j.jclepro.2019.119113.
[22] J. Azevedo u. a., Guidelines for industrial Symbiosis—a systematic approach for content definition and practical recommendations for implementation, Circ. Econ. Sustain., Feb. (2021), https://doi.org/10.1007/s43615-021-00006-3.
[23] M. Hossain, R.A. Aziz, C.L. Karmaker, B. Debnath, A.B.M.M. Bari, A.R.M.T. Islam, Exploring the barriers to implement industrial symbiosis in the apparel manufacturing industry: implications for sustainable development, Heliyon 10, Nr. 13 (2024) S. e34156. Bd.. Juli, https://doi.org/10.1016/j.heliyon.2024.e34156.
[24] S. Harris, M. Mirata, S. Broberg, P. Carlsson, und, M.A. Martin, A Roadmap for Increased Uptake of Industrial Symbiosis in Sweden, 2018, https://doi.org/10.13140/RG.2.2.31117.38886.
[25] International Synergies, A Roadmap for a National Industrial Symbiosis Programme for Turkey, 2019.
[26] D.P. De Alcantara, M.L. Martens, Technology Roadmapping (TRM): a systematic review of the literature focusing on models, Technol. Forecast. Soc. Change 138 (2019) 127–138, https://doi.org/10.1016/j.techfore.2018.08.014.
[27] D. Kanama, A. Kondo, Y. Yokoo, Development of technology foresight: integration of technology roadmapping and the Delphi method, Int. J. Technol. Intell. Plan. 4, Nr. 2 (2008) S. 184, https://doi.org/10.1504/IJTIP.2008.018316.
[28] S. Lee und, Y. Park, Customization of technology roadmaps according to roadmapping purposes: overall process and detailed modules, Technol. Forecast. Soc. Change 72, Nr. 5 (2005) 567–583. Bd.. Juni, https://doi.org/10.1016/j.techfore.2004.11.006.
[29] A. Lütje, M. Willenbacher, A. Möller, V. Wohlgemuth, Enabling the Identification of Industrial Symbiosis through ICT, 2019.
[30] J. Azevedo u. a., Industrial Symbiosis implementation potential—an applied assessment tool for companies, Sustainability 13, Nr. 3 (2021) S. 1420, https://doi.org/10.3390/su13031420.
[31] European Commission, Circular Economy Action Plan For a cleaner and more competitive Europe"n.d.
[32] Circular Benchmark Tool, Measuring & Monitoring Circularity in European Regions, 2023.
[33] European Commission, Measuring progress towards circular economy in the European Union – Key indicators for a monitoring framework"n.d.
[34] A. Feiferytė-Skirienė, Ž. Stasiškienė, Seeking circularity: circular urban metabolism in the context of industrial Symbiosis, Sustainability 13, Nr. 16 (2021) S. 9094, https://doi.org/10.3390/su13169094.
[35] European Environment Agency, Eco-Innovation Indexn.d.".
[36] H. Hollanders, N. Es-Sadki, A. Khalilova, European Commission, European Innovation Scoreboard, Publications Office of the European Union, 2022. https://data.europa.eu/doi/10.2777/309907.
[37] G. Valenzuela-Venegas, J.C. Salgado, F.A. Díaz-Alvarado, Sustainability indicators for the assessment of eco-industrial parks: classification and criteria for selection, J. Clean. Prod. 133 (2016) 99–116. Bd.. Okt. https://doi.org/10.1016/j.jclepro.2016.05.113.
[38] C. Ruiz-Puente, Proposal of a conceptual model to represent urban-industrial systems from the analysis of existing worldwide experiences, Sustainability 13, Nr. 16 (2021) 9292, https://doi.org/10.3390/su13169292.
[39] H.A. Verfaillie und, R. Bidwell, Measuring Eco-efficiency: A Guide to Reporting Company Performance, 2000.
[40] G.C. Gallopín, Environmental and sustainability indicators and the concept of situational indicators. A systems approach, Environ. Model. Assess. 1, Nr. 3, Art. Nr. 3 (1996), https://doi.org/10.1007/BF01874899.
[41] L. Fraccascia und, I. Giannoccaro, What, where, and how measuring industrial symbiosis: a reasoned taxonomy of relevant indicators, Resour. Conserv. Recycl. 157 (2020) 104799. Bd.. Juni, https://doi.org/10.1016/j.resconrec.2020.104799.
[42] J. Farquhar, N. Michels, J. Robson, Triangulation in industrial qualitative case study research: widening the scope, Ind. Mark. Manag. 87 (2020) 160–170. Bd.. Mai, https://doi.org/10.1016/j.indmarman.2020.02.001.
[43] S. Mishra und, A.K. Dey, Understanding and identifying 'themes' in qualitative case study research, South Asian J. Bus. Manag. Cases 11, Nr. 3 (2022) 187–192. Bd.. Dez. https://doi.org/10.1177/22779779221134659.
[44] M.G. Rietbergen, K. Blok, Setting SMART targets for industrial energy use and industrial energy efficiency, Energy Policy 38 (8) (2010) 4339–4354, https://doi.org/10.1016/j.enpol.2010.03.062. Bd.. Nr.
[45] J.T. Selvik, S. Bansal, E.B. Abrahamsen, On the use of criteria based on the SMART acronym to assess quality of performance indicators for safety management in process industries, J. Loss Prev. Process Ind. 70 (2021) 104392. Bd.. Mai, https://doi.org/10.1016/j.jlp.2021.104392.
[46] CIRCE, D3.2 Results of the self-assessment of Hubs4Circularity and action points to foster future progress. H4C Europe project, 2025. Nov. 2023. Zugegriffen: 27. Februar. [Online]. Verfügbar unter, https://app.h4c-community.eu/contents/1603/detail-content/IgHuKY8BxCLRtDkfMivI.
[47] M. Knöbl, J. Lindorfer, V. Rodin, und L. Ventura, „D8.5 Roadmap for the implementation of IS in the Follower cases (PU)", CORALIS project, 30 2024. Zugegriffen: 27. Februar 2025. [Online]. Verfügbar unter: https://www.coralis-h2020.eu/public-deliverables/d8-5-roadmap-for-the-implementation-of-is-in-the-follower-cases-pu/.