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ADVANCING CIRCULAR ECONOMY IN SLOVENIA: A SYSTEMATIC REVIEW OF INDUSTRIAL SYMBIOSIS NETWORKS AND THEIR OPPORTUNITIES

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Abstract: This article reviews the development and strengths of Industrial Symbiosis Networks (ISN) in Slovenia, which is crucial for transitioning to a Circular Economy (CE). Industrial Symbiosis (IS), as one of the tools for implementing a circular economy, promotes the collaborative use of resources, energy, and waste among industries, enhancing resource efficiency and reducing environmental impact. However, challenges such as inadequate regulatory support, underdeveloped markets for secondary raw materials, financial constraints, lack of awareness, and data-sharing issues hinder IS adoption. This article systematically reviews CE opportunities to enhance IS, including examples, digital platforms, eco-industrial parks, and government initiatives, using the PRISMA model (Preferred Items for Systematic Reviews and Meta-Analysis). By addressing these challenges and leveraging opportunities, Slovenia can further integrate IS into its industrial framework, advancing its CE goals. This analysis provides a foundation for future research and policy development in Slovenian Industrial Symbiosis.

Key-words: Industrial Symbiosis, Networks, Circular Economy, Resource Efficiency, Slovenia

1. Introduction

Economic and environmental pressures such as global warming and soil impoverishment have pushed governments to limit human environmental impact in the past two decades. A notable response has been implementing management systems within organisations to achieve sustainability. These systems create networks where the outputs of one firm become inputs for another, fostering interdependence and sharing services like transportation, waste collection, and utilities.

Despite frequent reports of rising pollution and environmental degradation, the urgency of these issues is not universally acknowledged. Understanding sustainable development is crucial for integrating ecological initiatives into daily life. This concept outlines goals to ensure future generations can enjoy a decent quality of life, requiring current sacrifices like changing habits and forgoing certain comforts.

Industrial activity has surged since the 19th century, driven by technological progress. Industry, which consumes about one-third of global energy (International Energy Agency 2008), significantly contributes to global warming through greenhouse gas emissions. In 2020, the total

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waste generated in the EU by all economic activities and households amounted to 2,135 million tonnes or 4,815 kg per capita (Eurostat 2023).
Governments have responded by taking measures to manage the use of energy sustainably. The United Nations Environmental Program (UNEP) emphasises waste minimisation technologies and procedures (Environment 2018).

Today, economic resource management is essential for companies, and the European Union emphasises the principles of an economy without waste. The CE is one of the most prominent concepts to come to the fore in the past decade in business, academia, and policymaking. This surge in interest is driven by its many benefits, including new business opportunities, innovative business models, and the development of new markets domestically and internationally. Businesses are motivated by these prospects (Geissdoerfer et al. 2017) and the changing preferences of consumers who increasingly demand sustainable products and services. (Rovanto and Finne 2023)
The spread of sustainable or "green" products and services, driven by enterprises implementing CE principles, attests to the CE concept's growing popularity. Additionally, the increasing prominence of CE in transdisciplinary research highlights its importance in addressing today's complex environmental challenges. Researchers are exploring and contrasting CE with traditional concepts such as "environmental sciences" and "sustainable development" (Sauvé, Bernard, and Sloan 2016). The growing body of academic literature, enhanced research funding, conferences, and training programs focusing on the CE, alongside its inclusion in international policy agendas and corporate sustainability reports, underscores its rising relevance and influence (Sauvé, Bernard, and Sloan 2016).
Moreover, the CE has significantly permeated policymaking, notably in the world's largest European Union and China markets. This integration reflects the global shift towards sustainability and recognising the CE as a viable pathway to achieve long-term environmental and economic goals (Uršič, Fric, and Rončević 2024).

The CE: the concept of achieving Sustainable Development
The CE as the economy of the future is one of the foundations that provides a recuperative system where materials move in a stable system, ensuring a balance between economic development and the protection of ecological resources. Ecological economic principles are essential if such results benefit companies and the environment.
This sustainable approach, where the efficient distribution of resources and the philosophy of completion of development, means that such an economy is different. Koenig 04/12/2024 16:06:00explains that the "CE" is a rounded or completed economic concept.
The CE aims for the efficient use of resources in combination with cleaner production and industrial ecology in a wider system that connects industrial companies, eco-industrial parks, networks and/or chains of companies and regional infrastructure to support resource optimisation. Public and private state-owned enterprises, government and private infrastructures, and consumers create a CE (Behne, 2016).
The CE returns materials to the environment, but even more challenging ideas and truths are growing within industrial ecology.
One of the key tools of the CE concept is industrial symbiosis (IS), where companies cooperate by exchanging waste, side of products, wastewater, and energy to use it again. IS can be defined as integrating traditionally separate industry industries that involve the physical exchange of materials, energy, water and/or by-products. Collaboration between industry partners is essential to achieve shared economic and environmental benefits (Ažman Momirski, Mušič, and Cotič 2021).
IS foundations are based on cooperation between companies based on synergies that enable geographical proximity or redundant materials. On the national level, countries have identified

barriers, including scarcity of systemic support, incomplete market secondary ones, lack of raw materials, financial incentives, and disconnection of spatial planning with IS.

1.1 Processed and disposed amounts of waste in Slovenia

The material circularity rate for the EU-27 represents the average performance of all members regarding resource efficiency and sustainability. In 2011, it amounted to 10.2%, and in 2018 it reached 11.6%. The rate has recently remained relatively stable at around 11%, with a slight increase in 2022.

The degree of circular use of materials in Slovenia has shown some variability over the years, but generally, it shows a positive trend. The rate of circular use of materials started at 5.9% in 2010 and increased to 9.4% in 2022. This puts Slovenia below the EU average by 2% and as much as 18.1% less than the Netherlands (Eurostat 2024a).

The total processed waste for various sectors of industry and crafts in Slovenia in 2022 amounted to 13,998,708 tons, while the total amount of disposed waste amounted to 803,811 tons. The data from the Slovenian Statistical Office show that the most processed waste is in the category "Construction waste, waste from the demolition of buildings", where as many as 10,116,647 tons of waste are processed. The most disposed waste is in the category "Municipal waste (household, similar) and separately collected fractions", where 402,010 tons of waste were disposed (Statistical Office of the Republic of Slovenia 2024b).

The most considerable growth in waste processing occurred in the category "Construction waste, demolition waste", where the number of tons of waste processed increased significantly from 2002 to 2022. Generally, most waste is in categories related to industrial processes, construction, and production, such as "Construction waste, waste from the demolition of buildings". In addition to the large increase in construction waste, the share of its processing has also increased. Almost all of this waste is processed (10,116,647 tons out of 10,169,376, which is 99.48%), part of it is disposed of (46,406 tons), and part of it is "Overlay and waste intended for construction at the landfill" (6,323 tons). 20 years ago, most were only disposed of, while more than 42% were processed. At that time, however, the largest share of waste came from thermal processes, most of which was processed (1,458,460 tons out of a total of 4,152,689, or 35%, and 82% of the processed was processed).

The lowest amount of waste is in categories related to more specialised industries or smaller processes, such as "Waste solvents, refrigerants, propellant gases", "Photographic industry" and "Inorganic chemical processes".

Data from the Statistical Office of the Republic of Slovenia in 2024 show increased waste from 2002 to 2022. The largest amounts of waste are generated in Western Slovenia (6.4 million tons). If we compare the years 2020 and 2021, we can see that the amount of waste in Western Slovenia increased significantly, while it increased more moderately in Eastern Slovenia. In 2002, significantly more waste was generated in Eastern Slovenia (3.2 million tons) than in Western Slovenia (900 thousand tons) as much as 5.5 million tons. The most waste is produced in the "Central Slovenia statistical region (3.4 million tons), followed by the Coastal-Karst (slightly more than 1.6 million tons) and Savinja (slightly less than 1.6 million tons) regions. In 2002, the most waste was generated in the Savinja region, namely almost 2 million tons, i.e. almost half (48.1%) of all waste generated in Slovenia that year. The least amount of waste is generated in Littoral-Inner Carniola (176 thousand tons) and the Carinthia region (225 thousand tons) (Statistical Office of the Republic of Slovenia 2024a).

2. IS: theoretical background

IS has gained more and more attention, especially since 1989, when industrial ecology created a new perspective of industrial development: industrial complexes should be designed to resemble natural ecosystems to optimally use of energy, water and material resources while reducing waste. The complexity of the process increased during this period. Although waste exchanges were not yet called IS synergies, the early process began right then. Among many examples, the

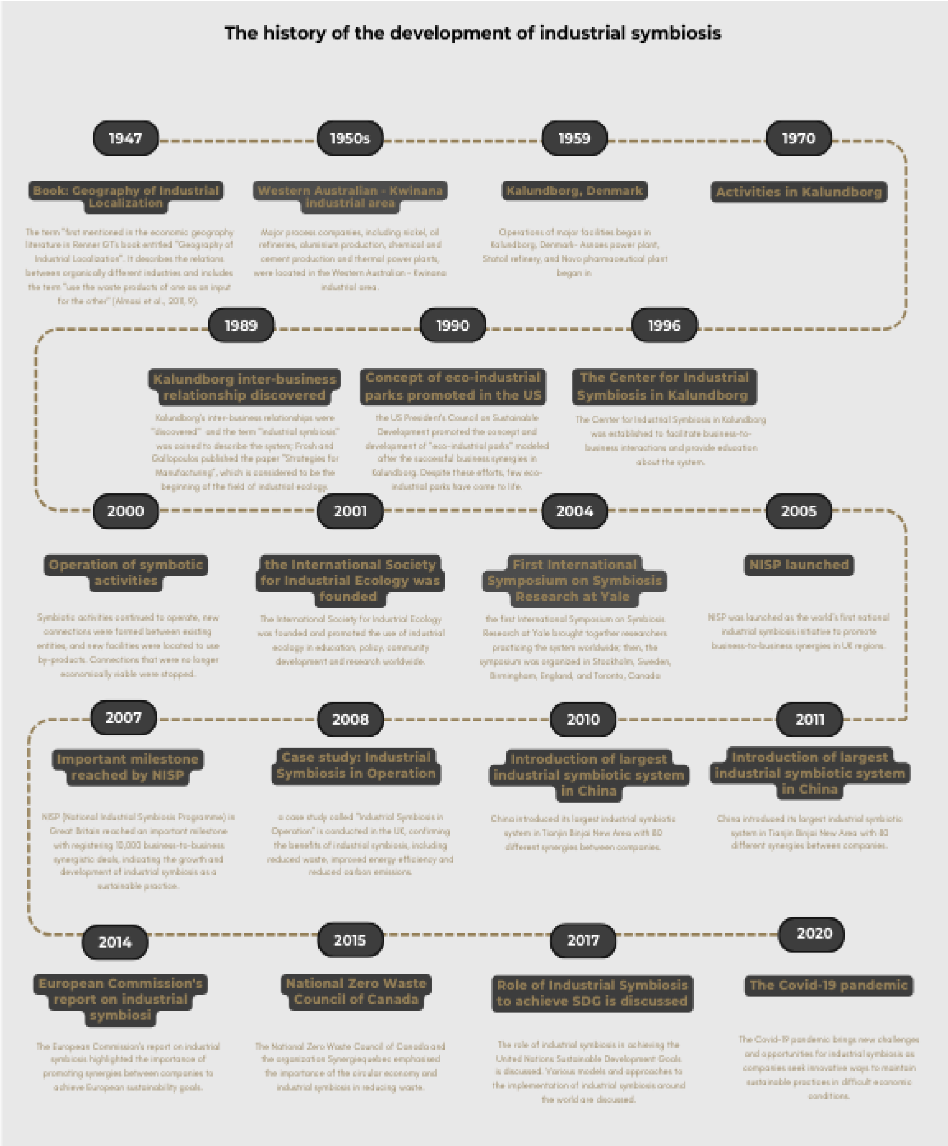
National Industrial Symbiosis Research Program (NISP) and the European Union worked with local partners to establish the largest IS system in Tianjin Binjai New Area (China) with 80 different synergies in March 2010 (Džajić Uršič 2020).

The literature on these industrial-type collaborative environments dates back 100 years to the economist Alfred Marshall, who studied them to understand Britain's leading position in textile production (Marshall, 2009).

The basic concept of IS could be the metaphor of an industrial ecosystem mimicking a natural ecosystem, which appears in the early literature on industrial ecology. In 1989, Frosch and Gallopoulos (1989) inspired much of industrial ecology in their book when they wrote of an "industrial ecosystem" in which "energy use and material consumption are optimised, and the effluents of one process serve as raw materials for another process" (Frosch and Gallopoulos (1989); Gallopoulos (1989, 144)). In the same year, Ayres wrote about both the biosphere and the industrial economy "as systems for the transformation of materials" and how studying this "industrial metabolism" can lead to shifts in the direction of increased efficiency of material and waste flows. Indeed, the editor of the Journal of Industrial Ecology, Reid Lifset, commented on the symbiosis exchange of materials and the enthusiasm for Kalundborg in the journal's inaugural issue but reassured readers that the journal "is not just about coincident facilities exchanging waste" (Lifset, 1997 1, cited in Chertow 2000, 317–318).

The history of the development of IS is presented in Figure 1.

Figure 1: Timeline of the development of IS.



Source: (Own, 2024)

Important aspects of cost productivity, environmental protection, resource management, greenhouse gas/emission reduction, and social aspects are put increased pressure on industrialised districts. IS emerged as a collective, cooperative, multi-industry approach to economic and environmental sustainability. Using the definition given by Chertow (2000), IS is defined as the union of "traditionally separate industries with a collective approach to gain a competitive advantage, where the basic activity is the exchange of materials, energy, water and by-products." Positive economic effects are seen in reducing costs and removing waste and by-products, with a competitive advantage over other economic entities and a better reputation for the economic entity or companies Chertow (2000). Companies, therefore, participate in an IS to exchange different resources within closed and sustainable cycles. Such cooperation reduces the input of materials, energy use, and waste. Compared to raw materials without waste, the low price of waste as a raw material increases the economic efficiency of individual organisations (recipients of waste) within networks of IS (Chertow, 2000, 2007).

2.1 The IS in Slovenia

In Slovenia, the topic of IS has been gaining traction since 2010; however, the research available is still limited (Ažman Momirski, Mušič, and Cotič 2021). In Slovenia, IS is driven by governmental initiatives and private-sector engagement. The Slovenian government has recognised the importance of IS in achieving its sustainability goals. It has been included in various strategic documents and action plans, which can be divided into national documents, networks, EU and other projects, conferences, and city activities (Ažman Momirski, Mušič, and Cotič 2021) that include, for instance:

- the SYMBI project, funded by the Programme 2014–2020 Interreg Europe, recognised these obstacles and temptations to strengthen IS between small and medium-sized enterprises. Key challenges identified included swinging quantities, secondary ones, lack of knowledge and capacity for raw materials, and the need for everyone to be trained (Symbi Interreg Europe 2022).
- VCG.AI platform: digital platforms where companies enable easy searching and bidding of resources, such as the VCG.AI platform, which uses artificial intelligence to connect companies and convert waste into resources that create income ('AI & Big Data Platform for Circular Bioeconomy' 2024).
- Interreg Central Europe project LUMAT: eco-industrial parks have become best practices to promote IS. The City of Kranj is currently a partner in the project. The project's main objective is to ensure sustainable land use in the integrated environmental management of functional urban areas (Cotic 2019).

Several successful examples of IS can be found in Slovenia. One notable case is the collaboration between AquafilSLO and HELLA Saturnus, where AquafilSLO uses thermal energy from HELLA Saturnus to heat its production facilities. Another example is Reusable Technologies, which develops advanced solutions for e-waste reuse, demonstrating the potential of IS in the CE approach. These initiatives highlight the practical benefits of IS and serve as models for other industries to follow.

Some evident projects in Slovenia are based on the approaches of industrial symbiosis:

- the EIT Urban Mobility Program marks a significant stride towards enhancing the competitiveness of European companies and accelerating the market deployment of laboratory innovations. Collaborations involving industry, municipalities, universities, and research institutes aim to foster positive changes in urban mobility, enhance city living conditions, and position this initiative as pivotal in transforming urban mobility across Europe (Ažman Momirski, Mušič, and Cotič 2021).
- EIT Raw Materials and the Adria Regional Center focus on ensuring sustainable supplies of raw materials, metals, and key resources essential for European industries. These initiatives promote innovation, entrepreneurship, and education within the raw materials sector, strongly emphasising mining, prospecting, recycling, and implementing CE practices (Ažman Momirski, Mušič, and Cotič 2021).
- the ECCA project, where the construction cluster spearheads international collaborations in the CE. This initiative enhances Slovenia's global influence and promotes sustainable construction practices, crucial for mitigating environmental impact (Ministry of Infrastructure RS 2022).
- the FULL CIRCLE program showcases how symbiotic relationships between paper mills and building material manufacturers transform waste into valuable resources, promoting resource efficiency and enhancing product quality (Republic of Slovenia 2018).

To diversify and enhance IS networks, Slovenia employs several strategic approaches. Moreover, establishing business networks and clusters encourages collaboration and knowledge exchange, which is crucial for scaling sustainable practices (Rončević and Tomšič 2017). Simmilar holds true for cases of technology transfer and collaborations between academia and industry (Besednjak Valič et al. 2022). Nevertheless, without policy interventions intersectoral collaborations are hard to establish (Besednjak Valič et al. 2023) however, strategic collaborations can be established (Rončević and Besednjak Valič 2022).

The evolution of IS networks in Slovenia underscores a dynamic process shaped by technological advancements and policy interventions. Projects like SYMBI, supported by Interreg Europe, illustrate Slovenia's efforts to foster regional sustainability through innovative waste management practices (Symbi Interreg Europe 2022). However, challenges such as limited awareness among businesses and regulatory complexities pose barriers to widespread adoption. Historically, the SYMBI project represented a significant milestone in addressing the challenges of establishing IS in Slovenia. The project identified various legal, economic, market, and financial obstacles, highlighting gaps in knowledge of CE strategies and practical approaches to implementing IS. Awareness of CE principles' economic and environmental benefits and IS was low, compounded by an undefined business-supportive environment. Pilot projects under the SYMBI initiative provided crucial training and practical experiences, fostering regional stakeholders' understanding and application of IS concepts. Notably, successful collaborations between companies, such as a synergistic exchange between a coffee producer and a mushroom grower, demonstrated how IS could simultaneously enhance economic efficiency and reduce environmental impact, serving as a model for positive interplay among Slovenia's economy, environment, and society (RRA LUR 2021).

2.2 Social frameworks

Due to the early development of industrial ecology and later the science of IS, there is little scientific literature, sources, and theories on how IS networks developed and were built in Slovenia.

The presented aspects of IS are not only technological or logistical systems but transcend the boundaries of different systems and are also social systems. Therefore, social systems, later called "networks of IS ", can be considered social networks. This suggests that links within networks of IS, e.g. in companies and households, among political, social, and economic actors operating in the context of bounded rationality, are limited in their rational decision-making, not only by their organisational values but also by the decisions of other organisations.

Since exchange, as the basic activity of industrial symbiosis, occurs between social actors and requires cooperation, communication and a certain degree of trust, their morphogenesis can be studied. The formation of networks within IS is a complex process, where success is highly dependent on establishing cooperation in several areas, including the physical, social and organisational areas. Neglecting just one of these areas can cause a significant delay or even more fragile development of a useful IS network (Republic of Slovenia 2018).

Based on the presented information, it is evident that Slovenia is growing in recognition of the need to shift economic paradigms towards sustainability. Companies and institutions are responding to these challenges through increased cooperation, innovation, and adjustments in business practices aligned with the CE concept. Organisations like SPIRIT Slovenia and initiatives such as SRIP play crucial roles in fostering and supporting these transformative changes (Börc 2023). In this case, SRIP has a pivotal platform in Slovenia, unifying various sectors and stakeholders to achieve CE objectives. With 87 members, including 56 companies, 15 knowledge institutions (including universities in Ljubljana and Maribor), and 14 non-governmental organisations (NGOs), including economic chambers, SRIP emphasises collaboration among small to medium-sized enterprises (SMEs), highlighting the importance of development cooperation, networking, trust, openness, and transparency (SRIP 2021). SRIP is structured around six key focus areas that underpin the transition to a CE: energy use, biomass and alternative raw materials, secondary raw materials, sustainable functional materials, green technologies and processes, and circular business models. The partnership provides its members with comprehensive services, including updates on CE developments, legislation, public tenders, and opportunities to participate in development projects. It fosters connections between knowledge institutions and the economy to jointly develop high-tech products and services (SRIP 2021).

Industrial symbiosis networks (ISN) in Slovenia represent a pivotal strategy for achieving sustainable development goals, particularly transitioning to a CE. Slovenia has emerged as a regional leader in integrating IS principles across various sectors, demonstrating notable strengths and fostering innovative approaches to resource efficiency and waste management.

In all initiatives, the most important document laying the foundation for Slovenia's CE/IS is the "Roadmap to the Circular Economy in Slovenia." This document selects four priority areas, makes proposals to the government and highlights best practices with an inclusive multi-stakeholder approach (Republic of Slovenia, 2018) .

The long-term dynamics of IS networking in Slovenia are intricately linked to the European Union's green transition and the country's efforts towards reducing dependence on imported raw materials. This necessitates a strong emphasis on technological innovations to meet committed sustainability goals. Integrating industries throughout the developmental process is central to this context, leveraging fundamental and applied research innovations. National financial incentives, facilitated through various research, infrastructure, and development programs, are critical in ensuring continuous funding for technologies that support green transitions (Republic of Slovenia 2019).

Building upon presentations and discussions, Slovenia recognises the importance of a unified and harmonised legal framework to facilitate comprehensive solutions. Establishing broad strategies requires trust, which evolves through inclusive dialogue involving relevant stakeholders such as companies, public institutions, non-governmental organisations, and political stakeholders. Stakeholders are increasingly aware of the potential benefits of IS and are actively engaging in voluntary initiatives. Expert guidance is crucial in assisting companies in mapping their waste streams and potentials, demonstrating the importance of a supportive environment and qualified personnel in implementing IS and CE principles (Republic of Slovenia 2019).

The implementation of IS in Slovenia is not without challenges. Systemic support and comprehensive regulatory frameworks are lacking, and existing policies are not sufficiently integrated with spatial planning and industrial practices. The market for secondary raw materials is underdeveloped, with issues related to the fluctuating quality and quantity of materials. Financial incentives for companies to engage in IS are limited, and there is a significant gap in awareness and understanding of the benefits and processes of IS among businesses. Moreover, concerns about sharing business-sensitive information can inhibit collaboration. This is the case of formal and informal social processes that intertwine and complement. Formal processes provide a wider framework, guidance, and support, while informal processes enable flexibility, adaptability, and faster responses in concrete cases of IS. The total operation of both social processes contributes to effectively implementing IS in Slovenia (Zelena Slovenija 2023).

IS, whether observed as an empirical outcome or as a theoretical, normative concept, is not only based on technological and economic factors but is also shaped by social forces (institutions, social networks, cognitive frames) as defining structural principles (Džajić Uršič 2020).

The main obstacles in developing an ISN in Slovenia are technical, informational, economic, political, and organisational, and we can easily place them into categories that Mirata and Emtairah (2005) argue. There are some categories to consider when discussing IS network development. Each category includes specific factors and potential resources that can either hinder or facilitate the implementation of IS:

- Technical obstacles include the characteristics of production assets, such as the physical, chemical, and geographical attributes of products, by-products, and waste. Additionally, processing resources, including energy, water, logistics, and management capabilities, pose challenges. The accessibility of technology that can enable synergies between companies is also a critical technical barrier.
- Informational obstacles arise from companies' reluctance to share business-sensitive information and the need for honest and reliable information across various activities. Effective information management systems are required to manage information dynamically and evaluate the feasibility of potential synergies.
- Economic and financial obstacles include the costs associated with primary production and the economic value of waste and by-products. High investments and costs to develop

and maintain synergies can be prohibitive. Moreover, the payback period and return on investment are crucial economic considerations that impact the viability of IS.

- Political obstacles stem from the nature of environmental legislation and regulations, which can impact IS development. Taxes, duties, penalties, and subsidies play significant roles, as do conditions for loans and subsidies that can either support or hinder IS initiatives.
- Organisational and motivational obstacles involve building trust and openness towards collaboration and new ideas. Companies' perception of risks associated with IS can affect their willingness to participate. Additionally, the organisational culture within companies and the presence of necessary institutional frameworks are critical for successful IS (Mirata and Emtairah 2005).

3. Methodology

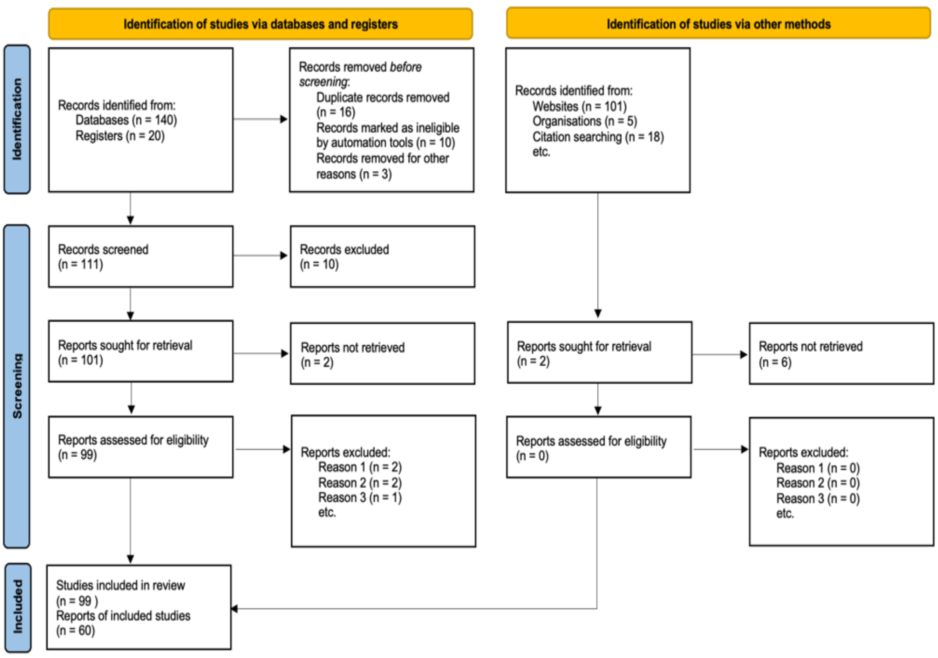
The article provides an overview of the state of the art. First, it presents key research approaches addressing IS and networks. Second, it continues by outlining theories and examples in Slovenia. The PRISMA model approach systematically reviews cases, and taxonomy reviews cases and taxonomy has been used. The authors do not develop new approaches or definitions but bring some importance to Slovenia.

This article includes several methodological approaches to review Slovenia's situation in the circular economy and IS field. The study employs a comprehensive systematic literature review to achieve this, adhering to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The authors used the PRISMA for new systematic reviews, which involved thorough searches of databases, registers, and additional sources (Figure 2). This method ensures a transparent and reproducible analysis and reporting of prior research.

The analysis is segmented into two parts: (1) data were gathered and extracted from multidisciplinary databases, such as Web of Science (WoS) and Scopus and (2) supplemented with resources from the authors' personal databases. These personal databases previously provided unique insights and perspectives.

Document analysis was integrated with qualitative content analysis results. This approach to analysing qualitative data enhances understanding of current issues and concepts in these fields.

Figure 2: The PRISMA flow diagram



Source: (Own and based on Page et al. 2021)

The PRISMA flow diagram illustrates the progression of information through the various stages of the systematic review, indicating the number of records identified, included, and excluded, along with the reasons for exclusion.
This approach involved identifying, screening, and analyzing 99 academic sources and 60 industry reports to ensure a comprehensive overview of the field. The review's aim was to synthesize existing knowledge, identify research gaps, and highlight areas for future research and practical implementation.

3.1 Key Thematic Insights

From the analysis, several key themes emerged that are critical to understanding the current state and future potential of IS and CE initiatives in Slovenia as follow

3.3.1 Thematic Area 1: Sustainable Resource Management

Much of the reviewed literature focused on sustainable resource management as a core component of industrial symbiosis. This theme addressed how companies and institutions in Slovenia are increasingly adopting practices that optimise resource use, minimise waste, and enhance material efficiency. Studies highlighted successful cases where waste products from one industry serve as raw materials for another, demonstrating the practical application of circular economy principles. For example, the study by Börc (2023) documented how Slovenian manufacturing firms have reduced raw material costs and environmental impact by reusing by-products within local industrial clusters.

3.3.2 Thematic Area 2: Technological Innovation and Implementation

Technological innovation emerged as another crucial theme. The reviewed sources frequently discussed the role of advanced technologies in enabling industrial symbiosis, including digital platforms, automation, and data analytics for waste tracking and resource optimisation.

3.3.3 Thematic Area 3: Policy and Regulatory Frameworks

The role of policy and regulation was a recurring theme across academic and industry sources. Various studies underscored the need for supportive regulatory frameworks incentivising circular practices and industrial symbiosis. Findings indicated that while Slovenia has made significant progress in aligning national policies with EU directives on waste management and circular economy, further enhancements are needed to streamline regulations and provide clear business guidelines. Reports from the Slovenian Industrial Strategy (2021-2030) (Republika Slovenija 2021) emphasised the importance of public-private partnerships and government support in fostering an environment conducive to circular economy initiatives.

3.3.4 Thematic Area 4: Economic and Social Impacts

Economic benefits, such as cost savings and new business opportunities, were highlighted as key drivers for adopting industrial symbiosis. However, several sources also pointed out the social implications, such as job creation and community engagement, as equally important. Studies indicated that ISN practices enhance environmental sustainability and contribute to regional economic development by creating new market opportunities and promoting local entrepreneurship. For example, the SRIP – Circular Economy (SRIP 2021) case study described a project where waste materials from one industry were used to create new products, leading to job creation and skills development in local communities.

3.3.5 Thematic Area 5: Challenges and Barriers to Implementation

Despite the positive outlook, numerous challenges to the widespread adoption of industrial symbiosis and circular economy practices were identified. Common barriers included a lack of awareness and understanding among businesses, insufficient funding for innovative projects, and logistical challenges in coordinating between different industries. Several reports, such as those by SPIRIT Slovenia (SPIRIT Slovenia 2024) stressed the need for educational initiatives and training programs to build the capacity of stakeholders to implement and manage ISN effectively. Additionally, the need for better infrastructure to support the exchange of materials was noted as a critical area for improvement.

3.4 Findings from Industry Reports

The industry reports provided practical insights into the current application of industrial symbiosis and circular economy in Slovenian businesses. These reports often presented case studies highlighting successful collaborations between companies and innovative waste management and resource efficiency approaches. A notable example from the National Report on Waste Management in Slovenia (2022) detailed how a network of SMEs in Slovenia developed a shared platform for exchanging waste materials, significantly reducing disposal costs and environmental impact (SURS 2022).

3.5 Trends, Patterns, and Comparative Analysis

A comparative analysis of the reviewed literature and reports revealed several trends and patterns:

- A growing alignment between academic research and industry practices indicates that theoretical insights are increasingly being translated into practical applications.
- The adoption of digital technologies for tracking and optimizing resource flows is becoming more widespread, driven by real-time data and automation benefits.
- Policy support and regulatory frameworks are crucial for scaling industrial symbiosis initiatives, with evidence suggesting that countries with more robust policies see higher levels of adoption and innovation.

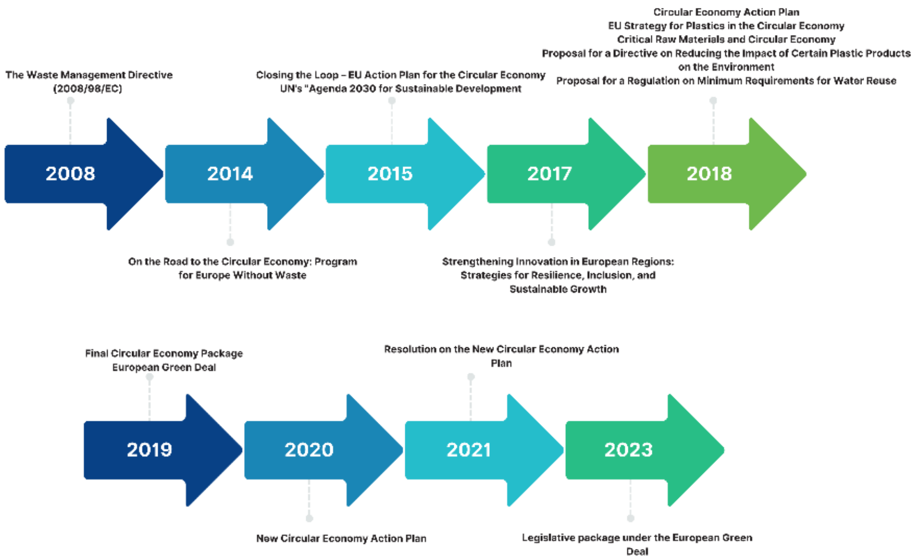
The systematic review conducted in this study provides a holistic understanding of the current landscape of industrial symbiosis and circular economy in Slovenia. By synthesizing findings from a broad range of sources, this review consolidates existing knowledge and identifies critical gaps and opportunities for future research. The insights gained from this review can inform policymakers, industry leaders, and researchers in developing strategies to enhance the implementation of circular economy practices, thus contributing to sustainable economic development.

4. Review of environmental EU policies: the period between 2008 and 2024

With the purpose of tracking and implementing environmental EU policy and transition to a circular economy, today, in the framework of European Commissions, mostly financially support European structural and investment funds (European Structural and Investment Funds), Horizon 2020 program, European fund for strategic investments (European Fund for Strategic Investments), the LIFE program and many others the rest (Bachtler et al. 2017; Pinyol Alberich, Pansera, and Hartley 2023; UNEP 2018).

In the sequel, the authors present the legislative-legal of the frame (presented as in Figure 3), that is, through the concept of CE and its tools in the framework of environmental EU politicians beginning to enforce the new approach to treatment waste. The (Ellen MacArthur Foundation 2024) concept of CE responds to the pressure of a growing economy, the consumption of limited resources, and the environment of career ability.

Figure 3: Legislation overview of the circular economy.



Source: (Own, 2024)

The Waste Management Directive (2008/98/EC) came into force and outlined the path to the new approach proceedings of waste, at which they become waste resource raw materials. Therefore, countries' EU members have accepted measures to waste in what a larger measure again uses (European Parliament and of the Council 2008).

In 2014, due to the low rate of waste processing in Europe, the European Commission introduced the policy "On the Road to the Circular Economy: Program for Europe Without Waste." This initiative proposed new legislation on waste management to enhance the existing framework, which had been in place for four decades (European Parliament and of the Council 2014).

In 2015, the European Commission furthered its commitment to a CE with the "Closing the Loop – EU Action Plan for the Circular Economy." This plan has aimed to reduce landfill waste, increase the reuse and recycling of key waste streams such as municipal and packaging waste, and align member states with best practices to foster necessary investments in waste management. Moreover, the UN's "Agenda 2030 for Sustainable Development" was adopted, integrating economic, social, and environmental dimensions across 17 Sustainable Development Goals, including Goal 12 on sustainable production and consumption (World Health Organization 2016).

In 2017, the European Commission published "Strengthening Innovation in European Regions: Strategies for Resilience, Inclusion, and Sustainable Growth." This document has emphasised enhancing regional innovation potential, increasing interregional cooperation, focusing on less developed regions, and developing coordinated EU policies to support innovation (European Commission 2017).

2018, under the "Circular Economy Action Plan," the European Commission has adopted several strategies and measures. The "EU Strategy for Plastics in the Circular Economy" aimed at transforming the lifecycle of plastics to ensure all plastic packaging is recyclable by 2030, limiting plastic waste and encouraging innovations. Additionally, the "Monitoring Framework Progress" was designed to track CE progress using ten key indicators, and the "Critical Raw Materials and Circular Economy" report aimed to enhance the circular use of critical raw materials (European Commission 2023a). Further, the European Commission introduced the "Proposal for a Directive on Reducing the Impact of Certain Plastic Products on the Environment" and the "Proposal for a

Regulation on Minimum Requirements for Water Reuse" (Council of the European Union Brussels 2019).
In 2019, the European Commission adopted the "Final Circular Economy Package" and the " European Green Deal " to guide the EU towards a green transition and climate neutrality by 2050 (European Council 2019)
In 2020, the "New Circular Economy Action Plan" was introduced, outlining modernisation initiatives for the European economy. This plan emphasised sustainable products and citizen participation in the CE (European Commission 2020a; 2020c; 2020b; 2023b).
In 2021, the European Parliament adopted the "Resolution on the New Circular Economy Action Plan," which called for stricter processing rules and binding targets for material use and consumption by 2030. This aimed to achieve a carbon-neutral, sustainable, non-toxic, and full CE by 2050 (European Commission 2022).
In 2023, the European Commission proposed a legislative package under the European Green Deal. This included temporary agreements on new environmental requirements for sustainable product design (European Commission 2023b).
The action plan for the new CE is a cornerstone of the European Green Deal and the new agenda for sustainable growth. The EU's transition from a linear to a CE aims to reduce pressure on natural resources, create sustainable growth and jobs, and achieve climate neutrality by 2050. The plan includes initiatives across the product lifecycle, promoting CE processes and sustainable consumption to maintain resource value within the EU economy (European Commission 2024).

5. Conclusion: proposals and recommendations

The findings from Slovenia's research on the circular economy's approach– IS, underline significant progress and opportunities for sustainable development. Establishing robust networks, such as those facilitated by SRIPs and platforms like e-Simbioza, has fostered collaboration among diverse stakeholders. These networks enhance resource efficiency and waste management, promoting innovation and resilience across various sectors. Looking ahead, sustaining and expanding these networks will be crucial. Longitudinal studies tracking their socio-economic and environmental impacts will provide invaluable insights into their effectiveness and areas for refinement. Additionally, integrating digital technologies into network operations promises to optimise resource flows and transparency, further enhancing efficiency. By cultivating these networks, Slovenia can forge a path towards a CE that conserves resources, catalyses sustainable growth, and enhances societal well-being.
As Slovenia continues to refine its policy landscape, international comparative studies will offer valuable benchmarks for aligning national strategies with global best practices. Through these concerted efforts, Slovenia can further consolidate its leadership in sustainable development, leveraging innovation and collaboration to propel its CE agenda towards resilience and prosperity.
The main activities and recommendations for further research in IS in Slovenia are as follows:

- Awareness raising and education: It is important to educate business entities, political decision-makers, and the public about IS, its benefits, and possibilities for sustainable development. The development of educational programs, workshops, and campaigns can contribute to promoting and expanding the use of IS.
- Organising events, forums and meeting platforms between companies, institutions and local communities is a powerful way to foster partnerships and networking. These platforms facilitate the exchange of resources and knowledge, enhancing the collective understanding and application of IS.
- Increasing support and incentives for IS: State and local authorities and institutions should develop policies and measures that encourage the introduction of IS, such as financial incentives, tax breaks, and simplification of bureaucratic procedures for the establishment and operation of ISN.

- Development of innovative business models: Promoting research and development of new business models based on IS can create innovative solutions for sustainable development and increase companies' competitiveness.
- Establishing appropriate benchmarks to monitor progress: Developing indicators and benchmarks to monitor IS's efficiency and effectiveness and regularly reporting on the results achieved can help identify successful practices and areas for improvement.
- Emphasising the need for international recognition of the Slovenian approach to IS is crucial. Engaging with foreign institutions, companies, and experts allows for exchanging experiences, best practices and technological solutions, contributing to this recognition and influence.
- Support for research and innovation: Investing in research and development in IS and promoting innovative solutions can help discover new possibilities for optimising resources, reducing waste and improving the sustainability of industrial processes.

The proposal of guidelines based on the performed analysis aims to address complex challenges while capitalising on emerging opportunities in Slovenia. They can pave the way for a resilient, resource-efficient future, driving economic prosperity and environmental stewardship by prioritising digital integration, sustainable design, policy alignment, socio-economic impacts, and knowledge sharing.

Implementing these guidelines will require a comprehensive approach and the cooperation of key stakeholders. Still, correct implementation can lead to long-term benefits for Slovenia's economy, society and environment.

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