Ref. Ares(2026)5255318 - 25/05/2026

THESEUS

Hub4Circularity

A First of a kind Hub for circularity demonstrator for Attica and peripheral regions

Grant Agreement No 101178059

DELIVERABLE 3.4

Symbiotic models v1

Work Package: 3

Digital Tools as enablers of Greek Attica H4C and common initiatives

LEAD BENEFICIARY:

Institute of Communication and Computer Systems (ICCS)

Document Sheet

Project acronym	**Theseus**
Project full title	A First of a kind Hub for circularity demonstrator for Attica and peripheral regions
Programme	Horizon Europe
Topic	HORIZON-CL4-2024-TWIN-TRANSITION-01-38
Type of Action	HORIZON Innovation Actions
Grant Agreement	101178059
Start day	1 December 2024
Duration	60 months

LEGAL NOTICE
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Health and Digital Executive Agency (HADEA). Neither the European Union nor the granting authority can be held responsible for them.

©Theseus Consortium, 2026
Reproduction is authorised provided the source is acknowledged.

Document Information

Deliverable number	D3.4
Deliverable name	Symbiotic models v1
Lead beneficiary	ICCS
WP	3
Related task(s)	3.2
Type	OTHER
Reviewers	Lucyna Lekawska-Andrinopoulou (ICCS), Poojan Timilsina (IRIS), Lovisa Harfeldt (RISE)
Delivery date	31.05.2026
Main author(s)	Babis Manousiadis (ICCS)
Contributor(s)	Poojan Timilsina (IRIS), Lovisa Harfeldt (RISE)

Dissemination level

PU	**Public**	**X**
SEN	Sensitive, limited under the conditions of the Grant Agreement	
Classified R-UE/EU-R	EU RESTRICTED under the Commission Decision No2015/444	
Classified C-UE/EU-C	EU CONFIDENTIAL under the Commission Decision No2015/444	
Classified S-UE/EU-S	EU SECRET under the Commission Decision No2015/444	

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

Document history

Version	Date	Changes	Reviewer/Contributor
V0.1	13.04.2026	First version	Babis Manousiadis (ICCS)
V0.2	18.05.2026	Second version after contribution and review	Lucyna Lekawska-Andrinopoulou (ICCS), Poojan Timilsina (IRIS), Lovisa Harfeldt (RISE)
V1.0	22.05.2026	Final version	Babis Manousiadis (ICCS)

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

Publishable summary

THESEUS is a Horizon Europe funded project, which develops a first-of-a-kind Hub for Circularity (H4C) in Greece, deploying systemic Industrial-Urban Symbiosis (I-US) concepts. The H4C activities are concentrated around the Attica region, which hosts the capital of Greece - Athens metropolitan area with almost 4 million inhabitants.

To achieve efficient resources -material, water, energy and waste- management as well as optimize flows, improve circularity-related rates and create added value for the territory and the region towards overall resilience and sustainability, several aspects should be considered beyond technicalities of flows, processes and infrastructure, including governance, jurisdiction, regulations, land use, spatial planning, local and regional strategies in areas and territories.

Industrial Symbiosis (IS) therefore involved to Industrial-Urban Symbiosis (I-US) and subsequently to Hubs4Circularity, reflecting a growing recognition of non-technical aspects, economic and social factor that can either enable or hinder the effective integration of circular solutions into territories, cities and regional contexts.

To develop digital tools facilitating these needs, Theseus will develop relevant regional matching frameworks for symbiotic models, that identify potential synergies, pre-assess their potential integration into specific local settings, and evaluate their estimated impact. This framework will be developed and deployed as a matchmaking digital module for creating symbiotic flows and it will be integrated into Theseus central end-user platform.

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

Contents

1 Introduction 9
1.1 Purpose of the deliverable 9
1.2 Relation with other Tasks 9
2 Matchmaking Frameworks 10
2.1 Existing work 10
2.2 Integrating regional dimensions 11
3 Theseus Regional Framework 12
3.1 Value chain logic 12
3.2 NACE coding system 14
3.3 Theseus regional expansion outline 15
3.3.1 Proposed indicators per dimension 16
4 Readiness levels in industrial symbiosis and value chains 16
4.1 Industrial Symbiosis 16
4.1.1 Industrial Symbiosis Readiness (INSYRE) 16
4.1.2 Insights from earlier applications and validations 18
4.1.3 ISRL validation and relevant symbiotic models 19
4.2 Value chains 19
4.2.1 Value Chain Readiness Level (VCRL) within Theseus 19
4.2.2 VCRL validation 20
5 The digital module 20
6 Discussion 23
7 Conclusions 23
8 References 24

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

List of Figures

Figure 1 Direct technical matching 10
Figure 3 Value chain dimensions. 13
Figure 4 Textile value chain in Attica region 14
Figure 5 NACE coding system 15
Figure 6 Conceptual overview of the INSYRE matrix at the network level 17
Figure 7 Conceptual overview of the INSYRE matrix at the individual resource exchange level. 18
Figure 8 THESEUS Digital Platform Architecture 21

List of Tables

Table 1 Template for Matrix A 11
Table 2 Template for Matrix B 12
Table 3 Impact factor initiation according to strategy paths 12

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

Abbreviations

Abbreviations	Full name
AI	Artificial Intelligence
CE	Circular Economy
DoA	Description of Action
EC	European Commission
EPR	Extended Producer Responsibility
eSC	Extended Steering Committee
EU	European Union
GA	Grant Agreement
H4C	Hub 4 Circularity
HMA	Electronic Waste Register
IS	Industrial Symbiosis
I-US	Industrial Urban Symbiosis
MFA	Material Flow Analysis
MFN	Material Flow Networks
PM	Project Management
PO	Project Officer
PSM	Process Simulation and Modelling
SC	Steering Committee
WP	Work Package

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

1 Introduction

THESEUS is a Horizon Europe funded project, which develops a first-of-a-kind Hub for Circularity (H4C) in Greece, deploying systemic Industrial-Urban Symbiosis (I-US) concepts. The H4C activities are concentrated around the Attica region, which hosts the capital of Greece - Athens metropolitan area with almost 4 million inhabitants. To achieve efficient resources -material, water, energy and waste- management as well as optimize flows, improve circularity-related rates and create added value for the territory and the region towards overall resilience and sustainability, several aspects should be considered beyond technicalities of flows, processes and infrastructure, including governance, jurisdiction, regulations, land use, spatial planning, local and regional strategies in areas and territories. Industrial Symbiosis (IS) therefore involved to Industrial-Urban Symbiosis (I-US) and subsequently to Hubs4Circularity, reflecting a growing recognition of non-technical aspects, economic and social factor that can either enable or hinder the effective integration of circular solutions into territories, cities and regional contexts. To develop digital tools facilitating these needs, Theseus will develop relevant regional matching frameworks for symbiotic models, that identify potential synergies, pre-assess their potential integration into specific local settings, and evaluate their estimated impact. This framework will be developed and deployed as a matchmaking digital module for creating symbiotic flows and it will be integrated into Theseus central end-user platform.

1.1 Purpose of the deliverable

The purpose of this deliverable is to develop a matchmaking framework to be developed and deployed as a matchmaking digital module for creating symbiotic flows, to be integrated into Theseus central end-user platform, reflecting the work of Task 3.2. Based on matchmaking frameworks from previous projects and related research, dedicated modules will be developed and will be specialized for the different value chains tackled in Theseus. Symbiotic flows will be identified and evaluated by new matchmaking and recommender algorithms to be developed and deployed. Module will identify and pre-assess potential symbiosis between organisations (e.g. similarities in NACE and Classification), resource needs and compatibility, capacities, supply and demand; aspects such as aspects such as processes, services required, distance etc. The evaluation and impact assessment of the proposed symbiotic models will be based on the further development of ISRL (industrial symbiosis readiness level)-Matrix for I-US developments and value chains. ISRL-Matrix will be tested and validated in 3-5 different cases, and it will be developed to a VCRL (value chain readiness level) in 3 Theseus value chains.

This document presents the baseline for this work, and it will be finalized in the two next versions:

- D3.5 Symbiotic models v2 in M36,
- D3.6 Symbiotic models final in M48.

1.2 Relation with other Tasks

This deliverable and Task 3.2 will interact with the below WPs/tasks, to exchange data and thus to enable sophisticated features.

- T2.3 Material flow analysis
- T2.4 Regional and interregional pathways
- T2.5 KPIs
- T3.1 GIS tool

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

- T3.3 PRLM
- WP10 models
- T11.2 Policy recommendations and barriers.

2 Matchmaking Frameworks

2.1 Existing work

There are several developed platforms enabling Industrial Symbiosis matchmaking frameworks around EU, such as SYNERGie, SYMBIOSIS ENEA Platform, Smart Symbiose, e-SYMBIOSIS, FISSAC IS Platform, LIFE M3P etc. Specifically, there are several previous works by ICCS, IRIS, HUD, RISE, such as extensive work from ICCS on Matchmaking Frameworks for Materials and Water (Akrivou C. et al, 2021; Akrivou C. et al, 2022; Łękawska-Andrinopoulou, L. et al, 2021; Łękawska-Andrinopoulou, L. et al, 2023; Tsimiklis, G. et al, 2020), as well as existing platforms such as Accelwater H2020 IS platform (ICCS), SWAN Platform (HUD, Angelis-Dimakis et al. 2021), AquaSPICE Enabling Platform (HUD, Angelis-Dimakis et al. 2023) and SHAREBOX (IRIS).

Overall, the baseline approach of resource matchmaking can be summarized in Figure 1 (IS2H4C Deliverable 4.2). The outflow from a waste provider, matches the needs of a receiver so to directly be used as secondary raw material. This matching can be performed with two main ways:

- By matching EWC codes directly, assumed that the receivers already know which EWC codes are suitable and compatible for their input flow needs.
- Via a knowledge database that includes EWC valorisation paths (via literature and documented practices) and, therefore, links the input material types with compatible EWC in a correlation matrix, e.g. input material A can be extracted from EWC B and EWC C.

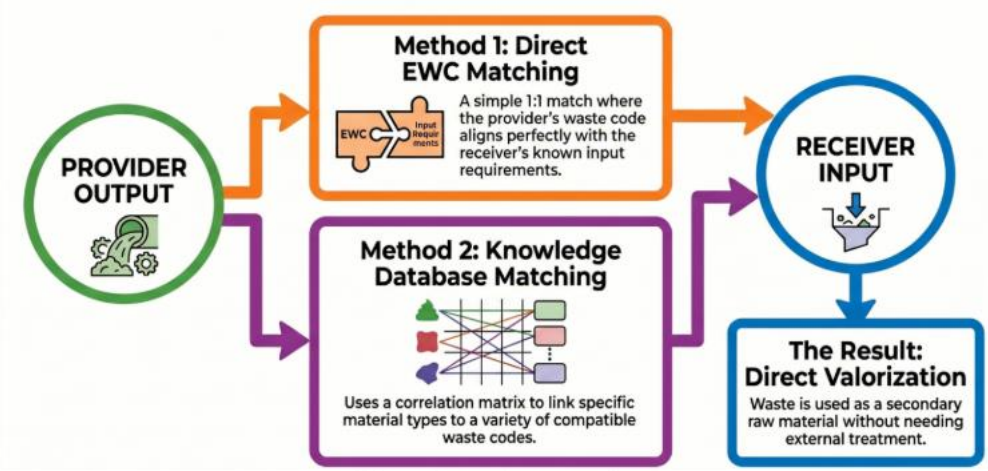


Figure 1 Direct technical matching

This section will be further elaborated in the next version of deliverable, according to the aspects and the extend that the technical matching of resources will be integrated into the final Theseus framework.

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

2.2 Integrating regional dimensions

Based on the initial steps within IS2H4C Horizon Europe project to regional matchmaking framework (Manousiadis C, et al, 2026), Theseus will significantly enhance this work, both in terms of extra regional dimensions to be integrated in the framework as well as in terms of validating the methodology in the regional environment of Attica. The regional scenery, including the special conditions of the region, is described via 2 Matrixes, formed with specific rules from regional information, gathered via various ways e.g. questionnaires. **Matrix A** provides a quantitative representation of the scale and extent of the waste streams within the region, capturing their relative magnitude and spatial significance. **Matrix B** moves beyond size-based metrics and reflects the various effects and impacts generated by the proposed synergies within the region. The full methodology is introduced by Manousiadis C, et al, 2026 in the framework of IS2H4C Horizon Europe project.

Table 1 Template for Matrix A

REGION'S NAME	-
NUTS2 [4]	-
NUTS3 (if applicable)	-
COUNTRY	-
1. EWC1 [12]	-
2. EWC2	-
3. EWC3	-
4. EWC4	-
5. EWC5	-
6. EWC6	-
7. EWC7	-
8. EWC8	-
9. EWC9	-
10. EWC10	-
11. EWC11	-
12. EWC12	-
13. EWC13	-
14. EWC14	-
15. EWC15	-
16. EWC16	-
17. EWC17	-
18. EWC18	-
19. EWC19	-
20. EWC20	-
21. WASTEWATER	-
22. SLUDGE	-
23. ELECTRICITY	-
24. HEATING	-

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

Table 2 Template for Matrix B

REGION'S NAME	-
NUTS2 [4]	-
NUTS3 (if applicable)	-
COUNTRY	-
ENERGY CONSUMPTION (X1)	-
RECLAIMED WATER (X2)	-
LANDFILL REDUCTION (X3)	-
GHG EMISSIONS (X4)	-
JOBS CREATED (X5)	-
GDP GROWTH (X6)	-

Table 3 Impact factor initiation according to strategy paths

Impact Factor	Factor's magnitude	Type
Energy consumption (**X1**)	**F1**	Environmental (Energy)
Reclaimed water (**X2**)	**F2**	Environmental (Water)
Landfill reduction (**X3**)	**F3**	Environmental
GHG emissions (**X4**)	**F4**	Environmental
Jobs created (**X5**)	**F5**	Social
GDP growth (**X6**)	**F6**	Economic

The Matrixes are then used within the framework to evaluate and prioritize the identified -technical feasible, based on the technical matchmaking of 2.1 - synergies.

This section will be further elaborated in the next version of deliverable, according to the Matrix rules that will be finally integrated into the final Theseus framework.

3 Theseus Regional Framework

Several extra aspects will be considered within Theseus on top of the previous matchmaking frameworks, not limited to regional dimensions. Insights on the different value chain stages specialities and NACE codes statistics upon industries, will be also utilized, while Industrial Symbiosis Readiness and Value Chain Readiness Levels will be used to enhance prioritization and result to a systemic evaluation of the identified synergies.

3.1 Value chain logic

Figure 2 below describes a value chain in general terms. A value chain consists of several actors with different functions that together add value to a product based on the requirements placed on the product as a whole and the requirements placed on the different actors in the value chain. The overall requirements for each actor are described and evaluated in the different transaction points that exist between the different actors, and it is at these points that value and quality are set. In each part of the chain, different additives (water, energy, materials, etc.) are added as well as work from different subcontractors, which also adds to the value of the product and contributes to the requirements placed on each part of the value chain. Each part of the

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

value chain will generate waste and residual products and these will need to be managed in a rational way, here there is the choice of sorting out different qualities for specific purposes in the vicinity of where the waste and residual product arise or of mixing these resources in order to have to sort and upgrade these resources at a later stage in order to be used in the next step. If there is an intention to return upgraded and recycled resources to the value chain that is the source of these or for that matter in another value chain, new transaction points will arise which then need to be able to contribute to the existing transaction points in a positive way from a value and quality aspect, there is also the possibility of forming a parallel value chain to the existing one that is circular and with perhaps a different quality and thereby a different value. In the project, the included value chains are based on the waste and residual product flows that are generated from different value chains and then need to be treated in different ways as they are in most cases mixed and not pure in terms of material, here there may be a gain in some cases to try to find these cleaner flows.

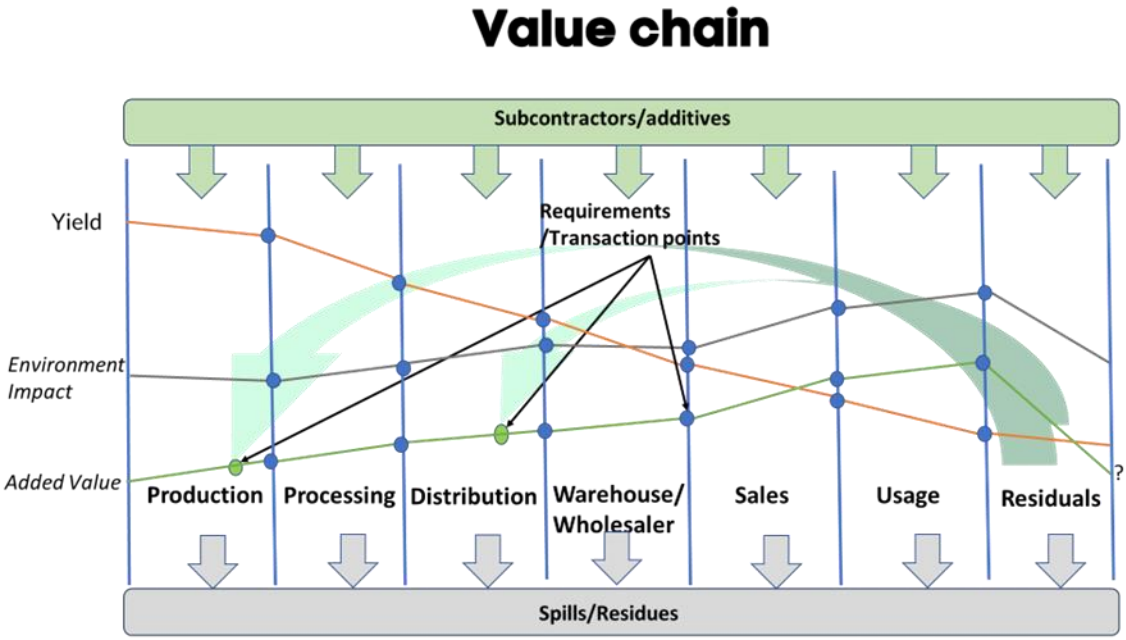


Figure 2 Value chain dimensions.

A value chain can be presented in different ways with different focuses; Figure 3 below is an example of a value chain and what the material flow looks like. To this image, which is also one of the value chains that will be studied in the project, transaction points and development of new products with included actors will be added.

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

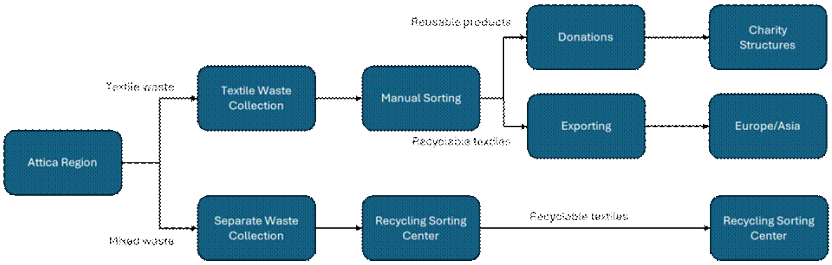


Figure 3 Textile value chain in Attica region

This section will be further elaborated in the next version of deliverable, according to the aspects that will be finally integrated into the final Theseus framework.

3.2 NACE coding system

NACE is a system used to classify companies and their activities according to the type of economic activity they carry out in each company/activity. The NACE codes help to indicate which industry a company belongs to and is used by authorities for statistics, analysis and administration. Other coding systems can also be linked to NACE that categorize and define materials and goods of various kinds. These coding systems are also used to divide, link and categorize statistics of different types by, for example, Eurostat Home – Eurostat or national statistical authorities, etc. Within the project, and particularly in the analysis of value chains, the categorization of actors using NACE codes is essential, as public data and official statistics are structured and linked to this classification system.

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

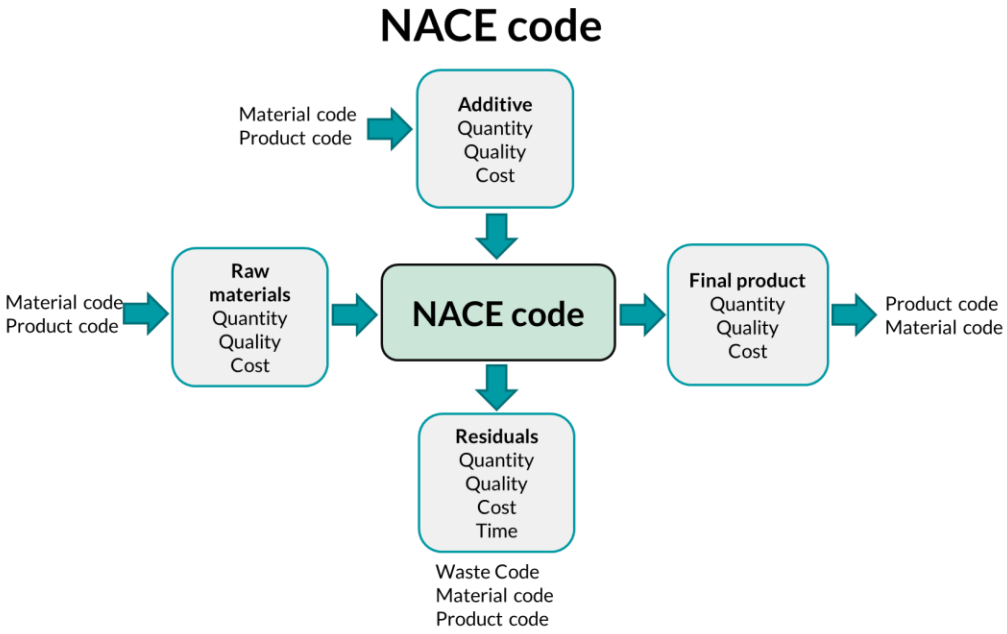


Figure 4 NACE coding system

This section will be further elaborated in the next version of deliverable, according to the aspects that will be finally integrated into the final Theseus framework.

3.3 Theseus regional expansion outline

Theseus will expand regional integration by adding the following extra dimensions to enhance the 2 introduced Matrixes or to create new criteria/scores. Based on relevant literature (Domini et al., 2025; ICLEI Europe, 2024; Södergren & Palm, 2025; Nugroho et al., 2025; Grimmel et al., 2025; Burgoa Francisco et al., 2025; Laybourn et al., 2025) the below dimensions will be examined:

1. Validate and enhance existing domains (region type, resources, infrastructure, regional strategy, impact e.g. size of population or GDP affected) with extra KPIs
2. I-US maturity, Institutional and Innovation Capacity
3. Industrial activities and sectors (NACE based), special comparative advantages, workforce and skills, exports/imports, Spatial Patterns
4. Industrial Symbiosis Networks (ISNs), I-US related services, Data and Digital
5. Governance models and Role of Authorities and Facilitators
6. Existing funding or support on the specific synergy/domain
7. Regulations, Constrains, Existing, Potential and future Policies, Procurement, Permissions
8. Time and scheduling of solutions (along with strategy),
9. Risk, Financing, Payback period, Uncertainty
10. Political, social, cultural and other special issues and constraints

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

11. Material, Energy, Water, Transportation and effort Nexus, waste to energy etc, Distance constraints etc.
12. Trade-offs or similar barriers e.g. Rich virgin material resources
13. Special dynamics per different value chain (textiles, MSW, bio-based, CDW)
14. Similarities (between industries, flows documented and to be exploited -practice, materials, very old procedure-), Intermediates
15. SDG connection
16. Nace codes statistics
17. Value chain per stage distribution

3.3.1 Proposed indicators per dimension

This section will be further elaborated in the next version of deliverable, according to the aspects that will be finally integrated into the final Theseus framework. The result will be the enhanced regional Matrixes A, B and new criteria/scores.

4 Readiness levels in industrial symbiosis and value chains

4.1 Industrial Symbiosis

4.1.1 Industrial Symbiosis Readiness (INSYRE)

Within the THESEUS project, the Industrial Symbiosis Readiness (INSYRE) tool is introduced as a structured and holistic methodology for assessing how prepared an industrial symbiosis collaboration is for implementation, upscaling, and long-term operation. The INSYRE tool builds on and further develops an earlier version known as the Industrial Symbiosis Readiness Level Matrix (ISRLM) tool (Harfeldt-Berg et al., 2025), developed within the EU-funded project CORALIS and a PhD-project funded by the Swedish Energy Agency.

The INSYRE tool is a structured framework developed to help actors understand how prepared they are to engage in industrial symbiosis collaborations. In this tool, the concept of readiness extends beyond technical feasibility and captures the broader set of conditions that must be in place for symbiotic collaborations to function and endure over time. These conditions include organizational coordination, business viability, legal aspects, societal acceptance, and environmental performance, all of which play a decisive role in whether industrial symbiosis initiatives can move from ideas to sustained practice (Harfeldt-Berg et al. 2025, other references).

The tool enables a structured assessment of a symbiosis initiative across several key perspectives. By scoring readiness levels in each perspective, INSYRE provides a clear overview of strengths, gaps, and interdependencies within a collaboration, supporting actors in understanding where further development is needed and how next steps can be planned. Within the previous projects, the tool was developed through an iterative co-design process, involving three rounds of testing with potential users (Harfeldt-Berg et al. 2025). Feedback from stakeholders directly informed further revisions, with each iteration improving

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

usability, clarity, and alignment with the needs of the actors involved. This process ensured that the tool evolved into a practical and intuitive tool grounded in the experiences of industrial symbiosis practitioners.

Furthermore, INSYRE is structured around two complementary levels of evaluation: the network level and the individual resource exchange level. This dual perspective allows users to evaluate both the overall readiness of the symbiosis network and the specific conditions required for individual exchanges to function in practice. Each level is assessed across nine readiness levels, grouped into four development phases: ideation, testing, preparation for full-scale operation, and full-scale collaboration. At the network level, the evaluation is centred around three perspectives, organizational readiness (ORL), societal readiness (SRL), and environmental readiness (ERL), while the individual exchange level examines technology and integration readiness (TIRL), business readiness (BRL), legal readiness (LRL), and environmental readiness (ERL). Together, these perspectives provide a coherent and balanced assessment of industrial symbiosis readiness, supporting informed decision-making and long-term collaboration development. Conceptual illustrations of the two evaluation matrices are provided in Figure 5 and Figure 6.

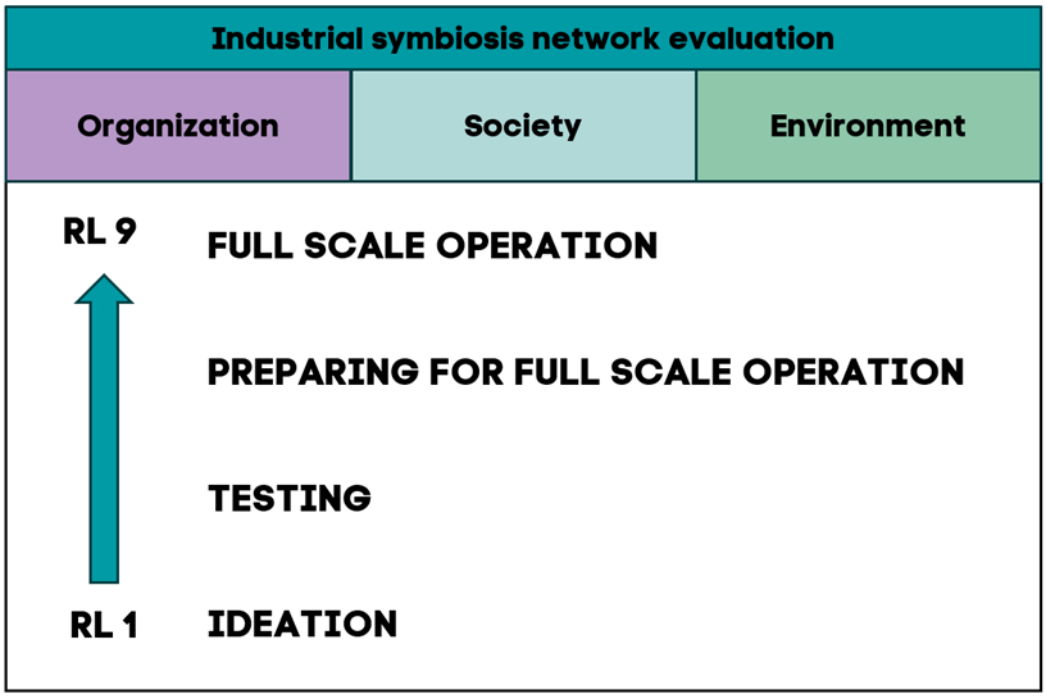


Figure 5 Conceptual overview of the INSYRE matrix at the network level

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

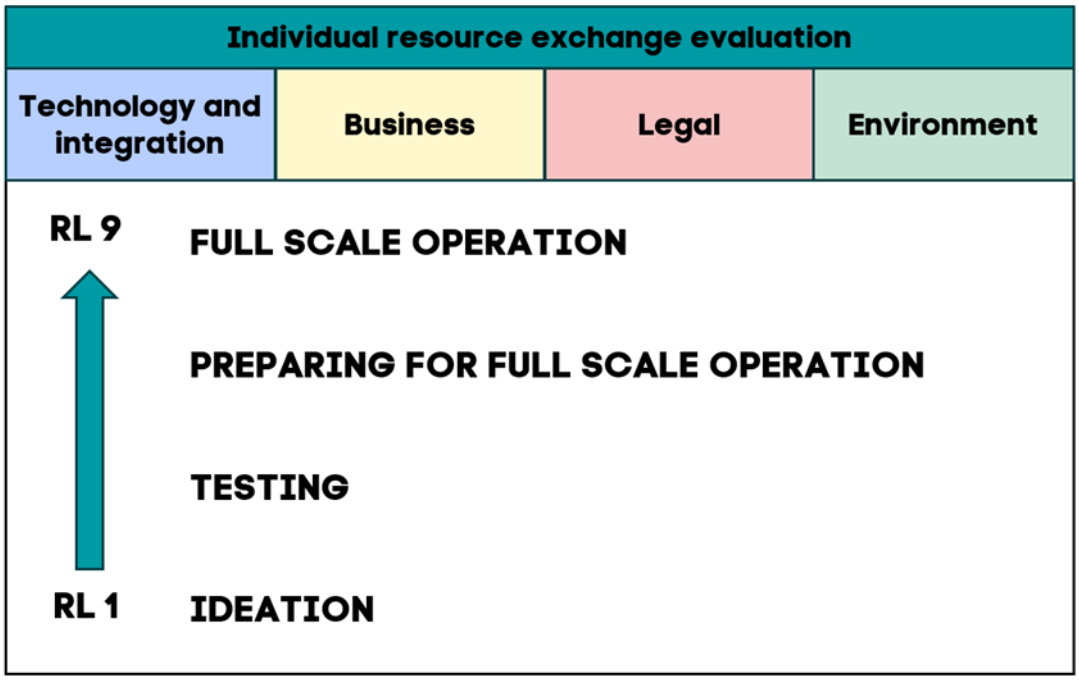


Figure 6 Conceptual overview of the INSYRE matrix at the individual resource exchange level.

4.1.2 Insights from earlier applications and validations

The earlier version of the tool was tested and applied in previous research and innovation projects. These included industrial symbiosis demonstrators in Spain, Italy, Sweden, and Austria within the EU-funded CORALIS project, as well as an additional industrial symbiosis network in Sweden studied as part of a PhD project. The collaborative and iterative development process surrounding the INSYRE tool generated several important insights. These insights directly informed the refinement and further development of the tool beyond its initial ISRLM version and will continue to guide future adaptations and adjustments within the THESEUS project.

Insights from the co-design development process demonstrated that the core strength of the matrix lies not in producing an absolute readiness score, but in structuring reflective dialogue and shared sense-making among actors. Users consistently valued the tool as a framework for discussing complex interdependencies, aligning expectations, and identifying blind spots across technical, organizational, economic, and institutional dimensions. This confirms that readiness assessment for industrial symbiosis is fundamentally a process-oriented and relational activity, rather than a purely analytical one (Harfeldt-Berg et al. 2025).

The timing of using the tool emerged as a critical factor influencing perceived value. While some actors saw strong benefits in using the matrix early to structure discussions and exploration, others found it difficult to apply when roles, exchanges, or network boundaries were still unclear. Conversely, in established networks the introduction of a new assessment tool risked the disruption of existing routines. This insight underscores the importance of adaptive depth and granularity, tailored to different development stages, rather than a one-size-fits-all assessment.

Finally, the testing indicated that continuous and repeated use can generate cumulative benefits beyond assessment, including trust-building, shared learning, and onboarding of new participants. Visual

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

representations of readiness levels were especially effective in supporting discussion, negotiation, and collective decision-making, reinforcing the tool's role as a boundary object across actor groups.

4.1.3 ISRL validation and relevant symbiotic models

THESEUS project, the aim is to further apply and develop the INSYRE tool through case testing in new contexts, drawing on insights from diverse actor perspectives, such as industry, public authorities, intermediaries, and researchers. This approach can help further develop and validate INSYRE into an even more user-friendly shared assessment tool and a structured development roadmap accessible to a wider audience and increased replication potential within Europe and beyond. By enabling actors to jointly assess current maturity, identify gaps and interdependencies, and articulate concrete next steps, the tool supports discussions regarding alignment of expectations, coordination of development efforts, and proactive risk management across different organizational contexts. In doing so, INSYRE functions not only as an assessment instrument but also as a collaborative learning and dialogue tool, strengthening the capacity of symbiosis networks to navigate complexity and advance toward long-term, sustainable operation.

Within the THESEUS project, the INSYRE tool will be tested and validated through application in three to five empirical cases. The industrial symbiosis initiatives are located in Athens, Malmö, and Mo-i-Rana. To capture a diversity of contexts, the selected cases can beneficially represent different stages of development. This enables the analysis to account for variations in drivers, enablers, and experienced barriers or challenges to industrial symbiosis, which are expected to differ across development phases and regional settings. New insights may further develop the INSYRE tool and therefore increase the replication potential of the tool.

This section will be further elaborated in the next version of deliverable, according to the aspects that will be finally integrated into the final Theseus framework.

4.2 Value chains

4.2.1 Value Chain Readiness Level (VCRL) within Theseus

One aim within the THESEUS project is to further develop the INSYRE tool so that it can be applied not only to industrial symbiosis collaborations but also to collaborations across value chains. In this context, a value chain approach refers to a structured perspective on inter-organisational collaboration along sequential stages of production, processing, distribution, and use, where actors are linked through flows of materials, energy, information, and value creation and is not limited to a specific geographical area.

In contrast to an industrial symbiosis perspective, a value chain perspective focuses on vertical relationships between upstream and downstream actors connected through different transaction points/nodes. While industrial symbiosis often emerges through opportunistic collaborations across sectoral boundaries, value chain collaboration is more commonly characterised by predefined roles, coordinated processes, and longer-term contractual relationships.

Developing INSYRE into a value chain–oriented tool implies a conceptual translation rather than a replacement of the symbiotic logic. Core readiness dimensions, such as technical compatibility, organisational capacity, governance structures, economic viability, and trust, remain relevant, but their interpretation shifts from network-level synergies to value chain-level coordination.

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

In a value chain context, INSYRE aims to guide and assess collaboration by examining how preparedness is distributed across actors at different positions in the chain, how interdependencies are managed, and how collective readiness influences the ability to implement, scale, and sustain collaborative solutions. Rather than assessing readiness for symbiotic exchange between peer actors, the value chain–adapted INSYRE focuses on readiness for coordinated transformation, where changes at one stage of the chain may require adjustments across multiple downstream or upstream actors.

4.2.2 VCRL validation

The Value Chain Readiness Level tool will be applied and tested in three or more different value chains identified within the Theseus project. These value chains are also geographically connected to Athens in Greece, Malmö in Sweden and Mo-i-Rana in Norway. The best cases will be selected based on task 2.5 and discussions with the replication partners.

The further development of the concept to a value chain application will mean that the focus of the tool shifts from assessing readiness for symbiotic exchange between actors within a network setting to evaluating preparedness for coordinated collaboration across sequential stages of value creation. This entails assessing how strategic alignment, governance structures, organisational and technical capabilities, and interdependencies are managed across upstream and downstream actors, as well as how potential changes at key transaction points within the value chain affect different actors within the existing value chain constellation.

The aim of applying and testing the tool in a value chain setting is to develop a methodology that can guide collaborative efforts across entire value chains and support the development of a shared and mutual understanding of value-creating processes within the chain. By making interdependencies, roles, and transaction points explicit, the tool is intended to facilitate coordinated action and informed decision-making among value chain actors.

This section will be further elaborated in the next version of deliverable, according to the aspects that will be finally integrated into the final Theseus framework.

5 The digital module

The THESEUS digital platform is developed under Work Package 3 (WP3 — Digital Tools as Enablers of the Greek Attica H4C), led by IRIS in Task 3.6. Its architecture follows a modular design based on independent and interconnected services, aimed at scalability and adaptability to the evolving needs of the Attica Circularity Hub, with potential for replication across other European contexts. The platform is described in detail in Deliverable 3.16. The architecture is organized into five distinct layers, ranging from user access to the technical infrastructure underpinning the entire system, as per Figure 7.

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

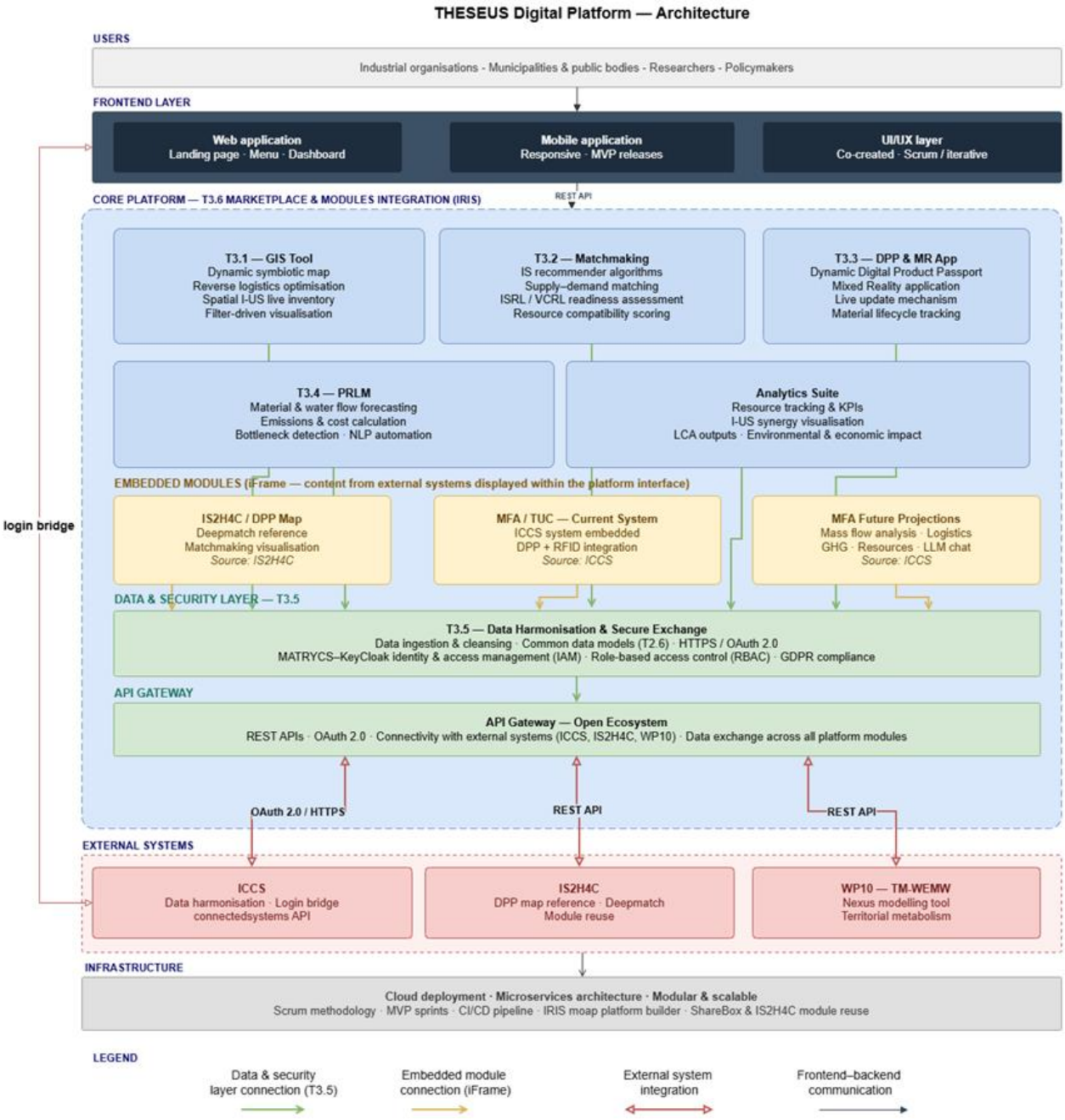


Figure 7 THESEUS Digital Platform Architecture

The user layer encompasses all actors interacting with the platform: industrial organizations, municipalities and public bodies, researchers, and policymakers. All users access the platform through the same entry points, regardless of their profile.

The access layer provides two entry channels: a web application and a mobile application, both featuring a device-adaptive interface designed through a co-creation process with end users. Development follows an agile working methodology (Scrum) with iterative releases of progressive functional versions (MVP, Minimum Viable Product), ensuring the platform evolves continuously in response to real feedback from hub actors. User authentication is managed through the ICCS login bridge, which connects directly to this layer before

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

users access the core platform, ensuring centralised and secure identity management from the first point of contact.

The core platform, managed under Task T3.6 with IRIS as lead, integrates the set of functional modules developed in parallel throughout WP3. The GIS tool (T3.1) provides a dynamic symbiotic map with spatial visualisation of industrial symbiosis activities across Attica, incorporating reverse logistics optimisation and a real-time inventory of symbiotic flows. The matchmaking module (T3.2) deploys recommender algorithms to identify synergies between organisations based on resource compatibility, supply and demand, and readiness levels assessed through the ISRL and VCRL frameworks. The Digital Product Passport (DPP) and Mixed Reality application (T3.3) enables dynamic tracking of material flows throughout their lifecycle, facilitating informed decisions by end users on reuse, recycling, and resource efficiency. The Predictive Resource Logistics Module (PRLM) (T3.4) generates forecasts of material and water flows, calculates associated emissions and costs, detects potential bottlenecks, and incorporates automation capabilities through Natural Language Processing (NLP). The analytics suite integrates the tracking of Key Performance Indicators (KPIs) and the environmental and economic impact assessment of industrial symbiosis synergies.

Within this core, the platform also incorporates three integrated modules via embedded windows, that is, content from external systems displayed directly within the platform interface without the user leaving the THESEUS environment. The first is the IS2H4C Deepmatch, integrating the matchmaking visualisation functionality developed in the sister project IS2H4C. The second is the current ICCS Material Flow Analysis (MFA) and Total Use of Commodities (TUC) system, embedded with support for Digital Product Passports and Radio Frequency Identification (RFID) technology. The third is the MFA future projections module, incorporating mass flow analysis, logistics modelling, and conversational artificial intelligence tools for resource management.

All modules within the core, both those developed in WP3 and those integrated via embedded windows, connect to the data and security layer (T3.5) through internal data connections. This layer is transversal to the entire platform and acts as an intermediary for all data flows: no data is processed or exchanged without first passing through it. T3.5 implements common data models aligned with T2.6, encrypted secure communication protocols, and a role-based identity and access management system (the MATRYCS–KeyCloak security enabler), which determines what information and functionalities each user can access according to their profile. Compliance with the General Data Protection Regulation (GDPR) and continuous security monitoring are built into the system from the outset, following a secure-by-design approach. The integration gateway, positioned immediately below T3.5, manages all platform connectivity with external systems through standard data exchange protocols, establishing bidirectional connections that enable both the sending and receiving of information with each integrated system.

The external systems with which the platform integrates are three. ICCS, through its data harmonisation system and open programming interface, also manages the user login and registration bridge described above. IS2H4C provides the deepmatch reference and matchmaking modules reused within the platform. The WP10 Territorial Metabolism Water-Energy-Materials-Waste (TM-WEMW) model contributes the territorial metabolism and resource nexus modelling tool.

The infrastructure layer underpins the entire system through a cloud deployment based on a modular, scalable architecture of independent services, managed via the IRIS moap platform builder. Development follows an agile working methodology with iterative cycles and a continuous update and deployment system, also incorporating existing modules from the ShareBox and IS2H4C platforms to maximise development efficiency.

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

Taken together, the THESEUS platform architecture establishes an integrated and open digital ecosystem for industrial urban symbiosis, designed not only to meet the operational needs of the Attica H4C during the project, but to serve as a replicable model for future Circularity Hub developments across Europe.

Based on the framework developed in chapter **Error! Reference source not found.**, a matchmaking digital module for creating symbiotic flows will be developed and integrated into Theseus central end-user platform. This effort will be reported in the next versions of the deliverable (D3.5, D3.6).

6 Discussion

To be elaborated in the next versions.

7 Conclusions

To be elaborated in the next versions.

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

8 References

Akrivou C., Łękawska-Andrinopoulou L., Manousiadis C., Tsimiklis G., Oikonomopoulou V., Papadaki S., Krokida M., Amditis A. (2022) Industrial symbiosis marketplace concept for waste valorization pathways. E3S Web Conf. 349 11005 DOI: 10.1051/e3sconf/202234911005

Akrivou, C., Lekawska-Andrinopoulou, L., Tsimiklis, G., & Amditis, A. (2021). Industrial symbiosis platforms for synergy identification and their most important data points: a systematic review. Open Research Europe, 1, 101.

Angelis-Dimakis, A., Arampatzis, G., Pieri, T., Solomou, K., Dedousis, P., & Apostolopoulos, G. (2021). SWAN platform: A web-based tool to support the development of industrial solid waste reuse business models. *Waste Management & Research, 39*(3), 489–498. doi:10.1177/0734242X21989413.

Angelis-Dimakis, A., Vyrkou, A., Pieri, T., & Earnshaw, S. (2023). *D2.4 – Enabling Platform for Water Symbiotic Schemes*. AquaSPICE Consortium / University of Huddersfield. The document is listed as AquaSPICE Deliverable D2.4, delivered in May 2023, with University of Huddersfield as lead beneficiary.

Burgoa Francisco, F., Koppelaar, R. H. E. M., & Hidalgo, D. (2025). Industrial-urban symbiosis: Enabling circular hubs for regional waste-to-resource transformation. In *Proceedings of the 12th International Conference on Sustainable Solid Waste Management* [Conference paper]. https://brinemining.ntua.gr/cyprus2025/files/proceedings/Industrial-Urban-Symbiosis_-Enabling-Circular-Hubs-for-Regional-Waste-to-Resource-Transformation-Fernando-Burgoa-Francisco1-Rembrandt-H.pdf

Domini, M., Vahidzadeh, R., Vaccari, M., Sbaffoni, S., De Marco, E., Beltrani, T., & Bertanza, G. (2025). Regional industrial symbiosis networks for waste minimisation: A case study from Italy. *Journal of Environmental Management, 394*, Article 127376. https://doi.org/10.1016/j.jenvman.2025.127376

Eurostat. "NUTS – Nomenclature of Territorial Units for Statistics: Overview." Accessed April 3, 2026. https://ec.europa.eu/eurostat/web/nuts.

Grimmel, P., Niemeyer, J. F., Tan, C. F., Sun, Y., Zhao, Y., Schöling, N., Yeo, Z., Mennenga, M., Carlow, V. M., & Herrmann, C. (2025). Urban–industrial symbiosis recommendation platform for urban factories: Leveraging historical exchange patterns through feature analysis for real-world applications. *Journal of Industrial Ecology, 29*(3), 656–669. https://doi.org/10.1111/jiec.70015

Harfeldt-Berg, L., Wallin, E., Löwgren, A., and Sommarin, P. (2025). Industrial symbiosis readiness level assessment – A Stakeholder co-designed matrix tool for guidance and evaluation. Resources, Conservation and Recycling Advances. 27, 200270. https://doi.org/10.1016/j.rcradv.2025.200270

ICLEI Europe. (2024, September). *Enhancing industrial (-urban) symbiosis at the local scale* [Briefing note]. ICLEI – Local Governments for Sustainability Europe. https://circulars.iclei.org/wp-content/uploads/2024/10/ICLEI-ES-briefing-note-I-US-1.pdf

Laybourn, P., Lombardi, D. R., & Park, H. S. (2025). *Industrial symbiosis and eco-industrial development for cities and regions: An introduction*. International Synergies Limited / STEAMhouse, Birmingham City University. https://international-synergies.com/wp-content/uploads/2025/05/Smart-Cities-Guide-DIGITALv2.pdf

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

Łękawska-Andrinopoulou L, Koumaki E, Cauchi N, et al.: Matchmaking framework for water and sludge based industrial symbiosis interactions. Proceedings of the 4th International Conference on Challenges in Environmental Science & Engineering (CESUST2023). 2023.

Łękawska-Andrinopoulou, L., Tsimiklis, G., Leick, S., Moreno Nicolás, M., & Amditis, A. (2021). Circular Economy Matchmaking Framework for Future Marketplace Deployment. Sustainability, 13(10), 5668.

Manousiadis C, Łękawska- Andrinopoulou L, KORBA A et al. Integrating regional dimensions into matchmaking frameworks for circular economy. Open Res Europe 2026, 6:66 https://doi.org/10.12688/openreseurope.21486.1

Nugroho, Y. A., Asih, A. M. S., & Sopha, B. M. (2025). Development of urban-industrial symbiosis to support sustainability: Bibliometric analysis and systematic literature review. *Discover Sustainability, 6*, Article 196. https://doi.org/10.1007/s43621-025-01030-1

Regional scenery – matchmaking. (2025). [Online questionnaire]. https://forms.gle/fG31FxBscuqVGAWj8

Södergren, K., & Palm, J. (2025). Governing industrial and urban symbiosis: Internal and external strategies for municipal development. *Journal of Environmental Management, 384*, Article 125469. https://doi.org/10.1016/j.jenvman.2025.125469

Tsimiklis, G., Koutsokeras, M., Björling, S., Peng, W., & Amditis, A. (2020, May). An ICT platform facilitating circular economy business models. In 2nd International Conference on Technologies & Business Models for Circular Economy.

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059