

Book of Abstracts

Advancing Industrial Symbiosis: From Learning and Awareness to Cross-Sectoral Action

WG3 workshop and conference
Piraeus. May, 26, 2026



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Digital Technology Watch Platforms for Industrial Symbiosis: A Systematic Landscape Review of Capabilities, Governance, and Impact Evidence

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ABSTRACT

Industrial symbiosis depends on firms making real commitments to exchange resources across organizational and sectoral boundaries, not simply recognizing that such exchanges are possible (Chertow, 2000). In particular, the phenomenon of digital “technology watch” platforms has become a standard means for creating this recognition. However, the question of what exactly facilitates coordination cost savings, what exactly facilitates the willingness to share sensitive information through the platform’s governance mechanisms, and what exactly demonstrates the effectiveness of the platform’s facilitated recognition in leading to meetings, feasibility studies, pilot projects, and actual exchanges remains poorly specified. This paper suggests a systematic review of the landscape of digital technology watch platforms for industrial symbiosis from January 2000 to January 2026. The timeframe is extensive for a few reasons. First, the first platforms were often built as directories or registries or project support tools that influenced subsequent platforms but were not necessarily documented or published in peer-reviewed journals. Second, the period from 2000 to 2026 allows for a comprehensive overview of the evolution of the phenomenon. Finally, the timeframe searched follows the PRISMA 2020 reporting guidelines with a clear protocol for searching, screening,

and extraction (Page et al., 2021). Relevant studies are those that describe a digital system that facilitates at least one function for progressing from recognition to action, including technology watch/scanning, knowledge curation, opportunity identification or matchmaking, brokerage workflow support (initiation of contact, confidentiality arrangements, feasibility coordination), or monitoring/reporting of outcomes.

For each platform, we create a capability stack and a governance profile. Governance is evaluated through a structured checklist grounded in information security management system requirements, with a focus on aspects such as confidentiality, access control, data minimization, verification and auditability, and the allocation of responsibility in the event of claims being contested (International Organization for Standardization, 2022). Impact evidence is graded through an outcome hierarchy that distinguishes between promotional claims and engagement metrics, behavioral metrics, conversion metrics, and outcomes.

This synthesis yields: (1) a taxonomy of platform generations and types from 2000 to 2026, (2) a governance and trust checklist that links platform design to participation constraints, and (3) a targeted evaluation agenda that makes “awareness to action” quantitatively tractable for auditing by practitioners and policymakers.

KEYWORDS

Industrial Symbiosis • Technology Watch • Digital Platforms • Data Governance • Systematic Review • Impact Evaluation

Business Liaison Coordinators as Institutional Actors for Awareness-Raising, Monitoring and Governance of Industrial Symbiosis: Evidence From the Vet System in Kosovo

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ABSTRACT

Industrial Symbiosis (IS) is being promoted more and more inside EU policy frameworks as an essential instrument for resource efficiency, cross-sectoral cooperation and the green transition. Accordingly, its successful implementation requires organized stakeholder participation, institutional capabilities and evidence-based monitoring together with awareness-raising strategies.

The research presents the findings of an internal assessment carried out as part of the project “Quality Assurance for the Work of Business Liaison Coordinators (BLCs)”, which was funded and carried out by the Ministry of Education, Science and Research of the Republic of Austria.

The assessment examines how BLCs function as institutional intermediaries operating between vocational education and training (VET), enterprises and public authorities, contributing to governance, communication and awareness processes relevant to Industrial Symbiosis. Moreover, the study assesses the project’s contribution to improving work-based learning (WBL), VET-business collaboration, learning communities, with a focus on monitoring awareness impact and institutional learning. The evaluation system uses outcome-oriented measures, including stakeholder comprehension, participation levels, coordination

effectiveness and sustainability of collaboration models and it is in line with ETF and EU quality assurance approaches. Acknowledging the complexity of the topic a mixed-method approach was adopted, containing desk research, surveys, semi-structured interviews and comparative case studies. All the data was gathered from project documents and important stakeholders, such as BLCs, VET school management, VET teachers, in-company instructors, businesses, policy makers and business associations. In addition, 10 pilot VET schools responded to two electronic questionnaires and two schools with distinct performance characteristics were chosen to serve as case studies.

The findings suggest that BLCs play a significant role in fostering structured communication, supporting feedback mechanisms and enabling evidence-based adjustments to cooperation practices.

By doing so they help strengthen institutional awareness, enhance policy coherence and build governance capacity all of which are essential conditions for advancing Industrial Symbiosis and other cross-sector partnerships.

Finally, the report closes with policy-relevant recommendations for improving monitoring frameworks, institutional capacity and assessing awareness impact within VET-led IS support systems.

KEYWORDS

Industrial Symbiosis • VET • Awareness Impact Monitoring • Governance and Institutional Capacity • Stakeholder Engagement; WBL • BLC

Measuring the Progress: A Performance Ranking of European Union Countries in the Circular Economy Era

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ABSTRACT

The circular economy represents a paradigm shift from the traditional “take-make-dispose” linear model toward a restorative and regenerative system designed to keep resources at their highest utility and value at all times. By decoupling economic growth from resource consumption and environmental degradation, this model serves as a cornerstone of the European Union’s strategic priorities and green transition goals. Based on the significance of this theme, this study aims to evaluate and rank the circular economy performance of the 27 EU member states by utilizing a robust multi-criteria decision-making (MCDM) framework. To ensure data reliability, 20 comprehensive indicators were retrieved from the Eurostat database, reflecting the multidimensional nature of circularity.

The methodological approach consists of a two-stage analysis. In the first stage, the Skewness Impact Through Distributional Evaluation (SITDE) method was employed to determine the objective weights of the indicators. The analysis identified the top five most critical criteria as: “Trade in recyclable raw materials”,

“Generation of waste excluding major mineral wastes per GDP unit”, “Private investment and gross added value related to circular economy sectors”, “Persons employed in circular economy sectors”, and “Recycling rate of packaging waste by type of packaging”. These results highlight that economic integration and labour market participation are as vital as waste management metrics in defining CE success.

In the second stage, the TOTal DIFFerential of Alternative (TODIFFA) method was utilized to rank 27 EU countries. According to the findings, the top ten performing countries are Germany, France, the Netherlands, Cyprus, Italy, Bulgaria, Malta, Spain, Lithuania, and Romania. The results demonstrate a heterogeneous landscape where leading industrial powers and several Mediterranean and Eastern European nations exhibit competitive performances. This study provides a comprehensive roadmap for policymakers, emphasizing the need for targeted strategies to harmonize circularity across the Union.

KEYWORDS

Circular Economy • EU Countries • SITDE • TODIFFA

Mapping Industrial Symbiosis for Circular Economy Transition: Comparative Insights Across Countries

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ABSTRACT

Industrial symbiosis, which allows industries to exchange materials, energy and by-products for mutual benefit, is a powerful driver of circular practices. Based on the principles of ecological mutualism and the circulation of nutrients within ecosystems, industrial symbiosis involves intensive cooperation between interested actors within a relatively limited geographical area. This study aims to map the development of Industrial Symbiosis across 23 countries, including 10 EU member states, 5 Western Balkan countries, 4 from Eastern Europe and the Caucasus region, 2 from the Levant, and 1 from North America, and to examine how cross-sectoral cooperation contributes to sustainable growth, resource efficiency and eco-innovation. For the purposes of the research, a multi-criteria analysis was applied to rank countries according to the degree of development of their industrial symbiosis practices using indicators such as recycling rates of municipal waste, recycling rates of all waste excluding major mineral wastes, circular material use rate, contribution of recycled materials to raw material demand (EOL-RIR), trade in recyclable raw materials, resource producti-

vity, and packaging and plastic waste generation per capita.

The ranking identified leading countries and critical factors enabling successful cross-industry cooperation, including high recycling rates, efficient material loops, integration of recycled materials into raw material supply, and reduction of packaging and plastic waste. The analysis reveals significant differences in adoption levels and highlights the elements that drive resource efficiency, waste reduction and the creation of new value chains. These findings provide practical insights for policymakers, business managers and decision-makers who want to strengthen cross-sectoral cooperation, promote eco-innovation and accelerate the transition to circular economy models. Integrating multi-criteria assessment with industrial symbiosis mapping, this research offers a comprehensive understanding of the operational and strategic factors that drive sustainability and competitiveness across countries, providing a basis for tailored policies and cooperation strategies to advance the green transition

KEYWORDS

Industrial Symbiosis • Circular Economy • Cross-Sectoral Cooperation • Resource Efficiency • Multi-Criteria Analysis

Bridging the Education Gap in Industrial Symbiosis for North Macedonia's Alignment With the EU Green Agenda

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ABSTRACT

Accession to the European Union is a core strategic objective for North Macedonia. This commitment requires the country to align its industrial policies with the EU Green Agenda. Industrial symbiosis (IS) offers a practical pathway to achieve these goals while simultaneously fostering long-term sustainable development. However, while national strategies emphasize the importance of circularity and IS, a significant “education gap” persists between high-level policy goals and operational implementation within the industrial sector. This paper examines the extent to which concepts related to circular economy (CE) and IS are reflected in the formal education system in North Macedonia, with a focus on primary, secondary, and tertiary education. Using qualitative document analysis, the study reviews official curricula and study programmes in order to identify the availability, accessibility, and relevance of CE- and IS-related content. The findings show that CE is already present across all educational

levels, although unevenly and with varying depth, most commonly through themes such as environmental protection, natural resources, energy efficiency, recycling, waste management, and sustainable development. By contrast, IS remains weakly represented and is mostly addressed only indirectly. The strongest entry points for CE were identified in vocational and higher education, particularly in chemistry and technology, agriculture, and economics-related programs. The paper concludes that North Macedonia already has a meaningful educational basis for expanding CE, but that a significant educational gap persists in relation to IS. To address this gap, the study recommends more explicit curricular integration of IS, stronger alignment with sectoral and industrial realities, and the development of accessible educational tools, including Macedonian-language training resources and digital learning formats.

KEYWORDS

Industrial Symbiosis • Knowledge Transfer • Education Gap • Circular Economy • North Macedonia

Policy-Driven Technological Innovation in Industrial Symbiosis: A Patent-Based Global Analysis (1971–2024)

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ABSTRACT

Industrial symbiosis (IS) plays a crucial role in accelerating circular economy transitions through the cross-sectoral valorization of waste. While a growing literature exists on how regional, national, and international policy and regulatory initiatives affect IS implementations, a significant gap remains in understanding how political and regulatory frameworks drive IS innovation. The main objective of this study is to assess how circular economy and waste-management policies across diverse regulatory environments have influenced technological progress relevant to industrial symbiosis. To this end, this study utilizes a dataset of 1,553 global patent publications filed between 1971 and 2024 under the Y02P80/30 subgroup of Cooperative Patent Classification (CPC) of EPO, entitled “Reducing waste in manufacturing processes”. Preliminary analysis suggests that the global technology landscape related to waste valorization has experienced three structural breaks in 2002, 2015, and 2018, resulting in four distinct periods, namely 1971-2001, 2002-2015;

2016-2018, and 2019-2024. These structural breaks coincide with the global initiatives on combating climate change, fostering sustainable development and waste-reduction such as the UN’s World Summit on Sustainable Development in 2002; Paris Agreement and UN’s Sustainable Development Goals in 2015, and the EU’s revised Waste Framework Directive in 2018 and the launch of European Green Deal in 2019. The analysis employed in this study further integrates major policy milestones from multiple countries and regions, including EU countries, the USA, China, Japan and South Korea. By comparing patenting trends before and after these regulatory shifts, the study evaluates how policy pressure and institutional awareness stimulate IS-enabling technological innovation. The study contributes to the literature by demonstrating how governance frameworks influence technological readiness for IS, and to WG3 objectives by providing empirical foundations for developing policy-responsive indicators of IS-related technological innovation.

KEYWORDS

Industrial symbiosis • policy-driven technological progress • patent landscape analysis • innovation dynamics

Educational Leadership and Institutional Learning in Advancing Industrial Symbiosis Awareness in Higher Education

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ABSTRACT

Industrial Symbiosis (IS) is widely recognised as a key strategy for advancing environmental sustainability and resource efficiency; however, its implementation remains uneven across regions and sectors. While technical and infrastructural dimensions of IS have been extensively examined, comparatively less attention has been paid to the role of education, leadership, and institutional learning in fostering awareness and enabling sustained cross-sectoral engagement at higher education institutions. This study addresses this gap by exploring how educational leadership and institutional learning processes contribute to the development of IS awareness among key stakeholders. Grounded in perspectives from educational leadership and organisational learning, the study conceptualises IS awareness not merely as knowledge acquisition but as a dynamic learning process embedded within institutional cultures, governance structures, and leadership practices. This study adopts a qualitative, exploratory research design with a policy-oriented perspective. Data were collected through two primary

sources: (a) document analysis of European Union policy documents related to industrial symbiosis, sustainability, and higher education, and (b) semi-structured interviews with eight stakeholders, including five representatives from higher education institutions and three from the public sector. Data were analysed using thematic analysis. Interview transcripts and policy documents were coded inductively and iteratively, following the stages of familiarisation, initial coding, theme development, and refinement. The findings indicate that industrial symbiosis awareness in higher education remains limited and fragmented, primarily due to weak educational leadership and insufficient institutional learning mechanisms. By conceptualising educational leadership and institutional learning as key mechanisms in advancing IS awareness at higher education, this study contributes a practice-oriented framework that offers policy-relevant insights for universities, public institutions, and policymakers seeking to strengthen institutional readiness and support the transition from awareness to action.

KEYWORDS

Industrial Symbiosis • Educational Leadership • Institutional Learning • Awareness
Knowledge Transfer • Higher Education

Key social and cultural factors influencing Industrial Symbiosis (IS) implementation

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ABSTRACT

Social and cultural dimensions are fundamental to the effective deployment of Industrial Symbiosis (IS), as they shape levels of societal awareness, stakeholder interaction, mutual trust, and the broader acceptance of circular economy practices. These dimensions affect not only the mechanisms through which industries share resources, but also the ways in which communities, institutions, and decision-makers participate in and support IS-related initiatives. This research explores these interdependencies using empirical evidence gathered from 85 participants representing 29 countries, including both EU and non-EU regions, and encompassing a wide range of professional profiles. Data were collected through a structured questionnaire addressing indicators related to awareness, stakeholder roles, perceived barriers, and societal involvement. The analytical approach applies multivariate elastic net regression techniques, in which individual survey responses are treated as standardized indicator variables. Variable normalization, aggregation, and scaling enabled the detection of statistically meaningful

associations among social, cultural, and institutional drivers influencing IS implementation. The findings indicate that IS adoption at the national level remains generally constrained, with most countries positioned at early or emerging stages of development. Key enabling factors include industrial demand, regulatory frameworks, and international sustainability objectives, while significant obstacles are associated with low awareness, limited cross-sectoral collaboration, and insufficient policy backing. Influence among stakeholders is most pronounced within academia, industry, and public authorities; however, coordination between these actors remains weak. Public understanding and local participation are notably limited, reflecting minimal integration within educational systems and a lack of leadership at the local scale. Cultural characteristics present both enabling and constraining effects, with cooperative norms facilitating progress in some contexts, while entrenched practices within traditional industries act as a barrier to transformation.

KEYWORDS

Industrial Symbiosis • Social and Cultural Drivers • Stakeholder Engagement • Public Awareness and Participation

Legal and Political Barriers to Industrial Symbiosis Development

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ABSTRACT

Industrial Symbiosis has evolved from a distant and often undesirable concept into a preferred approach within the European Union, gaining increasing attention in the context of sustainability transitions and the circular economy.

Despite its growing relevance, however, the practical implementation of Industrial Symbiosis remains uneven across EU Member States.

This paper examines how legal and political factors influence the development of Industrial Symbiosis, arguing that regulatory fragmentation and political

dynamics play a decisive role in shaping its adoption. Using a comparative qualitative case study of Denmark, Italy, the Netherlands, and Lithuania, the study reviews selected national experiences.

The findings show that legal clarity, political support, and institutional coordination are crucial enabling factors, while regulatory uncertainty and fragmented governance structures hinder progress. The paper highlights the need for greater policy coherence and stronger political commitment.

KEYWORDS

Industrial Symbiosis • EU Regulations • Legal Barriers • Political Barriers • Challenges • Fragmentation

Navigating the Symbiotic Transition: A Cross-Sectional Analysis of ESRS E5 Adoption in the European Automotive Industry

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ABSTRACT

The implementation of the Corporate Sustainability Reporting Directive (CSRD) and the accompanying ESRS E5 standard fundamentally restructures environmental disclosure requirements for the European automotive sector. This paper investigates the initial compliance strategies of seven major automotive manufacturers (OEMs) during the 2023-2024 reporting cycle, focusing on the operational transition from linear resource management to circular economy principles. Employing a cross-sectional mixed-methods approach, qualitative content analysis was utilized to map corporate reporting against the specific structural requirements of ESRS E5, specifically concerning resource inflows, outflows, and double materiality. Concurrently, a Fisher’s exact test evaluated the presence of institutional isomorphism regarding the explicit adoption of regulatory nomenclature between EU and non-EU entities. Qualitative results indicate a structural transition among EU-headquartered groups from traditional eco-efficiency models toward formalized industrial symbiosis, characterized by documented cross-sectoral material exchanges. Statistically, although complete observational separation occurred between EU and non-EU groups concerning nomenclature adoption, the limited sample size yielded a non-significant p-value. Ultimately, the findings suggest that early ESRS E5 adherence actively drives the standardization of sustainability terminology and facilitates the operationalization of closed-loop material networks within the applicable regulatory jurisdiction.

KEYWORDS

Key Performance Indicators • Circular Economy • Industrial Symbiosis • Automotive Industry • ESG Reporting

Cross-Sectoral Fermentation Pathways for Sustainable Production

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ABSTRACT

Fermentation-based processes are increasingly recognised as critical enablers of sustainable production within circular bioeconomy frameworks. However, their large-scale implementation remains constrained by sectoral fragmentation, economic barriers, and governance challenges. This presentation examines cross-sectoral fermentation pathways as integrative production models that connect agri-food systems, industrial biotechnology, waste management, and policy domains to enhance sustainability outcomes.

Drawing on recent biorefinery and systems-level studies, the analysis highlights how geographically and operationally integrated value chains can improve resource efficiency and economic viability. For instance, citrus-sugarcane biorefineries in Brazil demonstrate how agricultural residues can be valorised through microbial fermentation to produce polyhydroxyalkanoates (PHA), reducing feedstock costs while leveraging existing industrial infrastructure (Kanbe et al., 2024). Such cross-sectoral models illustrate the potential of fermentation to link primary production, waste valorisation, and biopolymer manufacturing.

The presentation further situates fermentation within broader systemic and technological contexts. Multi-sectoral metabolism analyses of water–ener–

gy–nutrient nexuses show that combining anaerobic fermentation with complementary processes such as composting or fungal cultivation can optimise resource flows at regional scales (Wen et al., 2021). In parallel, advances associated with Industry 5.0, including AI-enabled process monitoring, smart waste management, and digital traceability are shown to enhance the efficiency and circularity of fermentation-based systems in sustainable food production (Gaikwad and Anerao, 2025).

Despite these opportunities, significant barriers remain. Technical scale-up challenges, high capital costs, regulatory uncertainty, and socio-political acceptance continue to hinder commercial deployment of integrated biorefineries (Makepa and Chihobo, 2024). Cross-sectoral collaboration, supportive policy frameworks, and international knowledge exchange are therefore identified as key enablers for overcoming these constraints. Taken together, this presentation proposes a cross-sectoral analytical perspective on fermentation pathways, demonstrating how integrated biorefinery models and systemic coordination can position fermentation as a central driver of sustainable and low-carbon production systems.

KEYWORDS

Cross-sectoral fermentation • Sustainable production • Integrated biorefineries
Circular bioeconomy • Waste valorisation

Industrial symbiosis and entrepreneurship Croatian case studies

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ABSTRACT

Industrial symbiosis (IS) represents one of the key mechanisms for implementing a circular economy, enabling resource optimization through cooperation between companies from different industrial sectors. In the context of the Croatian economy, which faces challenges of low productivity, limited innovation capacity, and slow transformation towards sustainable business models, IS opens new opportunities for the development of sustainability- and innovation-based entrepreneurship. In this framework, green entrepreneurship occupies a special place, connecting economic growth with environmental protection and the efficient use of resources through innovative business models.

This paper explores the link between IS and green entrepreneurship (GE) by presenting a Croatian example of an IS-based entrepreneurial venture. Research applied quantitative analysis of secondary data on waste management in the member states of the European Union; a structural review of the academic literature on

green entrepreneurship and IS; and a case study methodology to exemplify the implementation of green entrepreneurship grounded in IS. Given the empirical focus on Croatia, the study provides country-specific insights while recognizing that some conclusions may have limited generalizability across the broader European Union.

The results show how IS can stimulate the development of innovative business models, especially in the waste, energy, and agriculture sectors, where there is significant potential to optimize resource flows. The analysis also highlights the need for institutional support, resource exchange platforms and education of entrepreneurs to encourage the broader application of IS solutions in Croatia. This paper contributes to understanding the role of entrepreneurship in implementing IS and offers practical guidelines for fostering entrepreneurial ecosystems geared toward sustainable economic growth.

KEYWORDS

Industrial symbiosis • waste management • entrepreneurship • innovation

Measuring What Matters: Knowledge and Competencies in CE and IS

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ABSTRACT

The increasing relevance of Circular Economy (CE) and Industrial Symbiosis (IS) in tackling contemporary sustainability challenges, such as resource scarcity and environmental degradation, calls for educational approaches that go beyond general awareness. In this context, the development of concrete competencies and practical skills becomes essential for the effective implementation of CE and IS practices. Empirical studies demonstrate a strong positive relationship between stakeholders' knowledge of CE practices and their sustainable attitudes and behavior, highlighting the importance of substantive understanding rather than superficial familiarity. Similarly, research conducted among students emphasises the need for a deeper comprehension of sustainability and circularity concepts in order to achieve established sustainability goals. However, despite the growing body of literature, research systematically addressing awareness of industrial symbiosis—particularly among younger populations—remains limited. Moreover, while several studies examine general awareness of CE-related concepts among young people, considerably fewer investigate their actual knowledge and the development of relevant competencies, thereby revealing a significant research gap in this field.

In response, this paper presents the development of a measurement scale aimed at assessing both knowledge and competencies in CE and IS. The goal is to reveal gaps between what young people currently think and know and the practical skills they need to apply these concepts effectively. To support this, a structured approach is proposed to develop a comprehensive competency map that highlights the key knowledge and practical skills essential to IS and CE contexts. Based on the existing literature, a conceptual assessment framework is introduced that distinguishes between awareness and conceptual knowledge, on the one hand, and practical skills and application, on the other. The measurement scale was constructed based on this framework, with items specifically designed to capture both respondents' understanding and their perceived ability to implement CE and IS practices.

By making this distinction, the framework not only identifies potential gaps in knowledge and skills among young learners but also contributes to the literature by providing a coherent, research-based model for evaluating learning outcomes in IS and CE education.

KEYWORDS

Industrial symbiosis • Circular economy • Awareness • Knowledge Assessment • Practical skills

Monitoring and Evaluating Awareness Impacts in Circular Economy Transitions: Bridging the Knowledge–Action Gap through Digital Tools and Industrial Symbiosis

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ABSTRACT

Many people agree that moving toward a circular economy is a key way to achieve sustainable development. However, its success depends not only on new technologies and ways of doing things, but also on the ability to turn awareness into real changes in behavior. Even though more and more attention is being paid to initiatives that raise awareness, there is still a knowledge-action gap, which means that being more aware of the environment does not always mean adopting circular practices. This study tackles the significant issue of assessing and tracking the effects of awareness in transitions to a circular economy by suggesting a comprehensive, data-driven framework that connects awareness initiatives to quantifiable results.

The study takes a conceptual and interdisciplinary approach by combining ideas from circular economy theory, industrial symbiosis, behavioral sustainability, and digital innovation through an integrative literature review. Based on these theoretical foundations, the study creates a multi-dimensional framework that links awareness inputs to behavioral proxies and measurable circular economy indicators. This framework is backed up by digital monitoring systems and feedback loops.

The findings indicate that conventional awareness metrics, including participation in training initiatives

or information dissemination, are inadequate for measuring genuine impact, as they do not accurately represent modifications in behavior and operational procedures. Data from both developing and developed economies shows that awareness only works when it is built into systems that allow for measurement, coordination, and ongoing feedback. For example, industrial symbiosis gives measurable signs like better use of resources and less waste, and digital technologies like AI and the Internet of Things make it possible to monitor things in real time and make evaluation processes more reliable.

The research enhances the literature by introducing a comprehensive framework that views awareness as a quantifiable and iterative process, rather than merely a cognitive result. The framework connects behavioral change to measurable circular economy performance indicators, making it a strong tool for policymakers and practitioners who want to create evidence-based sustainability programs. In the end, the results suggest that closing the knowledge-action gap requires a change to system-oriented and data-driven evaluation methods that turn awareness into an actionable and accountable driver of circular economy transitions.

KEYWORDS

The circular economy • The impact of awareness • The gap between knowledge and action
Monitoring and evaluation • Industry 4.0 • Industrial symbiosis

Urban Waste Repurpose under the Concept of Industrial Symbiosis

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ABSTRACT

Urban waste management has become a pressing global challenge as rapid urbanization, population growth, and rising waste volumes place increasing pressure on cities. With nearly 70% of the world's population expected to reside in urban areas by 2050, effective waste strategies are essential not only for environmental sustainability but also for public health and economic resilience. This study reframes the discussion of waste-to-energy (WtE) technologies within the broader context of industrial symbiosis (IS), a collaborative systems approach in which the by-products, energy flows, and residuals of one process become valuable inputs for another.

The study presents cutting-edge solutions in diverse cities in the world that convert waste into useful energy while reducing environmental impacts and explores how these innovations can gain societal endorsement when embedded in transparent, participatory, and equitable IS frameworks. Diverse examples were addressed, not only in regards to the WtE practices but also to the industrial settings in distinct places in Europe, Asia, North and South America, and Africa. Comparing technical parameters such as energy efficiency

and scale, environmental impacts (namely emissions), and the socioeconomic dimension (for instance urban vs rural settings), actionable insights for implementing WtE-enabled industrial symbiosis are provided, underscoring also the role of public acceptance in advancing urban sustainability.

The work shows how WtE technologies support circular resource flows and strengthen the foundations of sustainable urban waste systems. At the same time, it emphasizes that the success of WtE-based symbiosis is shaped profoundly by societal perception and acceptance, including public trust, perceived risks and benefits, community engagement, and the social legitimacy of shared-resource infrastructures.

Challenges and opportunities on achieving trade-offs were identified, an approach for the role of innovation in achieving sustainable cities and complementing broader climate goals being put forth. Future research directions point to the development of new methods, technologies and policies; the wide application of tools such as LCA and S-LCA to measure impacts, and addressing technical and non-technical uncertainties.

KEYWORDS

Industrial Symbiosis • Waste-to-Energy • Societal Acceptance • Circular Economy • Urban Waste Management • Sustainable Resource Exchange

Analyzing Barriers to Industrial Symbiosis Adoption Using DEMATEL: KPI-Oriented Insights

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ABSTRACT

SMEs, while forming the fundamental building blocks of the economic system, face difficulties in adopting sustainable production practices due to their limited resources. In this context, this study aims to encourage the transition of these businesses to environmentally friendly production processes in line with sustainable development goals by addressing ways to integrate industrial symbiosis, an element of the circular economy, into SMEs. Industrial symbiosis (IS) is an important sustainability approach that contributes to reducing environmental impacts by increasing resource efficiency in industrial systems. However, the adoption of IS practices by industrial actors is limited due to numerous economic, operational, organizational, and institutional barriers. Although these barriers are widely defined in literature, studies that systematically analyze the interactions and relative importance of these barriers and transform them into measurable performance indicators are limited.

The aim of this study is to analyze the factors hindering the adoption of industrial symbiosis and to propose appropriate key performance indicators (KPIs) for these barriers. This study first identified key barriers to adoption, including high logistics and processing costs,

lack of inter-firm collaboration and trust, insufficient data transparency, supply-demand imbalance, policy and incentive deficiencies, and inadequate research and innovation, through a literature review and expert opinions. Then, using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method, the cause-and-effect relationships between these barriers were revealed, and those barriers playing a critical role in the adoption process were prioritized.

The findings from the DEMATEL analysis were used as input to determine key performance indicators (KPIs) aimed at increasing the applicability of industrial symbiosis. The proposed KPIs, covering dimensions such as economic feasibility, logistical continuity, data quality and transparency, level of collaboration, and institutional support, aim to make the fundamental barriers encountered in IS applications traceable and comparable. This study provides a holistic assessment of the industrial symbiosis literature, analyzing adoption barriers using a DEMATEL-based approach and transforming these analysis results into KPI recommendations.

KEYWORDS

Industrial Symbiosis • Adoption Barriers; DEMATEL • Key Performance Indicators

Turning by-products into partnerships: Albania's debut on Industrial Symbiosis

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ABSTRACT

Industrial symbiosis is a collaborative approach in which traditionally separate industries engage in the physical exchange of materials, energy, water, and by-products in ways that create mutual economic and environmental benefits. Within the broader framework of the circular economy, industrial symbiosis plays a crucial operational role by transforming waste streams into valuable inputs, thereby reducing resource extraction, minimizing emissions, and increasing overall system efficiency. By fostering inter-firm cooperation and closing material and energy loops at the regional or industrial-cluster level, industrial symbiosis supports key circular economy principles such as resource efficiency, waste prevention, and sustainable production.

This paper presents and analyses the first documented case of industrial symbiosis in Albania, involving a network of four companies that actively cooperate through the exchange and reuse of by-products. The study highlights how inter-firm collaboration enables

waste streams generated by one company to become valuable inputs for others, significantly reducing the need for virgin resources and disposal. To systematically capture and evaluate these interactions, the paper employs material flow chart analysis, mapping all material exchanges among the five participating firms. This analytical approach provides a comprehensive visualization of resource flows and interdependencies within the network, demonstrating how coordinated by-product sharing can lead to an almost zero-waste production system. There are currently very few studies directly linked to industrial symbiosis in Albania, so by documenting this pioneering Albanian experience, the paper contributes empirical evidence to the literature on industrial symbiosis and illustrates its practical potential for advancing circular economy objectives in emerging contexts.

KEYWORDS

Industrial Symbiosis • Material Flow Chart • Zero Waste • Case Study Analysis
IS Barriers • Business collaboration

