

*Original scientific paper*

## **INDUSTRY SYMBIOSIS – LITERATURE REVIEW AND SITUATION IN NORTH MACEDONIA**

**Aleksandar Erceg<sup>1</sup>**  
**Jovana Damoska Sekuloska**  
**Vera Boškowska**

### **Abstract**

Industrial symbiosis is a sub-area of industrial ecology and involves using waste or by-products from one actor as resources for another actor to achieve ecological and economic benefits. Industrial symbiosis is of central importance for the reuse of resources and the avoidance of waste. It is driven by opportunities for collaboration and synergies facilitated by geographical proximity (Chertow, 2000). In other words, industrial symbiosis is a link between industrial facilities or companies where the waste or by-products of one company become raw materials for another.

Industrial symbiosis (IS) can reduce the amount of industrial waste and the need to recover raw materials from waste generated by one industry as raw materials for another. These relationships are driven by several factors, such as resource-saving economic benefits that meet environmental requirements, e.g., reducing greenhouse gas emissions, natural resource scarcity and reducing waste that would otherwise end up in landfills and incinerators. The IS concept uses symbiotic collaborations and business linkages to close the loop.

Keywords: Industry symbiosis, opportunities, barriers, North Macedonia

*JEL classification:* Q53; L65; O13

### **INTRODUCTION**

Industrial ecology is a field of study that studies the materials and energy flow within industrial systems. It considers the environmental implications of these flows and the interplay of regulatory, political, economic, and social factors that influence resource utilization and conversion (Isenmann, 2018; Saavedra et al., 2018). A core principle of industrial ecology is the concept of closed-loop material cycles, which seeks to minimize waste and pollution (Fet& Deshpande, 2023). Inspired by the efficiency and sustainability of natural ecosystems, industrial ecology advocates for designing industrial systems that emulate these processes, where the by-products of one system can serve as inputs for another.

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<sup>1</sup>**Aleksandar Erceg, Ph.D.**, Associate Professor, Josip Juraj Strossmayer, University of Osijek, Faculty of Economics in Osijek, Croatia; **Jovana Damoska Sekuloska, Ph.D.**, Associate professor, University of Information Science and Technology “St. Paul the Apostle” Ohrid; **Vera Boškowska, Ph.D.**, Assistant Professor, University of Skopje, Republic of North Macedonia.

The circular economy is a production and consumption model that focuses on extending the lifespan of products and resources (Bruel et al., 2018). By minimizing waste, maximizing resource efficiency and emphasizing long-lasting product design, the circular economy departs from the traditional linear economic model of "make, use, dispose." Instead, it encourages continuous reuse, repair and recycling of materials whenever possible, thus promoting a more sustainable and regenerative approach to economic activity. Industrial symbiosis is a specific form of industrial ecology that focuses on the collaborative exchange of materials and by-products between industrial companies (Ghisellini, Cialani&Ulgiati, 2016). By reusing waste or by-products from one process as inputs for another, industrial symbiosis aims to achieve both environmental and economic benefits and promote a more sustainable and resource-efficient industrial ecosystem. (Figure 1)



**Figure 1.** Industrial symbiosis illustration  
Source: ChatGPT, 2024

The illustration underlines the mutual benefit and sustainable exchange within the framework of an eco-industrial park. It makes it meaningful for the companies involved and, at the same time, shows a network of interconnected industries that exchange resources such as energy, water, raw materials and waste products. Although the circular economy and industrial symbiosis are geared towards sustainability, their focus differs. The circular economy includes materials and products of all kinds, while industrial symbiosis focuses on industrial waste and by-products. Industrial symbiosis is a more targeted strategy that serves as a tool to implement a circular economy in an industrial setting by optimizing resource use. While industrial symbiosis can contribute to a more circular economy, it does not necessarily require the complete closure of material loops. Conversely, the circular economy takes a broader perspective, including upstream measures, waste prevention, and a holistic approach to sustainable development. Although sector-specific characteristics can help to differentiate the

circular economy and industrial symbiosis, their boundaries are not always clear and overlaps between the two concepts are often evident.

The paper presents the concept of industrial symbiosis and the latest studies. In the first part, the paper provides a literature review on industrial symbiosis, its definition, obstacles and opportunities for its development. The second part of the paper summarizes the most known industrial symbioses worldwide, and the possibility of industrial symbiosis in North Macedonia is evaluated. In the last part, the paper will present the conclusion and suggest further research.

## 1. PREVIOUS RESEARCH ON INDUSTRIAL SYMBIOSIS

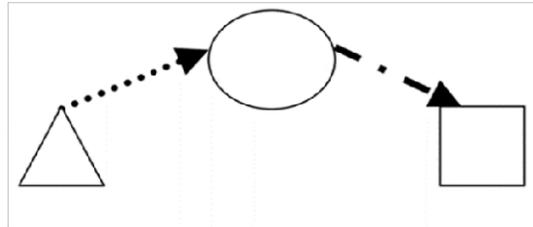
In the literature on Circular Economy, research typically follows three primary approaches: the macro level, which examines economic and social factors; the micro level, which supports firms in adopting circular principles and promotes new consumer behaviors; and the meso level, which explores Industrial Symbiosis (IS) initiatives and eco-industrial parks (Merli, Preziosi, & Acampora, 2018). This categorization situates IS clearly within the domain of Circular Economy. To analyze IS more thoroughly, Yap and Devlin (2017) proposed a multilevel framework that examines the enablers and barriers of IS at the societal, network, and enterprise levels.

Traditionally, the most widely used definition of IS is the one proposed by Chertow (2000), which states that industrial symbiosis, a component of industrial ecology, involves the collaboration of distinct entities to achieve competitive advantages through the physical exchange of materials, energy, water, and by-products. The core elements of IS are cooperation, and geographic proximity often enhances synergistic potential. Lombardi and Laybourn (2012) provided a more contemporary definition of industrial symbiosis. Domenech et al. (2019) summarize that IS is a systems-based approach to creating a more sustainable and integrated industrial system by identifying business opportunities that capitalize on underutilized resources (such as materials, energy, water, capacity, expertise, and assets). Domenech et al. (2019) further clarify that IS involves organizations from different sectors engaging in mutually beneficial transactions, repurposing waste and by-products, and innovatively sourcing inputs to maximize the value of residuals. This may include utilizing waste or by-products from one sector as inputs for another. More recently, the European Committee for Standardisation (CEN) (2018) reached a workshop agreement defining industrial symbiosis as the practice whereby one company or sector utilizes the underused resources of another—broadly defined to include waste, materials, by-products, water, logistics, residues, energy, capacity, expertise, equipment, and thereby extending the productive life of resources.

Industrial symbiosis has been driven by various factors, including resource conservation, economic gains, compliance with environmental regulations (such as reductions in greenhouse gas emissions), natural resource scarcity, and the minimization of waste destined for landfills and incineration (Domenech et al., 2019). To address these objectives, industrial symbiosis has expanded globally, delivering positive economic, environmental, and social outcomes (Park & Behera, 2015; Zhang et al., 2017).

To differentiate IS from other types of exchanges, a "3–2 heuristic" is often used as a minimum criterion (Chertow, 2007). According to this approach, at least three

distinct entities must participate in the exchange of at least two different resources for the arrangement to qualify as a core form of IS (see Figure 2). This heuristic highlights the complexity of IS relationships, contrasting them with linear, one-way exchanges by requiring the involvement of three entities, none primarily focused on recycling activities.



**Figure 2.** Example of 3-2 symbiosis  
Source: Chertow, 2007: 13

Industrial Symbiosis involves collaboration among companies or industries to exchange materials, energy, water, and by-products and share services, utilities, and facilities (Chertow, 2007; Costa & Ferrão, 2010) (see Table 1). Realizing IS requires identifying potential symbiosis opportunities. Therefore, pinpointing viable exchanges of resources between industries is crucial to advancing IS in practice.

**Table 1.** Types of resources for IS synergies

Material and waste exchanges	Sharing
<i>Raw materials:</i> in IS, surplus raw materials from one company can be used by another, minimizing the demand for new raw materials and enhancing resource efficiency.	<i>Utilities and infrastructure assets:</i> shared facilities and infrastructure within industrial clusters can improve resource efficiency, reduce costs, and boost operational effectiveness through collective services and investments.
<i>By-products:</i> These are secondary outputs from manufacturing that, though not the primary product, hold potential value. By-products may include substances dissolved in a process or wastewater.	<i>Logistics services:</i> IS promotes collaboration in logistics, enabling companies to share networks, consolidate shipments, and optimize operations to reduce costs, emissions, and traffic congestion (UNIDO, 2018).
<i>Energy resources:</i> in IS, surplus energy, such as heat or steam from manufacturing, can be repurposed by neighboring companies for heating, cooling, or other operational needs, thereby reducing energy consumption and emissions. Utilities like compressed air and warm water can also offer synergistic opportunities.	<i>Expertise, skills, and specialized knowledge:</i> companies can share best practices, research insights, and technical expertise through IS to enhance processes, optimize resource use, and collaboratively develop sustainable solutions.
<i>Water:</i> IS enables wastewater from industrial plants in proximity to be treated at shared facilities, conserving freshwater and lowering	

environmental impact.

Source: adapted from Chertow, 2007; Costa & Ferrão, 2010; Domenech & Davis, 2011; Domenech et al., 2017; Erceg, Činčurak Erceg & Božić, 2017; Henriques et al., 2021; Fraccascia et al., 2021; Činčurak Erceg, 2024

Industrial symbiosis relationships have been driven by several factors, including resource conservation, economic benefits, compliance with environmental regulations such as greenhouse gas reduction, scarcity of natural resources, and minimizing waste destined for landfills and incineration (Mortensen & Kørnøv, 2019; Domenech et al., 2019). Consequently, industrial symbiosis has expanded globally to address these demands, yielding positive economic, environmental, and social outcomes (Martin & Harris, 2018; Zhang et al., 2017; Neves et al., 2020). When examining drivers and barriers, the literature categorizes these indicators in various ways. Besides the commonly used terms 'drivers' and 'barriers,' other terms like 'opportunities,' 'enablers,' 'challenges,' 'benefits,' and 'incentives' frequently appear in reports, reviews, and studies. A concise classification of these factors identifies those that "can unlock, facilitate, and support the development of synergies (enablers, drivers, triggers), and those that may obstruct or impede the realization of an initiative (barriers, challenges)" (Henriques et al., 2021: 7). For this paper, the term 'drivers' also encompasses opportunities, benefits, enablers, incentives, triggers, motivators, and similar terms, while 'barriers' includes challenges and related factors. Typically, authors identify four main categories: 1) financial, 2) technological, 3) regulatory, and 4) institutional drivers and barriers (Fraccascia et al., 2021). Some studies provide more detailed distinctions. For instance, Henriques et al. (2021) identify policy, social, economic, management, informational, geographical, and intermediary enablers and barriers, while Rahman et al. (2016) include technological, financial, informational, regulatory barriers, organizational barriers related to trust, and factors of risk and uncertainty.

The reviewed studies highlight the multifaceted nature of industrial symbiosis and the various barriers and enablers (Table 2) that affect its implementation. Economic incentives, regulatory frameworks, and awareness are critical drivers, while challenges include a lack of infrastructure, weak regulatory support, and informational deficits. The role of local governments, state institutions, and supportive policies is paramount in overcoming these barriers and promoting sustainable industrial practices. IS can significantly contribute to the Circular Economy and sustainable development by addressing these challenges and leveraging the identified opportunities.

**Table 2.** Summary of the different IS drivers and barriers

#	DRIVERS	BARRIERS
1	Economic benefits, cost reduction, financial incentives	Infrastructure and Technology
	Environmental performance benefits,	Data Management and Information Sharing
2	environmental responsibility, waste minimization, emissions reduction (GHGs, wastewater, etc.)	
3	Social (increased awareness, community	Health, safety and environment

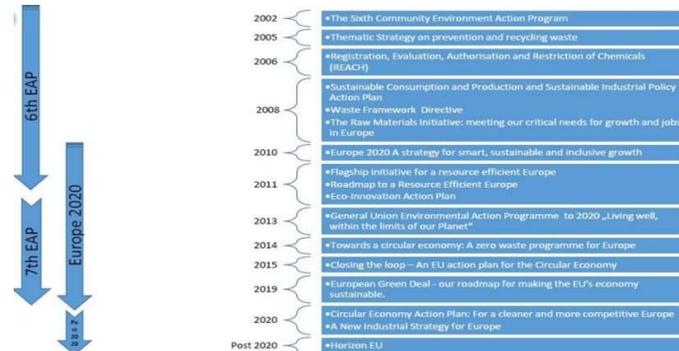
	engagement, stakeholder demands)	
4	Regulatory pressure, environmental regulations, supportive policies	Governmental, Regulatory and Policy Barriers
5	Sustainable industrial production, enhanced resource efficiency	Economic and Financial Barriers
6	Improved competitiveness, improved productivity,	Market and supply chain barriers
7	Marketing advantages, cross-sectoral partnerships	Organizational and Managerial Barriers
8	-	Cultural and Social Barriers
9	-	Other

Source: LIAISE, 2024

Economic benefits (Maillé&Frayret, 2016) and increased profitability will likely be the initial IS drivers. In most cases, these benefits result from sharing by-products or reducing the costs associated with waste disposal. Gabriel, Schögggl and Posch (2017) have identified a new trigger for the search for waste recovery opportunities. For energy-intensive companies, energy efficiency is cited as an essential trigger (Karner, Theissing, &Kienberger, 2017). In addition, companies see potential benefits in sharing services, utilities and knowledge (Wu, Qi, & Wang, 2016). The European Commission report (European Commission, 2018: 109) on fostering industrial symbiosis market potential, best practices, and policy actions highlights several regulatory instruments to support the spread of industrial symbiosis. These include:

- Establishing end-of-waste criteria to streamline procedures,
- Defining by-products separately from waste under Article 5 of the Waste Framework Directive,
- Imposing landfill bans and setting targets for landfill diversion,
- Creating an internal market for recovered materials or material flows,
- Implementing eco-design criteria for recyclability, secondary material usage, and end-of-life considerations,
- Standardizing secondary materials to ensure consistency,
- Clarifying the legislative framework to accommodate new business models, such as leasing,
- Enhancing waste segregation practices to preserve material purity (European Commission, 2018).

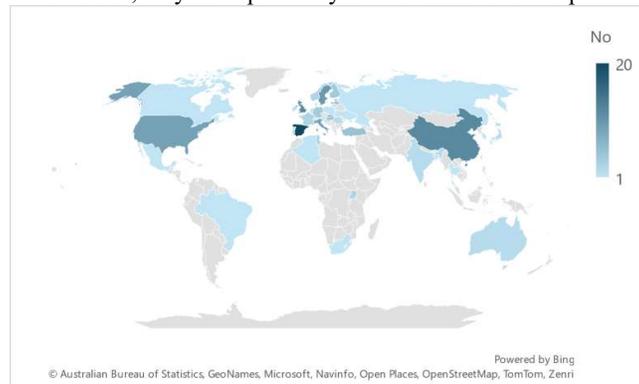
Matti (2021) concluded that six topics emerged from policies (Figure 3) that directly or indirectly support industrial symbiosis, including materials security, resource efficiency, pollution and waste reduction, eco-innovations, green growth and greenhouse gas emissions.



**Figure 3.** EU Policies Relevant to Industrial Symbiosis  
Source: Matti, 2021

### 3. INDUSTRIAL SYMBIOSIS IN THE WORLD

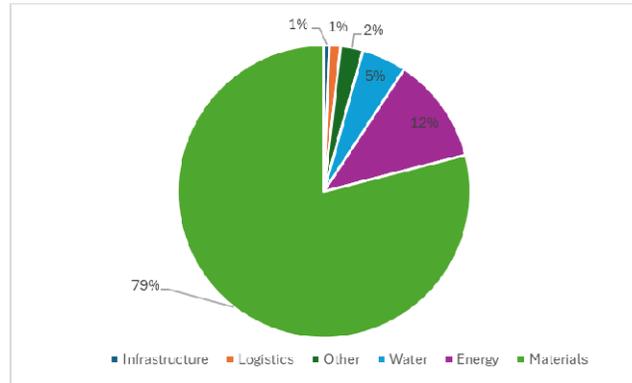
Industrial symbiosis can be found all over the world. Based on the EU projects like Scaler (2020), Maestri-Spire (2020) and LIAISE Cost Action (2024), authors were able to identify one hundred sixty-two worldwide examples of industrial symbiosis (Figure 4). Although this is a high number of identified examples, these findings have limitations since the authors could not recognize all of them, and due to the limited access to available data, they were primarily oriented towards Europe.



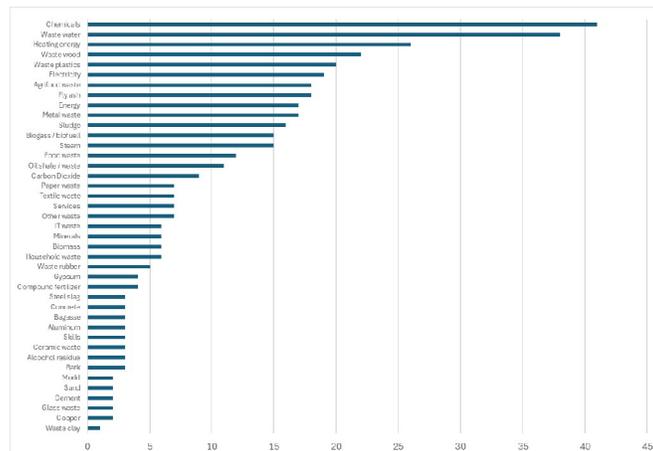
**Figure 4.** Industrial symbiosis worldwide examples  
Source: authors according to Scaler, 2020; Maestri-Spire, 2020; LIAISE Cost Action, 2024

According to Figure 4, examples of industrial symbiosis can be found in 48 countries worldwide. Europe is leading with the most identified examples (116; 72%), followed by Asia (20; 12%) and the Americas (14; 9%). The lowest number of industrial symbiosis examples was identified in Africa. Most industrial symbiosis practices worldwide concern various industries (45; 29%), followed by waste management (12; 8%) and the chemical industry (10; 6%). The research has identified industrial symbiosis in 33 different industrial sectors. Within the different industrial sectors, 27 sub-sectors are involved, with the chemical (18 cases) and metal (16

instances) industries leading the way. Within identified industrial symbiosis examples, authors have identified different streams (Figure 5) and resources being exchanged (Figure 6).



**Figure 5. Industrial symbiosis streams**  
Source: authors according to Scaler, 2020; Maestri-Spire, 2020; LIAISE Cost Action, 2024



**Figure 6. Industrial symbiosis exchanged resources**  
Source: authors according to Scaler, 2020; Maestri-Spire, 2020; LIAISE Cost Action, 2024

The most identified streams in industrial symbiosis examples are materials (128; 79%) and energy (19; 12%). Infrastructure and logistics are two streams that are not used as others, but this shows a new potential direction in industrial symbiosis, along with the use of knowledge. On the other hand, when the data on resources exchanged in identified industrial symbiosis was analyzed, the most exchanged were chemicals (41), followed by different types of waste (water 38; heating energy 26; wood 22; plastics 20). Our analysis showed that within 162 identified industrial symbiosis, 42 different resources are being exchanged. It is essential to state that in the analysis, the authors

did not separate resources into sub-types (i.e., chemicals were used as a sum of all the different chemicals being exchanged).

In the next section of the paper, we will present one of the most well-known examples of industrial symbiosis in Kalundborg, Denmark, to give more insight into industrial symbiosis.

### **3.1. Kalundborg industrial symbiosis**

Kalundborg is the best-known example of IS worldwide and is regarded as a reference case for similar projects. It represents a self-organized model where companies spontaneously recognized the benefits of symbiosis and entered contracts that eventually led to the development of an industrial park (Redmond, 2023).

Kalundborg Symbiosis is one of the few examples of an organically evolving network of strategically unconnected companies working together to improve resource utilization and share knowledge (Kalundborg Symbiosis, 2024). This unique network can provide valuable insights into the processes that drive ecological networks to evolve from one-off collaborations to sustainable cooperative relationships. The symbiosis began with cooperative agreements between several industrial companies to share a vital resource (water) and utilize waste resources (heat, steam and gas) (Saikku, 2006). Today, the industrial symbiosis between the six main partners (oil refinery, power plant, biotech company, gypsum board company, waste management company and soil remediation company) and Kalundborg Municipality is characterized by network cooperation based on the exchange of energy and resources such as heat, steam, water, gypsum, refinery gas, liquid fertilizer, biomass, sludge, ash, etc. (Redmond, 2023). In addition, new companies have joined the Kalundborg symbiosis over time, and the exchange of resources and waste streams has expanded. Kalundborg is recognized as a system based on the existing opportunities and shortcomings, the geographical location of the industries in the port and the political incentives that have led to its success (Chertow, 2007).

It was established in response to groundwater scarcity, which prompted the partners to join forces. The project was developed for economic reasons (cost reduction) and existed for quite a long time before it was recognized as an industrial symbiosis. Although the project started from an external destabilizing factor, Kalundborg's relatively small size and isolation influenced the establishment of regular communication between staff and managers, and the financial success of the initial implementation accelerated the overall effort (Nillson, 2016). Later, an institutional platform - the Center for Industrial Symbiosis - was established on the industrial park site. Industrial symbiosis was not driven by technological innovation, as the technology used was conventional, but its utilization was what can be called innovative. However, the internal symbiosis has been extended over the years to external companies that process the waste of the internal participants.

Kalundborg successfully reuses waste and saves energy, creating a symbiosis of resource exchange that increases the partners' resilience and profit. It has around 30 waste streams, while more are waiting to be tested and used as streams. This type of symbiosis is estimated to result in CO<sub>2</sub> savings of 635,000 tons/year, which translates into €14 million in various benefits for society and the economy as well as the coveted ~€24 million in financial savings for the companies (Transition Aps, 2021). Financial

measures are crucial in Kalundborg's performance management system, as each project is evaluated primarily on its economic feasibility. Many collaborations developed within Kalundborg Symbiosis have served as prototypes for similar IS initiatives worldwide. Therefore, it should come as no surprise that Kalundborg Symbiosis, one of the first examples of industrial symbiosis, has reached a level of maturity that represents a different kind of vanguard and challenge to broaden the scope of collaboration (Valentine, 2016).

#### **4. POSSIBILITY FOR INDUSTRIAL SYMBIOSIS IN NORTH MACEDONIA**

The Macedonian economy is facing significant economic and environmental challenges caused by the growing demand for raw materials, dependence on imported resources and the increasing volume of waste. A vital aspect of the country's commitment to sustainable development, as outlined in Macedonia's National Strategy for Sustainable Development (2010-2030), is the effective implementation of circular economy principles. This approach aims to improve resource management and prevent overexploitation of natural resources, which aligns with the United Nations Sustainable Development Goals (SDGs) (OECD, 2024). The concept of IS offers significant potential for promoting sustainable economic growth and improving environmental conditions in the Macedonian economy. However, the implementation of IS faces challenges regarding legal framework, public awareness and practical implementation. Macedonia's regulatory environment concerning IS is still evolving. Although the country has made progress in adopting EU environmental standards, there is a lack of specific regulations that actively promote IS practices. Existing laws deal primarily with waste management, environmental protection, and industrial emissions, indirectly supporting IS. For example, the Macedonian Law on Waste Management aligns with the EU Waste Framework Directive and emphasizes the principles of waste reduction, reuse and recycling, which align with IS. A regulatory framework promoting the information society or the circular economy is still lacking (OECD, 2024).

Public awareness of the circular economy and the concept of the information society remains very low: 77% of citizens do not know precisely what the circular economy entails (RCC, 2022). This lack of awareness also extends to businesses, government agencies and the public regarding the principles of the Information Society. As a result, IS development is inhibited, and the motivation in various industries to adopt sustainable practices decreases. Many Macedonia sectors are unfamiliar with IS and its cost and waste reduction potential. Consequently, many opportunities for symbiotic partnerships — such as exchanging by-products or waste materials between companies — often go unnoticed, resulting in missed opportunities for waste reduction and resource optimization (OECD, 2024). This widespread lack of understanding fosters an environment where IS remains undervalued and under-researched.

The Macedonian economy faces significant challenges in promoting IS due to inadequate institutional and financial support structures. Without targeted funding, technical support or organizational backing, it is difficult for companies to take the necessary steps to implement IS. The lack of incentives — such as tax incentives, grants or subsidies for companies adopting IS models - makes it even more difficult for them to take advantage of these opportunities (OECD, 2024). Addressing these issues

could promote the development of IS by removing barriers and encouraging companies to enter symbiotic partnerships. Although EU funding and various international resources are available for sustainability projects, Macedonian businesses often struggle to access these funds due to limited guidance, concerns about eligibility and a general lack of information. As a result, a significant amount of potential financial support for IS remains largely untapped.

The Macedonian economy, heavily dependent on the manufacturing, agriculture and energy sectors, provides numerous opportunities for IS. These sectors generate significant amounts of by-products and waste that could be reused and utilized for IS. The OECD analysis of the circular economy in North Macedonia (OECD, 2024) highlights four critical sectors and materials within the Macedonian economy. It outlines measures that can be applied at different life cycle stages and by various actors in these sectors: Construction, Biomass and Food, Textiles, and Mining and Metallurgy.

The construction sector has significant potential for the circular economy, as it consumes many primary materials and plays a vital role in waste generation. In 2022, construction waste accounted for 3.8% of total waste generation (MAKSTAT, 2022). The transition to a circular economy offers numerous opportunities to reduce dependence on primary construction materials and minimize overall waste. This can be achieved by increasing the use of secondary raw materials, improving the recovery and recycling of construction and demolition waste and developing sustainable building materials. The National Waste Management Plan outlines strategies for sorting construction waste into components and recycling inert materials — such as bricks, tiles and concrete — into recycled aggregates (OECD, 2024). These aggregates can be used in various projects, including road construction, paved surfaces, and concrete and asphalt mixes (OECD, 2024). A recent European Commission (2020) analysis presented a case study on construction and demolition waste from raw materials from raw minerals, showing its potential as a construction material that meets the end-of-waste (EoW) criteria. One notable opportunity within this sector is the by-products of the cement industry, such as fly ash and slag. These materials can be effectively integrated into construction products, reducing the need for raw material extraction and the amount of waste going to landfill.

The biomass and food sector were selected due to its excellent economic and political importance and considerable potential for the circular economy and decarbonization in North Macedonia (OECD, 2024). This sector accounts for up to 10% of the national gross value added in primary production and almost 15% combined with the food industry (Ministry of Education and Science, 2023). The potential of the circular economy and decarbonization in the biomass and food sector is remarkably high, as it can contribute significantly to environmental protection and climate change mitigation by extending the life cycle of bio-based products, materials and resources (OECD, 2024). Organic waste accounts for about 45% of municipal waste (Ministry of Environment and Spatial Planning, 2021). Biomass represents an opportunity for North Macedonia to utilize additional natural resources for its economy and products while closing the biological cycle of biodegradable materials (OECD, 2024). The food system is often highlighted as a priority area in national circular economy strategies as it consumes a lot of land, water and energy and generates significant waste (Salvatori, Holstein & Böhme, 2019). The OECD advocates funding

and technical support for research and innovation projects to convert biomass, especially from forestry, into higher value-added bio-based products and services (OECD, 2024). To facilitate the transition to a circular economy in the biomass and food sectors and implement effective initiatives across the entire product life cycle, North Macedonia needs to introduce several cross-cutting measures, focusing primarily on strengthening cooperation between stakeholders, raising awareness of the circular bioeconomy among businesses and households, and educating citizens and municipalities (OECD, 2024). Effective coordination between sectors, value chains, and stakeholders is crucial for promoting IS practices. The Pelagonija Agricultural Waste to Biogas Project is a prime industrial symbiosis (IS) example. The project is in a large agricultural region, Pelagonija, and aims to convert agricultural waste into biogas, such as manure and crop residues. This initiative addresses waste management challenges, reduces methane emissions and provides a renewable energy source for local consumption.

The circular economy offers significant opportunities to transform the textile industry into a more sustainable and circular model, where textile waste is reduced and reused as a raw material for other sectors. Cross-company value retention processes emphasize that waste should be diverted for reuse or recycling instead of being thrown away (OECD, 2024). Research shows that around 25-40% of all fabrics used in garment production are left behind as fabric or textile waste (Aus et al., 2021). Most of this waste is generated in the cutting phase of textile production (Aus et al., 2021). The effective management of textile waste generated during production is a top priority for North Macedonia. A significant amount of waste is generated during the cutting processes, which are often not optimized and depend on a low level of digitalization and automation. If it is impossible to recycle the textile waste into equivalent products, the waste can be transformed into lower-quality products through a process known as "downcycling". Currently, most recycling efforts focus on producing insulation materials for the automotive and construction industries and absorbent textiles for cleaning purposes (Switchmed, 2020). This practice represents a promising opportunity for the Macedonian textile industry to create new value from textile waste. The case of the textile company Netam is an example of the implementation of IS practices in the textile industry in the Macedonian economy. Netam specializes in producing and selling various textile products, including non-woven fabrics, bed linen, pillows, blankets, mattresses, and covers. The company is dedicated to collecting, recycling and processing waste materials from the textile industry to create new products. The latest product line includes insulation sheets, fabric rolls, geotextiles and other insulation materials used in construction and other industries. Using innovative technology, Netam is tackling the problem of textile waste, which accounts for around 15% of total gross textile production, by converting the waste into usable products for the construction sector.

The OECD has recognized the mining and metallurgy sectors as essential priority areas for promoting circular economy practices in the Macedonian economy, as they have a significant economic impact and have the potential for implementing various circular initiatives. These initiatives can improve the circular supply and use of products and equipment used on-site and in metal processing while improving the management of extracted resources and waste (OECD, 2024). This may include recovering embedded value from mining and processing waste through recycling,

reuse, detour and reprocessing of these materials on site. In addition, waste exchanges with other industries could be established, and by-products could be commercialized through industrial symbioses (Smart Prosperity Institute, 2021). In its Roadmap for a Circular Economy in North Macedonia, the OECD advocates the promotion of industrial symbiosis to optimize the use of waste generated by mining and metal processing companies while supporting the development of markets for secondary raw materials.

To advance industrial symbiosis (IS) practices in the Macedonian economy, a structured approach to regulatory support, public awareness and institutional backing is needed. According to the OECD, the economy needs to be focused on (OECD, 2024):

1. awareness-raising initiatives, education and other information tools
2. multi-stakeholder cooperation within and across value chains
3. financial support measures
4. supporting legislation and economic instruments

National campaigns highlighting the benefits of industrial symbiosis (IS) for the economy and the environment could help to create a positive image of IS. We can change public opinion and gain support by highlighting the value of waste as a resource and the environmental benefits of reducing landfills. Organizing workshops for business owners and managers in critical sectors such as industry, agriculture, and energy can promote the economic benefits of IS. These events could feature real-world case studies, cost-benefit analysis and partnership-building strategies. In addition, integrating IS concepts into academic programs and vocational training can help develop a new generation of sustainability-conscious professionals. Universities can also run IS pilot projects by collaborating with local industries to demonstrate successful IS practices. Finally, partnering with the media to publicize success stories about IS projects can improve public understanding and generate interest in the industry.

Strengthening cooperation, information sharing and exchange of best practices among all stakeholders in North Macedonia is crucial for establishing effective information systems (IS). The OECD has proposed the development of an economic business platform to promote industrial symbiosis in the country's green industrial zones. Ongoing amendments to the Law on Industrial and Environmental Zones could include provisions encouraging resource recovery and recycling and creating a supportive framework for business partnerships and cooperation initiatives (OECD, 2024). In addition to improving waste management practices, these changes could incentivize industrial symbiosis so that one company's waste or by-products can serve as input for another. Such strategic initiatives promote sustainable practices and increase the potential for businesses to collaborate and thrive within a mutually beneficial ecosystem. This approach aligns with North Macedonia's commitment to develop a more sustainable and collaborative economic landscape and create a solid foundation for increased business partnerships and cooperation efforts (OECD, 2024). A notable example of promoting cooperation in Macedonia's green zones is the Turkey Materials Marketplace (TMM) (OECD, 2024). Launched in 2016, TMM is an e-commerce platform dedicated to industrial symbiosis. It provides a secure online space for companies to share data on materials and explore reuse opportunities. By reducing storage costs and improving waste management and environmental performance, TMM offers economic benefits for both buyers and sellers.

Financial support for projects and initiatives through grants and loans can significantly reduce the capital costs of investing in industrial symbiosis (IS) and help overcome economic and information barriers. Public funding is essential in supporting the development of innovative IS business models, technologies and strategic partnerships. In addition to public funding, companies need to secure private funding to support and expand their IS activities. Many IS projects are expected to receive partial funding from the Fund for Innovation and Technological Development (FITD), as seen in initiatives such as the Netam and the "Izonet" project. Although financial incentives for green investments in the Macedonian economy are gradually increasing, they mainly focus on energy efficiency and renewable energy sources. The existing financing programs and incentives lack targeted measures that promote circular economy and IS practices.

Creating an enabling environment that supports and encourages industrial symbiosis (IS) practices is recognized as a crucial prerequisite for the development of IS. Introducing tax incentives for companies adopting IS models, subsidizing the costs of symbiotic exchanges and offering rewards for improvements in energy and resource efficiency could increase the attractiveness of IS practices as viable alternatives. Macedonia's existing Waste Management and Environmental Protection Law supports recycling and resource efficiency. By expanding these laws to explicitly promote IS practices — such as waste exchange, energy exchange and resource optimization - the government can provide crucial legal support for IS initiatives.

Industrial symbiosis (IS) is an emerging sector in the Macedonian economy with significant growth potential. While there are still regulatory and logistical challenges, capitalizing on existing opportunities and learning from case studies can pave the way for a sustainable industrial ecosystem in the country.

## **CONCLUSIONS**

By exchanging resources such as energy, materials or water, industrial symbiosis can reduce the cost of purchasing raw materials and disposing of waste. By selling by-products or waste that would otherwise be disposed of, companies can open new sources of revenue. These secondary revenue streams help increase profitability and financial stability. Industrial symbiosis optimizes resource utilization and enables companies to make the most of limited materials, resulting in lower production costs and a more sustainable supply chain. Companies that find creative ways to reuse waste can become more competitive through new, sustainable business models and improved products.

Industrial symbiosis can stimulate economic development in a region by creating interconnected industrial networks, attracting new businesses and boosting the local economy through increased demand for support services. This can be seen in the industrial symbiosis examples worldwide, especially in the Kalundborg industrial symbiosis examined, which has brought significant savings for included companies and resulted in economic benefits for society and the economy. These financial benefits of industrial symbiosis can improve the economic performance of individual companies and the overall resilience and sustainability of the regional economy. As such, industrial symbiosis is a valuable economic and environmental progress model.

Promoting industrial symbiosis (IS) practices in the Macedonian economy represents both a challenge and an excellent opportunity to solve urgent economic and environmental problems. The country's dependence on raw material imports and the growing volume of waste makes it clear that a transition to a circular economy that emphasizes resource efficiency and waste reduction is urgently needed. Although Macedonia has made progress in aligning specific environmental policies with EU standards — such as the Law on Waste Management — the lack of legislation focusing on IS, combined with limited public awareness and institutional support, is a significant barrier to its adoption. The potential for IS in critical sectors— such as construction, biomass and food, textiles, and mining and metallurgy— shows that the country is ready to adopt symbiotic practices, especially given the extensive waste and by-products generated in these industries. Successful case studies such as the Pelagonija Agricultural Waste to Biogas project and the textile company Netam initiatives show how IS can convert waste into valuable inputs, generate renewable energy sources and reduce environmental impact. However, these isolated examples highlight the need for a broader systemic framework and incentives to facilitate IS partnerships across all sectors. To create a conducive ecosystem for IS, the Macedonian economy needs to implement targeted regulatory, financial and awareness-raising strategies. Introducing the information society in Macedonia could reduce the country's dependence on imported resources and contribute to achieving the Sustainable Development Goals (SDGs), especially those focused on sustainable consumption, climate action and resource efficiency. With a strategic commitment to the information society, Macedonia can capitalize on its existing industrial strengths and pave the way for a more sustainable, resilient and economically dynamic future. To determine the potential of industrial symbiosis in Northern Macedonia, further research on possible waste streams within potential symbiosis members is needed using different methodologies (i.e., Life cycle assessment methodology (ISO, 2006)).

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