



SYMSITES

ECOSITES implementation for industrial-urban symbiosis through social and technological solutions

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List of Acronyms

Acronym	Definition
AI	Artificial intelligence
AMR	Antimicrobial-resistant
AnMBR	Anaerobic membrane bioreactor
HVNR	High-value new resources
IIoT	Industrial Internet of Things
IT	Information technology
ITRMP	IT Regional Management Platform
I-US	Industrial-urban symbiosis
IUSM	Industrial-Urban Symbiosis Potential Map
κ-SDSS	Social Decision Support System
MATCH	Smart Matchmaking
NRW	Non-recyclable waste
OFMSW	Organic fraction of municipal solid waste
PA	Public Authorities (also PAs where plural)
PHA	Polyhydroxyalkanoates
SRT	Solids retention time
SMCO	Smart Monitoring, Control, and Optimization
WW	Wastewater
WWTP	Wastewater treatment plant



Disclaimer

Deliverable D3.5, “Final Report – Best Practice Guidelines for Public Authorities: needs and solutions for system implementation”, is the final output of WP3 “The IT-Based Regional Management Platform (ITRMP)” within the SYMSITES project. It represents an updated version of Deliverable D3.4 and presents the consolidated structure and complete content of the guidelines addressed to Public Authorities, describing how the implementation and use of the SYMSITES ITRMP decision-support platform can effectively support the planning and implementation of industrial–urban symbiosis (I-US) projects.

This final version incorporates additional information, refinements and lessons learned from the implementation of the ITRMP at the EcoSites, resulting in a comprehensive and final set of best practice guidelines.

Executive Summary

This guidelines document is tailored for Public Authority (PA) officers, outlining how the implementation and use of the SYMSITES ITRMP decision support platform can be a valuable tool for planning and/or implementing industrial-urban symbiosis (I-US) projects. It provides an accessible overview of I-US concepts, highlights the benefits for PAs, and explains how the IT Regional Management Platform (ITRMP) can be used to support decision-making processes in real-world contexts.

The ITRMP is presented as an integrated framework that supports PAs, as well as all stakeholders involved in creating smarter, more resilient urban and industrial environments, throughout the full lifecycle of I-US initiatives.

Its application across the SYMSITES EcoSites demonstrates the potential of this approach in diverse territorial contexts. The results highlight the importance of reliable data, coordinated stakeholder engagement, and the need to explicitly consider social impacts alongside environmental and economic performance. They also show that the effectiveness of I-US initiatives depends not only on technological solutions but also on governance structures and the quality of interactions between actors.

The document structure begins by addressing the role of PAs in the rise and success of I-US, including its conceptual basis, benefits, and regulatory context. It then presents the technologies and system architecture required to enable I-US functioning, followed by a dedicated section describing the ITRMP platform and its role in supporting decision-making processes. Subsequently, the document assesses the needs of PAs, focusing on key challenges such as legal barriers, technical and economic constraints, and stakeholder coordination. The following sections outline practical solutions and best practices for implementing the ITRMP, supported by insights from the EcoSite case studies, including key findings, governance considerations, and the transferability of results to other regions. The document concludes with overall findings and future directions.

Overall, a practical and transferable roadmap is provided for PAs seeking to implement Industrial-Urban Symbiosis, contributing to more efficient resource management, enhanced circularity, and more resilient and sustainable territorial systems



1. Introduction

1.1. Purpose and intended audience of the Guidelines

This document aims to provide practical guidance to Public Authorities (PAs) wishing to promote the implementation of industrial and urban symbiosis in their territory. It is based on the use of the Regional Management Information Platform (ITRMP), a decision-making tool designed to support territorial policies on circularity, economic resilience and environmental sustainability.

1.1.1. Purpose

The Guidelines provide the reader with clear and accessible guidance on how to implement and use the ITRMP decision support platform. It describes how the platform can be integrated with existing public sector infrastructure and shows how it can be used to support effective decision-making in industrial-urban symbiosis initiatives from the perspective of public entities.

The guidelines aim to:

1. Clarify the role of Industrial-Urban Symbiosis (I-US) in the Circular Economy.
2. Present the main features and benefits of the ITRMP platform.
3. Outline the steps and elements to be considered in terms of data governance, system integration and public involvement.

1.1.2. Target audience

This guide is primarily intended for local authorities, regional development agencies, urban planning managers and municipal technical services, providing them with operational tools for integrating IUS into resource management and development strategies.

It is especially thought for PA officers responsible for urban planning, infrastructure management, environmental monitoring, and policy development in the perspective of I-US implementation, management or transformation.

1.2. Structure and scope of the Guidelines

This section provides an overview of the document's chapters and explains how to navigate through the topics. The structure follows the ITRMP modular design, ensuring the guidelines align with the platform's capabilities.

1.2.1. Scope of the Guidelines

These guidelines outlines include:

1. The benefits of I-US for circular economy initiatives.
2. The challenges PAs face in urban waste, water, and resource management and how I-US may help.
3. The SYMSITES EcoSite I-US models and how ITRMP tools help their implementation.
4. The conditions required to implement the ITRMP and how to get the most out of it.

The ITRMP has been developed in the SYMSITES project to offer new digital solutions and models to enable the assessment of I-US viability and best configurations at regional and city level, facilitating exploring optimal resource flows and socio-environmental benefits from a central tool that integrates data to support public policy formation and management.

1.2.2. Map of content

This guideline is organized as follows (Table 1-1).



Table 1-1. Map of Content Table.

Ch. 1	The role of Public Authorities in the rise and success of Industrial-Urban Symbiosis	Explains in a concise manner the concept of I-US and why local and regional PAs should implement it. Introduces the I-US concept, its benefits, and the policy and regulatory framework supporting I-US. Explains the key distinctive features of the EcoSite I-US model developed in the SYMSITES project.
Ch. 2	New technologies and architectures needed for I-US functioning	Presents the I-US enabling process technologies brought in by SYMSITES. Explains I-US enabling information and decision support technologies
Ch. 3	The ITRMP Platform for I-US Implementation	Outlines the overall ITRMP system and its integration and role in the wider public sector systems. Introduces each ITRMP module's main functionalities: 1. SMCO (Smart Monitoring, Control and Optimization) 2. IUSM (Industrial-Urban Symbiosis Mapping) 3. MATCH (Smart Matchmaking for Resource Optimization) 4. κ-SDSS (Policymaking based on Social Factors)
Ch. 4	Addressing the needs of Public Authorities implementing an I-US	Outlines the PAs needs addressed in the ITRMP, covering I-US challenges, legal barriers and regulatory barriers, lack of stakeholder coordination, technical limitations, and how the ITRMP helps overcome these issues'
Ch. 5	Solutions and Best Practices for implementing the ITRMP	Provides best practices, a step-by-step approach, and solutions for optimal implementation and adoption of the ITRMP, examining requirements for each module: smart monitoring, strategic planning, resource optimization, and policymaking.
Ch. 6	Governance Models and Policy Recommendations	Discusses how the ITRMP interacts with governance models, embedding economic and social issues and public-private partnership strategies in decision-making frameworks. How ITRMP deals with data governance, including public, industry and market engagement, monitoring & evaluation.



1.2.3. ITRMP reading maps by user group dealing with I-U S policy making

The following map (Figure 1-1) provides tailored reading paths through the ITRMP guidelines document **also for key user groups usually involved in I-US implementation along with PAs:** industrial and business actors and facility operators and technical managers.



Figure 1-1. How to navigate the guidelines.

1.3. The role of Public Authorities in the rise and success of Industrial-Urban Symbiosis

This chapter provides PAs with an essential understanding of what I-US is, its benefits for municipalities, and how local and regional governments play a key role in its implementation. It also

introduces the regulatory and policy framework supporting I-US and how it connects to circular economy goals, highlighting the benefits, challenges, and regulatory considerations.

1.4. The concept of I-US in the Circular Economy Strategy

1.4.1. Defining Industrial-Urban Symbiosis

In its most operational definition, I-US establishes mutually beneficial relationships through leveraging resource flows between plants across sectors and urban communities, processes, and materials, to transport, transform, re-use and store resources, combining the valorization of by-products, waste, wastewater and CO₂ with the aim to extract maximum value from all resources.

Urban-industrial symbiosis extends the concept of *industrial symbiosis*, a part of the industrial ecology field, to urban-industrial synergies. The I-U S can be considered as an extension of the industrial symbiosis that aims at creating advantageous synergies between firms.

Taking advantage of the geographic proximity, the I-US promotes the exchanges of waste, resources, and energy between urban and industrial areas, as well as the sharing of infrastructure. According to the United Nations Industrial Development Organization, clustering of industries and the creation of eco-industrial parks promote the development of urban-industrial synergies and allow to reduce the cost of joint infrastructure.

The I-U S concept arose from existing IS projects to fully exploit the advantages of a collaborative approach in reducing the environmental impact at a local level. Due to fast urban development, urban areas generate an increasing amount of waste, and they play an important role in water and energy consumption.

The basic concept underpinning the I-U S approach is that urban waste can be delivered to nearby industrial clusters for energy valorization or recycling, while industries can provide back available extra electrical or thermal energy, avoiding the building of new plants, improving existing plants' saturation, and reducing waste landfill.

As the IS can bring benefits to the local communities, allowing local resources to save and reducing waste to be managed by the local infrastructure, the I-U S builds up relationships between cities and local industrial sites that can harmonize the coexistence of living and production areas, improving the environmental, social, and economic sustainability of the whole system.

In this sense it can be seen as a network of people and businesses working together to improve how resources in cities and industries are used. The government (local, regional or higher level) usually plays a central role in this approach, which involves facilitating the exchange of waste and interaction between companies and the community.

1.4.2. I-US supports the Circular Economy

The I-US approach is integral to advancing circular economy objectives.

I-US implementation aligns specifically with EU Circular Economy Action Plan goals, in that it

- reduces raw material dependency by reusing industrial and urban waste, optimize resource use, also diminishing environmental impacts.
- cuts greenhouse gas emissions by optimizing energy and material flows, reducing environmental impacts.
- creates local economic opportunities through sustainable waste valorization, hence fostering sustainable urban development over multiple dimensions.

I-US sits at the intersection of industrial ecology and circular economy thinking and is strongly supported by EU policy.



1.5. How it works in practice

This section presents the main models of symbiosis and their distinctive characteristics in a straightforward manner that is nonetheless representative of reality, especially from the perspective of a PA.

The simplistic I-US model involves synergistic exchanges between different stakeholders:

- Urban areas provide biowaste, wastewater, and otherwise non-recyclable waste to industrial facilities.
- Industries process these materials to recover valuable by-products such as energy, treated water, and raw materials.
- The recovered resources are returned to the urban environment (e.g., renewable energy, bio-based materials, fertilizers).

These flows can take on different configurations that depend on the context and the availability of resources and industrial processing capacity, on the way in which the I-US was (or is) created, on political will and on the distribution of real power among the actors.

1.5.1. Origin of I-US

The idea of I-US, and how it works in practice, developed over time from earlier work on Industrial Symbiosis and related environmental management strategies.

The best-known example of Industrial Symbiosis is the network in Kalundborg (Denmark). It is important because it was so big and complicated, and it made people in academic and policy communities think about the idea of IS in the late 1980s and early 1990s.

The Kalundborg symbiosis happened naturally, through a series of agreements between major local industries starting in the 1960s. The first drivers were mostly based on saving money and using resources: the first big exchange in 1961 involved the Asnæs coal-fired power plant (which later used biomass instead) supplying extra steam and heat to the nearby Statoil refinery and, later, in 1961, to the Kalundborg municipality for its district heating system, driven by wanting to get money from unavoidable excess of energy. There was also a lack of water in the region, which led to people working together, like the refinery supplying treated wastewater to the power plant.

Coming I-US models will possibly detach from the current 'industrial bias', where the city is seen in most cases just as a 'different firm' on the industrial symbiosis scene.

The realization of next-generation urban-industrial symbiosis models will heavily rely on robust multi-stakeholder collaboration and supportive governance structures. Municipalities are expected to act as key facilitators, bridging the gap between urban and industrial actors and creating an enabling environment through favorable planning, permitting, and potential incentives. It will be especially important to build trust and a shared vision among businesses, local authorities, research institutions, and citizens.

This joint approach will help us find ways to work together and deal with rules. It will also help us make sure that people accept these linked systems.

1.5.2. The EcoSite I-US model

The SYMSITES EcoSite technology model is designed to accept a combination of urban and industrial waste streams - including municipal wastewater, organic biowaste (such as food scraps and brewery effluent), and non-recyclable industrial waste such as textile residues - and transform them into valuable recovered resources: clean water suitable for reuse, biogas or hydrogen for energy, nutrient-rich bio-fertilizers, and specialty biochemicals.

The model is modular and can be containerized in several cases, enabling rapid deployment and straightforward adaptation to the specific waste streams and resource needs of each local context, as demonstrated across four diverse European settings.



Its key advantage for Public Authorities is that the same core technology platform can be configured to match what a territory already generates and what it most needs - without requiring bespoke infrastructure design from scratch.

Full technical specifications, process diagrams, and site-specific configurations are available in the SYMSITES EcoSite book and in project deliverable D3.1.

1.6. Benefits of I-US for Public Authorities

PAs are increasingly challenged to find sustainable solutions for managing urban and industrial waste while simultaneously fostering economic growth and protecting the environment. The concept of I-US represents an effective strategy to address these challenges, especially when implemented through integrated technology models that can convert different waste streams into valuable resources, like the SYMSITES EcoSite model. This approach offers economic, environmental, and social benefits from a PA standpoint, alongside considerable political potential when the key stakeholders on the industrial, societal and scientific sides are actively involved.

A well-established I-US framework brings economic benefits, in terms of enhanced cost efficiency and stimuli to local economic development. Fiscally, I-US offers authorities an opportunity to improve the cost-effectiveness of waste management, and, beyond direct cost savings in waste management, I-US acts as a catalyst for local economic development.

I-US has been demonstrated to result in the creation of new industries and value chains within the urban-industrial basin. The generation of valuable outputs generate revenue streams that have the capacity to offset operational costs or be reinvested in public services and enhance the competitiveness of existing local industries and attract new businesses seeking sustainable and resource-efficient operations. The operation, maintenance and management of these facilities need skilled labor, hence generating new employment opportunities that frequently offer higher remuneration, impacting directly on local levels and quality of employment.

I-US is also a powerful tool to achieve significant environmental improvements. PAs that promote I-US help to change to a more circular economy and to environment protection by supporting the development of markets for secondary resources encouraging businesses to use recycled and recovered materials.

The social benefits of I-US for PAs are equally significant, contributing to improved employment opportunities, better working conditions, and enhanced community well-being. The establishment and operation of I-US facilities and processes create new jobs, from entry-level positions to highly skilled roles, and more controlled and safer working environments compared to traditional ones.

Overall community well-being gains as well from a cleaner environment, better public health outcomes and a more aesthetically pleasing living environment. From a socio-political viewpoint, I-US projects foster a sense of ownership and promote environmental awareness and participation in sustainable practices.

In short, using technology to create models that combine urban and industrial material (and energy) flows is a good idea for PAs who want to build communities that are more sustainable, strong and prosperous. I-US makes things cheaper, helps the local economy, is better for the environment, uses resources better, and makes people happier. By working with I-US, PAs can change waste-related environmental problems into good political opportunities.

1.6.1. Economic benefits

I-US economic advantages manifest primarily through substantial cost savings in waste management, the creation of new and diverse revenue streams, and robust stimuli for job creation and local economic growth. In essence, I-US transforms waste from an economic burden into a catalyst for sustainable job creation and regional prosperity.



One of the most immediate and tangible economic benefits of implementing I-US for Pas is the significant reduction of the financial burden of waste management. Cities and municipalities allocate substantial portions of their budgets to the collection, transportation, and disposal of urban and industrial waste (be it directly on the public budget or indirectly reflected by tariffs of waste management utilities and costs of industrial waste processing).

An integrated I-US model directly addresses this financial burden by diverting large volumes of waste and wastewater from these costly disposal pathways. By processing diverse waste streams - like food waste, urban and industrial wastewater, textile waste, and organic residues from industries - and transforming them into valuable recovered resources, the amount of material requiring end-of-life processing is drastically reduced, along with the related costs. Similarly, doing or facilitating co-processing of wastewater with other organic streams, municipalities might optimize the performance of their wastewater treatment plants, potentially reducing energy consumption and the need for expensive chemical inputs. Furthermore, in general, optimizing the processing of waste and waste waters closer to sources within a symbiotic network can reduce transportation distances and associated costs.

An additional economic advantage of I-US for PAs is the creation of new and diverse revenue streams through the sale and utilization of recovered resources. Unlike traditional waste management, which is primarily a cost center, I-US establishes a system where discarded materials are transformed into valuable products with market value.

All process actors involved in I-US can generate income by selling the outputs of the valorization processes, and/or getting fiscal benefits from the exchange. Public utilities and municipalities operating I-US facilities get direct benefit, and PAs governing industrial I-US processes can benefit from taxation or privileged contracts.

For example, the biomethane produced from anaerobic digestion can be upgraded and injected into the natural gas grid, sold as a renewable vehicle fuel, or used to generate electricity and heat, providing a consistent revenue source. The digested sludge, processed into nutrient-rich bio fertilizer, can be sold to agricultural businesses, landscaping companies, or even directly to residents, creating a market for a product derived from waste. Treated water, meeting appropriate quality standards, can be sold for industrial process use, irrigation, or other regulated applications, generating revenue and reducing the demand water resources feeding potable water supplies. The potential to produce hydrogen from certain waste streams opens up opportunities to participate in the growing hydrogen economy, offering significant future revenue potential.

These new revenue streams provide PAs with alternative funding sources that allow for reinvestment in other public services or infrastructure. Moreover, the ability to generate revenue from waste valorization makes I-US projects more financially attractive and sustainable in the long term, facilitating investment from both public and private sectors. By actively promoting the markets for these recovered resources, PAs can further enhance the economic viability of I-US initiatives.

Urban-Industrial Symbiosis is also a driver of job creation and local economic growth, particularly within the emerging circular economy. The development, construction, and operation of integrated waste valorization facilities and industrial processes require a diverse workforce, creating direct employment opportunities across various skill levels in facility management, process operation, technical maintenance, laboratory analysis, and logistics.

Businesses can emerge around each specific waste-recovery stream, the marketing and distribution of recovered resources (like bio fertilizer or biomethane), and the development of new technologies and services related to I-US. The symbiotic exchange of resources between urban and industrial actors also fosters new business relationships and collaborative ventures. For example, a food processing plant might partner with a local anaerobic digestion facility, or a textile recycling company might supply material to a business producing recycled fiber products.



PAs can play a decisive role in facilitating and encouraging I-US entrepreneurship and innovation by providing a supportive regulatory environment, offering incentives for I-US projects, and investing in the necessary infrastructure. The focus on local resource recovery and utilization also helps to retain economic value within the region, rather than exporting waste and importing resources, contributing to a more resilient and self-sufficient regional economy, providing long-term benefits for the community.

1.6.2. Environmental benefits

I-US delivers significant environmental benefits, contributing to the tasks of mitigating pollution, conserving natural resources, and addressing climate change.

A primary environmental benefit of I-US is its significant contribution to reducing CO₂ emissions and lowering the overall carbon footprint of urban and industrial areas through two main mechanisms: energy optimization and reduced transportation.

Energy intensification within an I-US framework can be achieved integrating energy networks between industries and urban areas, allowing for the sharing and more efficient use of energy resources, like in the case of energy-recover of organic waste using processes like anaerobic digestion to produce biomethane that can be used to generate electricity and heat for industry and homes, replacing energy from fossil fuels and thereby reducing the CO₂ emissions associated with this energy.

Reducing transportation is another way to lower the carbon footprint through I-US. By processing waste closer to where it is made and using materials that have already been used once more in the network, I-US members cut down on transporting waste and raw materials over long distances, use less fuel and produce less CO₂. Similarly, the exchange of recovered waste and resources between nearby entities within the I-US network reduces the environmental impact of transportation throughout the value chain.

Reducing the need for virgin material extraction is another environmental benefit of I-US (resulting from improved efficiency in resource use). By establishing systems where waste streams are repurposed and reintegrated into the economy, I-US significantly decreases the demand for virgin raw materials.

For example, the production of bio fertilizer from digested sludge provides a sustainable alternative to synthetic fertilizers, reducing the need for energy-intensive production of nitrogen fertilizers and the mining of phosphorus and potassium. The reuse of treated wastewater for industrial processes or irrigation conserves freshwater resources, reducing the need for withdrawal from surface or groundwater sources. Recovering valuable materials like metals, plastics, and fibers from industrial solid waste streams through sorting and processing technologies reduces the need for mining, drilling, and manufacturing of new materials.

I-US inherently leads to better overall water and waste management practices by promoting integrated and sustainable approaches.

A key aspect is the improved management and potential reuse of water. Urban and industrial wastewater streams are significant sources of water and nutrients. Within an I-US framework, these streams are treated not just for safe discharge but also for potential resource recovery. Treated wastewater meeting appropriate quality standards can be a valuable resource for industrial processes, reducing the demand for potable water and new freshwater abstraction, reducing the overall water footprint of the region and improving water security.

Moreover, the integration of systems has been demonstrated to facilitate the effective management and potential detoxification of hazardous components, to which contributes the integration of waste valorization technologies, as foreseen by the SYMSITES EcoSite model with anaerobic digestion for organic waste and advanced treatment processes for industrial waste streams. The processes themselves can be designed to be more environmentally friendly, for example, by using renewable



energy sources to power the facilities or by recovering energy from the waste streams being processed. This development leads to a further decrease in reliance on fossil fuels.

Finally, PAs implementing I-US can establish higher standards for waste and water management, triggering or reinforcing the environmental virtuous circle in the area.

1.6.3. Social and governance benefits

I-US offers significant social and governance benefits for PAs by fostering inter-actors' collaboration, enhancing resource security, and aligning with regulatory frameworks, which contributes to more resilient, well-governed, and prosperous communities. These benefits reinforce the bond between PAs and their constituents, easing effective leadership when addressing key societal challenges: improving urban resilience, strengthening public-private collaboration, optimizing resource flows, enhancing regulatory compliance and meeting sustainability goals.

For PAs, improved urban resilience translates into greater security and stability for their communities. I-US improves urban resilience by lessening vulnerabilities associated with external longer supply chains, that also may behave unpredictably. Improved urban resilience means less exposure to price fluctuations for essential resources and a more reliable supply chain for local industries and services, thanks to localized resource recovery loops: in times of crisis, the system will be better equipped to maintain essential functions and recover more quickly. PAs can actively promote resilience by incorporating I-US into urban planning, infrastructure development, and preparedness strategies.

For I-US to work well, local authorities, businesses (both in the city and in industry), and research and academic institutions must all work together. Public-private partnerships and inter-institutional collaboration are especially important for both encouraging and implementing innovations for sustainable practices and to make this idea work effectively. Such a collaborative environment needs and encourages transparency, trust, and mutual understanding between the public and private sectors.

PAs are particularly important because they bring different people and groups together and make it easy for them to work together. First of all, they can come up with a political plan and set of ways to put it into action. This could include platforms and networks that bring together different stakeholders to spot opportunities where everyone can benefit, share information on waste and what is needed in terms of resources, and develop joint projects. PAs can leverage these partnerships to co-finance projects, share risks, and ensure that I-US initiatives are aligned with broader regional development goals.

Businesses can get big benefits by using new, cheap secondary resources and opportunities to turn waste into assets. This helps public institutions understand how the sector works and what it needs, so they can develop better policies. Research centers can help to develop and improve technologies and business models that turn waste into useful resources. They can also assess how well these technologies perform in terms of the environment and the economy.

This will improve the relationship between the government and private companies, and help make better decisions, use resources more efficiently, and develop new technologies and business models more quickly. This shared leadership style can also deal with changing situations better, which leads to better results that last.

Many regulatory frameworks, particularly those in the European Union, set specific targets for waste reduction, recycling rates and the reduction of waste going to landfill. Once again, the application of I-US provides PAs with a tool to improve regulatory compliance and effectively achieve national and international sustainability and waste reduction targets.

PAs can use I-US to make their waste management, environmental permitting, and resource management processes more efficient by setting out clear rules and benefits for I-US projects. They can encourage businesses to use more sustainable practices and make it easier for them to follow environmental rules. Taking a proactive approach to following the rules not only avoids potential



penalties but also gives evidence that the Public Authority acts as a responsible and forward-thinking governing body that is committed to sustainability. Furthermore, I-US aligns with broader sustainability goals: reducing greenhouse gas emissions, conserving natural resources, preventing pollution, and fostering green transition, which are often embedded in national and regional policies.

In the end, PAs implementing I-US demonstrate leadership in environmental governance and contribute to achieving climate commitments.

1.7. The role of Public Authorities within the I-US model

PAs are key actors in the development, implementation and sustainability of industrial-urban symbioses. Their involvement can range from being the primary driver of I-US initiatives to coordinating symbiotic networks that emerge spontaneously. In order to maximize the potential of I-US to deliver economic, environmental and social benefits, it is important to understand these roles, the influence of external policies and the key issues facing policy makers.

1.7.1. Public Authorities as I-US initiators

In many cases, the symbiotic relationship between industry and cities is the result of conscious political will and a clear strategic vision on the part of local governments, regional governments, and even national governments. When government departments assume the role of facilitators, they take an active leadership position, set development agendas, and establish the necessary frameworks to promote the development of industry-urban integration.

The role of authorities in this context includes identifying and prioritizing the potential benefits of I-US for the urban area or region (cutting costs, attracting investment, creating job opportunities, and improving environmental quality). Deciding to actively promote the implementation of I-US may involve several steps.

The first step is strategic planning and policy formulation, as it is fundamental to clarify the vision and strategy for I-US in the region, taking into full consideration its integration with overall urban development, industrial policy, waste management plans, and climate change, and the most urgent challenges and response strategies. This process includes setting targets, identifying priority waste streams, and researching potential mutually beneficial exchange opportunities. It also includes formulating strategies and regulations to support these targets and exchanges.

Second, it is necessary to create enabling frameworks, such as the establishment of a legal and regulatory environment conducive to the facilitation of I-US is imperative. This may entail the streamlining of permitting processes for waste valorization facilities, the development of clear guidelines for the exchange of secondary materials and energy, and the implementation of economic incentives such as subsidies, tax reductions, or preferential procurement policies for products derived from symbiotic activities.

The third step is infrastructure development, either direct or indirect, including soft infrastructures. Investment in, or facilitation of the development of, necessary infrastructure is almost always required in order to support I-US. Infrastructure may include pipelines for the transfer of wastewater or biogas, shared processing facilities, or digital platforms for the matching of waste streams with potential users.

Awareness raising and capacity building is a much-needed accompanying measure. It is about educating businesses, citizens and other stakeholders about the concept and benefits of I-US, developing the capacities of municipal staff to support these initiatives and foster a culture of collaboration and efficiency in the use of resources.

Initial financing and attracting investment are a key enabler bridging to implementation. In fact, it is necessary to provide initial financing for feasibility studies, pilot projects or the establishment of basic I-US infrastructure. Initial financing also plays an important role in attracting private investment by demonstrating the viability and potential performance of I-US projects.



When I-US is implemented through political will, the Public Authority acts as the lead architect, laying the groundwork and providing the necessary impetus to overcome initial obstacles and drive the transition towards a more circular economy.

1.7.2. Public Authorities as I-US coordinators

PAs can also play an important coordinating role when I-US arise more spontaneously, following a bottom-up approach. This usually happens when companies identify mutually beneficial opportunities for exchange and start working together. As the network grows to a certain size, a more structured approach is needed to optimize the flow of resources, expand participation and solve systemic problems. As coordinators, PAs play a role as facilitators and enablers by providing the necessary support structures and recommendations so that I-US initiatives can flourish and spread their full potential.

In this context, the role of PAs shifts from initial creation to promoting, supporting and expanding existing mutually beneficial activities. Their tasks usually include the following steps.

First, mapping and analyzing existing waste and resource flows in the region, understanding their scale and nature, and identifying potential new connections.

Once understood the main patterns, promoting the creation and development of networks. This can be done providing businesses with platforms and opportunities to establish contacts, exchange information on waste streams and resource needs, and explore potential symbiotic relationships. This may also include organizing seminars, setting up online platforms or providing specific dissemination services within the framework of the I-US initiative.

An important task is about removing barriers. It implies first identifying and then removing regulatory, logistical or information barriers that may hinder the spontaneous formation of symbiotic networks. This may include explaining regulatory requirements, helping companies navigate approval procedures or removing infrastructure bottlenecks.

Technical and professional support is another important area of activity, which includes providing technical knowledge, carrying out technical-economic analyses or recommendations on best practices to help companies optimize symbiotic exchanges and introduce relevant value-adding technologies.

Taking care and helping to expand successful initiatives by supporting the growth and expansion of successful small-scale symbiotic relationships can be done establishing links with additional partners, facilitating access to finance or supporting the development of the necessary infrastructure.

Finally, monitoring and evaluation is a mandatory institutional duty of public intervention. This means monitoring the effectiveness of I-US networks in terms of waste reduction, resource reuse, emission reduction and achievement of economic benefits, and use this information to adjust current support and policy.

1.8. Impact of EU policy and regulatory frameworks on I-US

The European Union has an important role in shaping the urban-industrial symbiosis (I-US) landscape through a wide range of policies, guidelines and funding programs. These frameworks provide strong motivation, clear guidance and, in many cases, legal obligations that significantly influence the actions and responsibilities of PAs involved in promoting and implementing I-US initiatives. The EU's policy is important in making this change. It sets the standards and pushes for this change to happen.

1.8.1. Key EU Policy and Regulatory Drivers

Several key EU policies and regulatory frameworks are particularly influential in driving I-US:

The WFD, Waste Framework Directive (Directive 2008/98/EC, as amended by Directive (EU) 2018/851) is a foundational directive establishing the legal basis for waste management in the EU. Its core principle is the waste hierarchy, which prioritizes prevention, followed by preparing for reuse,



recycling, other recovery (e.g., energy recovery), and finally, disposal. I-US intrinsic functioning supports this hierarchy by encouraging the diversion of waste from lower-value options towards higher-value recovery and recycling pathways. And the WFD impacts on PAs because it sets binding targets for member states regarding municipal waste recycling and preparing for reuse. PAs, responsible for municipal waste management, are directly tasked with meeting these targets. Promoting I-US, becomes a preferred strategy for PAs to achieve compliance. The emphasis on extended producer responsibility also encourages industries to take responsibility on the end-of-life management of their products, opening to greater engagement in symbiotic relationships for material recovery.

The Circular Economy Action Plan (COM (2020) 98 final): Building on the first CEAP from 2015, the current plan is a key component of the European Green Deal, that outlines the agenda for transitioning to a circular economy, with a focus on sustainable product design, empowering consumers, and stimulating circularity. The CEAP explicitly recognizes the importance of industrial symbiosis in achieving resource efficiency and reducing waste, providing a strong political signal and strategic direction for PAs to prioritize circular economy initiatives, including I-US. The CEAP encourages to develop national and regional circular economy strategies that incorporate I-US principles, with a focus on specific value chains (e.g., textiles, plastics, electronics) that highlight areas where I-US can be particularly impactful: PAs are called to facilitate symbioses within these sectors. Public procurement may also play an important role in stimulating markets for circular products and services, which can benefit businesses involved in I-US.

Directives on Specific Waste Streams (e.g., Urban Wastewater Treatment Directive (EU) 2024/3019 recast, Industrial Emissions Directive (EU) 2024/1785) are among the EU numerous directives targeting specific types of waste and emissions. PAs are responsible at different levels for implementing and enforcing these legislations that set standards and increasingly encourage or mandate resource recovery. The Urban Wastewater Treatment Directive requires the collection and treatment of urban wastewater, and while primarily focused on pollution control, there is a growing emphasis on resource recovery. The Industrial Emissions Directive requires industrial installations to use Best Available Techniques to prevent or reduce emissions and waste, and its reference documents highlight resource efficiency and symbiotic opportunities. PAs are called to consider waste and wastewater not just as problems and costs but as potential resources, aligning regulatory compliance with I-US objectives.

The RED, Renewable Energy Directive (Directive (EU) 2018/2001, as amended by Directive (EU) 2023/2413) sets binding common targets for the share of renewable energy in the EU's energy mix and includes specific provisions on non-biogenic renewable fuels and biofuels. Under this legislation, biogas and biomethane, which is a key product of many I-US organic waste treatment processes, receive a strong market push. Authorities responsible for energy policy, urban planning, and waste management can enhance the economic viability of I-US projects by promoting market mechanisms. The directive also supports renewable energy infrastructure and encourages investment in equipment capable of utilizing biomethane produced through I-US networks.

The EU provides significant financial support through various programs to promote research, innovation, and the implementation of projects aligned with its policy objectives, including the circular economy and I-US (e.g., Horizon Europe, LIFE, ERDF). PAs can act as applicants, partners, or facilitators in accessing these funds, leveraging them to de-risk investments and accelerating the development of I-US networks within their regions through feasibility studies, pilot projects, collaborative initiatives, and, as in the case of the ERDF, investment in I-US infrastructure.

1.8.2. How EU Frameworks Impact Public Authority Actions

The cumulative impact of these EU policy and regulatory frameworks on PAs involved in I-US is profound.



EU policy provides a clear strategic direction towards a circular, resource-efficient, and low-carbon economy, making I-US a logical and supported approach for PAs.

Directives like the WFD and those on specific waste streams impose legal obligations and targets that PAs must meet, making I-US a necessary tool for compliance.

Policies like the RED and funding programs create market opportunities and provide financial support that enhance the economic viability of I-US projects, making them more attractive for public investment and facilitation.

EU frameworks encourage harmonization of approaches across member states and promote the dissemination of best practices in waste management and resource recovery, providing PAs with models and guidance for implementing I-US.

Altogether, EU policy and rules have a big influence on how PAs work to encourage the exchange of resources and ideas between different industries in cities, as they provide the necessary context, targets, and support mechanisms that make I-US an essential part of the scaffold of modern sustainable governance.

1.9. Issues on the table of I-US policymakers

Although the advantages of I-US are obvious, PAs have significant decisions to make: they must consider various interests, comprehend complex laws, and ensure fair benefits for everyone involved.

Key questions for decision-makers include determining how much government involvement is appropriate, deciding on the right timing for decisions, and preventing conflicts between different government levels. Additionally, they need to consider public acceptance of these projects, long-term impacts, and funding methods.

One major issue is timing: politicians often face election deadlines and other constraints, which don't always line up with the time needed to see the results of I-US projects. This mismatch makes long-term planning challenging, and policymakers - particularly at the local level - must strike a balance. They should support I-US projects with rules and incentives but avoid too much control.

Since I-US projects require long-term strategies and investments, often surpassing political cycles, decision-makers must think ahead to maintain consistent policies and regulations. They also need to determine the appropriate scale for these initiatives, whether to focus on specific industrial parks, entire cities, or broader regions, and which industries and waste streams to prioritize.

Below we briefly review key issues facing policymakers in public administrations, particularly at the local level.

It is important to define how much the government should get involved in helping the cities and businesses work together more closely. To start I-US projects and fill gaps in the circular market, strong public support is often needed. However, policymakers must be careful: if they overstep, it can disrupt the economy or slow down business innovations; the main challenge is to find the right balance. PAs should blend regulations, incentives, and market freedom to foster progress without hindering innovation. It's the difficult task of creating an environment where both public support and private initiatives work together effectively, finding the right balance between smart regulation, well-targeted incentives, and letting market forces do their part.

Another challenge regards the time and scope of decisions. I-US projects require in general long-term planning and investment, spanning several political cycles (often not aligned throughout administrative levels). While policymakers and public administrators clearly should make decisions with a long-term perspective, ensuring continuity and stability in policy and regulatory frameworks, they are constrained by their time in power. Furthermore, unless there is an incumbent context like in the case of single-industry clusters, it is critical to define the appropriate reach and sectoral scope



of I-US initiatives, which bring in questions like if the focus should be on a specific industrial park, an entire city, or a broader region, and which waste streams and industries should be prioritized.

Because I-US intersects with various policy areas (waste management, environmental protection, energy, industrial policy, urban planning), policymakers need to identify and address potential conflicts or inconsistencies between these domains to arrange a coherent framework for I-US. For example, energy regulations might conflict with waste regulations, or land-use planning rules might hinder the co-location of symbiotic partners.

Multilevel collaboration/conflict among PAs is another critical topic. I-US more often than not requires collaboration across different levels of government (at least municipal and regional, but sometimes national). Conflicts can arise due to differing priorities, resources, regulatory approaches, or political framework. While challenging, ensuring effective communication, coordination, and burden-sharing among these different levels of Public Authority must be achieved for successful I-US to be implemented. This requires building strong multilevel governance and a shared commitment to common goals related to I-US (and circularity in a wider scope).

For I-US projects it is indispensable to gain - and maintain - social acceptance: this involves engaging with local communities, addressing concerns about potential environmental impacts (e.g., disturbances, odor, traffic), ensuring fair distribution of benefits, and providing transparent information about the processes and their outcomes. Well thought communication and pervasive education are also needed to unbiased public perception of waste and recycled products (which can be a barrier) and to gain support.

In order to assess and ensure the long-term environmental, economic, and social impact of I-US initiatives, PAs need to install and run robust monitoring and evaluation frameworks to track performance against objectives and identify areas for improvement. Policymakers need to consider the potential for technological obsolescence, market changes for recovered resources, and the need for ongoing adaptation and innovation within the I-US network.

Almost always PAs must come to terms with securing adequate and sustainable financing for I-US projects. Even in the most optimistic industry-urban symbiosis plans, where revenue streams from recovered resources can contribute substantially, initial capital investments for infrastructure and technology can be substantial. Policymakers need to explore diverse financing mechanisms, including public funding, private investment, environmental performance bonds, and innovative financial instruments, and create an attractive investment environment for I-US initiatives.

Addressing these hot issues to unlock the full potential of I-US requires all parties on the PAs side to be adaptable, collaborative, and forward-thinking. The reward is more sustainable urban-industrial development and a resilient, prosperous, and environmentally sound urban and industrial ecosystem.



2. New technologies and architectures needed for I-US functioning

The implementation of I-US models introduces specific technical needs, which are addressed through a combination of innovative technologies and systemic approaches. On the one hand, advanced processing technologies allow the transformation of underutilized waste streams into valuable products, contributing to circular economic objectives. On the other hand, the realization of I-US necessitates new business-flow architectures capable of supporting secure and efficient data exchange within organizations and across organizational boundaries. Decoupled architectures minimize interdependence across parties, facilitate the integration of heterogeneous data sources and scaling of user interfaces while allowing simulate and monitoring material scenarios, exchange management and explore social impact. Furthermore, the functioning of I-US inherently involves the public sector, whether in the initiation, regulation, or maintenance of symbiotic relationships, making governance an important part at different stages of the I-US's life cycle.

2.1. I-US enabling process technologies brought in by SYMSITES

The SYMSITES project brings together a set of innovative technologies that enable the recovery of valuable resources from waste streams typically found in urban-industrial settings. From a Public Authority perspective, what matters is what each technology can treat and what it produces.

- **Anaerobic Membrane Bioreactor (AnMBR).** Treats mixed urban wastewater and organic biowaste → produces clean reusable water, biogas for energy, and digestate for fertilizer.
- **Pyrolysis system.** Treats non-recyclable waste such as textiles and olive stones → produces biochar for water treatment and platform chemicals (e.g., benzoic acid) for industrial reuse.
- **Side-stream upgrading - hydrogen production.** Treats biogas from AnMBR → produces green hydrogen as a renewable energy carrier.
- **Side-stream upgrading - bioplastics (PHA).** Treats fermentation effluents from organic waste processing → produces polyhydroxyalkanoates, a bio-based alternative to conventional plastics.
- **Nutrient recovery.** Treats liquid effluents from AnMBR → recovers ammonium sulphate for use as agricultural fertilizer.
- **Adsorption column with carbon-based materials.** Treats water to remove pathogens, antimicrobial-resistant bacteria, and emerging contaminants → produces safe, reusable water meeting regulatory standards.

Together, these technologies allow an EcoSite to close multiple resource loops simultaneously, converting what would otherwise be waste management costs into recoverable value for the local economy.

For full technical descriptions and process-level specifications, see SYMSITES project deliverables D2.1–D2.4 and the EcoSite book.

2.2. I-US enabling information and decision support technologies brought in by SYMSITES

The information and decision-support technologies developed within SYMSITES facilitate the implementation of I-US by providing:

- **Data traceability and simulation of valorization processes.** Enable the configuration, monitoring, and optimization of resource valorization processes using data-driven models. By supporting operational decision-making, they enhance process efficiency, reduce waste, and ensure optimal system performance.





- **Simulation of material scenarios.** Facilitate the territorial simulation of material flows through the integration of geolocated data and multicriteria analysis. This supports the identification and evaluation of I-US scenarios based on technological feasibility, environmental impact, and economic viability across different regions.
- **Exchange management.** Allow for the identification of optimal resource exchanges between relevant actors. By evaluating parameters such as resource type, quantity, distance, and value, it promotes collaboration and enables the efficient use of materials within I-US.
- **Social impact exploration.** Assess the social implications of I-US strategies. These tools analyze the effects of different scenarios on local communities, considering economic, social, and environmental dimensions. This enables the development of inclusive and sustainable I-US policies.



3. The ITRMP Platform for I-US Implementation

3.1. Overview of ITRMP

The ITRMP developed within SYMSITES is presented as a key digital tool for supporting, establishing and managing I-US at the regional level. The ITRMP integrates features that address the operational, business and social aspects of the I-US framework, offering various functionalities to the potential stakeholders in the context of I-US, depending on their responsibility in the context of water, waste, industry management and policy making. These features may be classified into three main categories:

- I) **Smart Operation:** Monitors waste, water and resource flows at the facility level, helping the optimization of circular economy processes through data-driven insights.
- II) **Smart Business:** Facilitates the collaboration of different actors within the I-US paradigm, enhancing industrial-urban synergies through supporting collaborations and connections among stakeholders.
- III) **Smart Social Decision Making:** Supports policy makers using AI-based simulations, considering the socio-economic impact linked to policy decisions related to the I-US concept. It also provides a map of I-US potential at a regional level, evaluating economic and environmental indicators in each scenario.

The ITRMP bridges the gap between municipal authorities, industries and waste operators, providing coordination tools for industrial-urban resource exchanges.

3.2. Public Authorities dealing with I-US: how the ITRMP supports better decisions

The ITRMP offers PAs a powerful, integrated Decision Support System that has been tailored to leverage their capacity to deal with the complexities of Industrial-Urban Symbiosis. ITRMP gives PAs the tools they need to make better decisions by combining modules for regional potential assessment (IUSM), market matchmaking (MATCH), in-depth social impact analysis (κ -SDSS), and operational monitoring (SMCO). It helps with planning, understanding and growing the I-US market, and supporting the management of I-US operations. Using the ITRMP tools helps PAs deal with the challenges and make the most of I-US for lasting urban and regional growth.

3.2.1. Why a DSS for Public Authorities dealing with the challenges of I-US

I-US represents a paradigm shift towards more sustainable urban, regional and industrial development, and PAs play a crucial role in fostering, managing, and regulating these complex ecosystems. However, effective governance of I-US presents significant challenges because PAs must navigate intricate interactions between diverse stakeholders (industries, communities, service providers), balance competing economic, environmental, and social objectives, and make strategic decisions under conditions of considerable uncertainty. Successfully implementing and managing I-US requires robust tools to support informed decision-making, which is where the ITRMP intervenes.

3.2.2. Decision Support Systems (DSS) for I-US Policymaking

The κ -SDSS module gives Public Authorities a structured way to explore the social consequences of I-US decisions before committing to them.

It allows PAs to compare different policy options and project configurations, anticipate unintended effects on employment, community cohesion, and living conditions, and identify the most socially effective points of intervention, all before any real-world action is taken.

Rather than relying on deterministic forecasts, κ -SDSS uses exploratory computational modelling (Fuzzy Cognitive Mapping and Agent-Based Modelling), which is a strength because it allows PAs



to examine a wide range of plausible social futures resulting from their choices, rather than being locked into a single projected outcome that may not reflect the complexity of real communities.

The result is better-informed, more socially aware decision-making, with the PA remaining in control of the strategy and accountable for the outcome.

3.2.3. ITRMP: Purpose and Core Functionalities for Public Authorities

The overarching purpose of the ITRMP is to provide an integrated IT platform that supports PAs and other stakeholders in effectively managing and promoting I-US activities at urban and regional scales. It achieves this goal through four distinct - but interconnected – modules (Figure 3-1), each offering specific functionalities relevant to PA decision-making.



Figure 3-1. ITRMP modules.

3.2.3.a. IUSM (I-US Potential Map): aimed at supporting strategic planning.

This module serves as a strategic planning tool, enabling PAs to assess the potential for I-US development within the regions. It helps evaluate the feasibility of transforming various waste streams (such as biowaste, wastewater, or non-recyclable waste) into HVNR by considering technological availability, economic viability, environmental impacts, transport and the potential to foster collaboration and strengthen connections among relevant stakeholders.

The IUSM core functionalities are:

1. **Component Library**

Stores on potential I-US elements, including waste streams, HVNRs, available technologies, HVNR produced, markets, and existing entities/work centers. These entities are categorized according to their economic activities, supporting the identification and structuring of interactions and collaboration opportunities among actors within the system.

2. **Scenario Configuration**

Allows PAs to define and configure specific I-US scenarios for analysis. Scenarios can be based on selected geographical areas (e.g., municipalities) or specific work centers. Users (politicians, PA officials, planning professionals, and researchers) assign roles to each entity within the scenario (e.g., waste generator, technology provider, HVNR consumer), explicitly reflecting their participation and interactions within the system, and enabling the representation of collaborative networks among stakeholders.

3. **Potential Analysis**

Calculates key indicators for configured scenarios, including environmental balances (Carbon Footprint, Water Depletion) and overall economic balance. It supports the assessment of collaboration-driven I-US configurations and allows comparison between different scenarios to identify the most promising strategies and geographical areas for implementation, based on both performance indicators and inter-actor synergies.

3.2.3.b. MATCH (Smart Matchmaking): to facilitate synergies

While primarily aimed at facilitating collaboration among stakeholders involved in industrial-urban symbiosis, the MATCH module enables users to identify, rank, and contact actors based on their



compatibility with specific search criteria. It also helps identify potential actors that could contribute to the development of markets for products derived from such valorization processes. In this regard, it provides PAs with insights into the dynamics of interaction among stakeholders within their territory and supports the practical feasibility of establishing symbiotic links in the I-US framework.

MATCH core functionalities are:

1. **My components**
contain information about the elements of a verified entity: waste and/or HVNR generated/produced, technology capacities, markets and pricing for waste/HVNRs, etc.
2. **Stakeholder's information**
contains information about the work centers that are related to the elements of the previous section, detailing their roles and locations. This database also reflects the potential contribution of each actor to circular value chains.
3. **Matchmaking**
users can configure the search based on their own criteria. Weight coefficients are available for amount, quality, distance and price. These filters support the identification, ranking, and prioritization of the most relevant actors for establishing effective symbiotic relationships.

3.2.3.c. *κ-SDSS (Social Decision Support System): assessing social impacts*

Within ITRMP this module is the most directly targeting DSS for PAs, focusing specifically on the social dimension of sustainability. It supports PAs in assessing data and interpreting the potential social impacts of I-US projects and policies under consideration. It helps explore the complex social dynamics related to employment, working conditions, living standards, and community development within the I-US context.

κ-SDSS core functionalities are:

1. **Domain Knowledge Management**
provides a structured knowledge base including a domain-specific vocabulary/thesaurus and ontology focused on social questions relevant to I-US, ensuring clarity and consistency.
2. **User-Centric Experimentation**
allows PAs to define "Decision Case Studies" reflecting real-world policy decisions. Users set up experiments by defining a "do-nothing baseline" and configuring "interventions" (policy changes or I-US project parameters) they want to test.
3. **Simulation Engines**
employs two simulation approaches. Fuzzy Cognitive Mapping (FCM) to analyze the network of influences between different factors, and Agent-Based Modelling (ABM) to simulate the social response resulting from behavior and interactions of I-US actors under different configurations.
4. **Reporting and Analysis**
generates reports allowing to investigate and compare the outcomes of different simulated interventions against the baseline, helping PAs understand the potential social consequences of their decisions.

3.2.3.d. *SMCO (Smart Monitoring, Control and Optimization): Overseeing Operations*

The SMCO module functions as a strategic instrument to enhance operational efficiency in waste/resource recovery facilities. While primarily intended for internal use within industrial organizations, its generated data and analytical outputs are indirectly relevant for PAs involved in regulation, compliance monitoring, and performance assessment within the I-US framework. By providing tools for lifecycle management of valorization facilities, the module supports broader objectives related to resource efficiency, environmental sustainability, and regulatory alignment.



Its core functionalities include tools for process digitalization, real-time monitoring through IIoT sensor networks, support for start-up and traceability, setting up alerts for deviations, and predictive modelling for operational simulation-optimization.

For PAs, the added value of SMCO lies in strengthening traceability of materials, equipment, and process data, thereby enhancing informed communication with organizations. Through these indirect benefits, SMCO contributes to more robust waste recovery monitoring, facilitates compliance pathways, and supports regional environmental governance strategies.

3.2.4. Data Governance and Security Considerations and Challenges

Public sector IT environments are rarely ideal as they involve legacy systems, heterogeneous data formats, and strict security requirements.

The ITRMP has been designed with this reality in mind, incorporating built-in technical responses that allow the platform to operate effectively even where digital infrastructure is fragmented or partially outdated.

- **Modular, cloud-compatible architecture.** The platform can integrate with existing municipal systems through API-based connections, without requiring full replacement of legacy infrastructure.
- **Standardized data exchange protocols.** The ITRMP supports recognized standards (JSON, OPC UA) to ensure interoperability across agencies and data sources with different formats.
- **Robust cybersecurity framework.** Data security is ensured through encryption (HTTPS), role-based access control, and alignment with sector-specific standards including ISO/IEC 27001 and the NIS-II Directive for relevant activity areas (energy, water).
- **Controlled data sharing.** Access is managed through standardized delegated protocols (OAuth 2.0), ensuring that only authorized personnel access sensitive information, while enabling structured collaboration with industrial partners under pre-established agreements.

These design choices mean that adopting the ITRMP does not require a PA to first resolve all of its IT challenges because the platform is built to work within them.

Table 3-1 below illustrates some of the key challenges encountered in practice, along with possible approaches addressed within the ITRMP.

Table 3-1. Examples of challenges and possible solutions in data governance.

Challenge	Solution
Municipal IT systems are outdated	Transition to modular, cloud-based architectures that support API-based integrations. cloud-based solutions with API integration.
Different data formats used by agencies	Adopt standardized data exchange protocols (e.g., JSON, OPC UA).
Public sector cybersecurity concerns	Implement security frameworks and sector-specific standards (e.g., ISO/IEC 27001) To contribute to the promotion of the new NIS-II, in those fields of activities included under this umbrella (Energy or Water, among others).



Challenge	Solution
Secure delegated access to data	Utilize standardized protocols such as OAuth 2.0 to support delegated access control

3.2.5. Benefits of adopting the ITRMP from a Public Authority point of view

The ITRMP platform offers PAs a pathway to more effective, efficient, and equitable management of Industrial-Urban Symbiosis, moving beyond fragmented approaches to provide a holistic decision support system. By integrating strategic assessment, market insights, social impact exploration, and operational awareness, it supports better-informed decisions, enhances long-term planning, and strengthens governance through improved compliance and transparency.

3.2.6. Strategic planning

ITRMP provides the data-driven foundation necessary for robust, long-term strategic planning and informed investment decisions related to I-US. ITRMP data-driven insights for strategy come from:

- **Quantitative regional assessment.** The IUSM module offers a quantitative and geographically explicit assessment of the region's I-US potential. It maps resource availability (wastes), transformation potential (technologies), and market opportunities (HVNR consumers), providing a solid evidence base for strategic goal setting.
- **Multi-dimensional impact assessment.** IUSM calculates concrete environmental (Carbon Footprint, Water Depletion) and economic indicators for different scenarios. The κ -SDSS complements this by providing structured, albeit often qualitative or relative, insights into the social dimension, exploring impacts on employment, living conditions, and community development. This integrated assessment allows PAs to understand and weigh trade-offs between different sustainability pillars when formulating long-term strategies.
- **Understanding system dynamics.** The κ -SDSS simulations help PAs understand the complex, often non-linear dynamics and feedback loops within the socio-economic fabric of the city / region as it interacts with I-US development. This goes beyond static analysis to explore how interventions might play out over time.
- **Value chain visibility.** The combination of IUSM and MATCH data provides visibility into potential I-US value chains within the region, highlighting strengths, weaknesses, and gaps that might require strategic intervention (e.g., investment in specific infrastructure, support for certain technologies, or development of specific markets).
- Informed long-term planning and investment, which the ITRMP allows us to investigate from the facets:
 - *Targeted infrastructure development.* IUSM analysis helps PAs identify the most promising geographical areas for I-US development or specific infrastructure investments (e.g., collection networks, centralized treatment facilities) based on resource mapping and calculated potential.
 - *Social policy alignment.* κ -SDSS simulations inform the development of complementary long-term social policies needed to support successful and equitable I-US implementation. Insights gained can guide investments in targeted workforce training programs, affordable housing initiatives linked to I-US job growth, or specific community engagement strategies to address concerns identified through simulation.
 - *Resource allocation.* By enabling the comparison of different I-US scenarios based on their calculated potential and multi-dimensional impacts (environmental, economic, social), ITRMP helps PAs allocate limited public funds and resources more effectively to the initiatives likely to yield the greatest sustainable benefits.



- *Future-proofing.* The ability to model different scenarios and interventions allows PAs to test the robustness of their strategies against potential future changes (e.g., shifts in technology, market prices, or social priorities), contributing to more resilient long-term plans.

3.2.7. Operational efficiency

One key con ITRMP helps streamline the day-to-day operations and decision-making processes of PAs involved in I-US, towards achieving enhanced responsiveness.

Across the ITRMP, streamlined decision-making processes are achieved through:

- **Centralized information hub.** ITRMP acts as a central repository for diverse data that is critical for I-US management. The IUSM module consolidates regional data on waste streams, potential resources (HVNRS), technologies, markets, and stakeholder locations and roles. The MATCH module adds information on active, verified stakeholders interested in collaboration. The κ -SDSS module provides a framework for organizing complex social data and baseline conditions. This centralization drastically reduces the time, and effort PAs would otherwise spend gathering disparate information from multiple sources.
- **Rapid scenario exploration.** Traditional policy analysis can be time-consuming. ITRMP's simulation tools accelerate the exploration of alternatives. PAs can quickly configure and analyze different I-US scenarios using IUSM to assess environmental and economic feasibility. Similarly, the κ -SDSS module allows PAs to rapidly set up experiments, define interventions (policy changes), and simulate their potential social impacts using FCM and ABM, providing timely insights into complex social dynamics.
- **Focused analysis.** The SDSS module, with its user-centric design, enables PAs to directly address specific social concerns by formulating targeted "Decision Case Studies" and experiments, making the analysis highly relevant to immediate social policy questions.
- **Market insight.** The MATCH module provides a quick overview of potential industry synergies and market readiness, allowing PAs to assess the viability of specific I-US connections without conducting extensive, time-consuming manual surveys or consultations.

The goal of enhanced responsiveness is pursued in the ITRMP through facilitating the tasks of:

- **Anticipating challenges.** The simulation capabilities, particularly within κ -SDSS, allow PAs to anticipate potential unintended social consequences or emerging issues related to I-US projects (e.g., impacts on local employment dynamics, housing affordability, or community cohesion). This foresight enables proactive policy adjustments rather than reactive responses.
- **Adapting to opportunities.** The IUSM module allows PAs to **quickly model and assess** the potential of new opportunities, such as the emergence of a new waste valorization technology or the identification of a significant new waste stream in the region. Scenarios can be rapidly configured and analyzed to inform swift strategic responses.
- **Informed operational oversight.** When data-sharing agreements are in place with SMCO-using operators, PAs gain near real-time visibility into regional resource flows, replacing delayed self-reporting with structured, traceable operational data.



3.2.8. Compliance and transparency

The ITRMP enhances governance by supporting regulatory adherence and fostering public trust through more transparent, accountable and evidence-based processes.

The ITRMP contributes to the goal of improved regulatory adherence through:

- **Alignment with spatial and environmental plans.** The geographical mapping and scenario analysis within IUSM help PAs ensure that proposed I-US activities and infrastructure are compatible with existing land-use plans, zoning regulations, and regional environmental protection goals.
- **Proactive social risk management.** The κ -SDSS module explicitly incorporates analysis of social factors relevant to ethical governance, such as human rights impacts, working conditions, equity, and community health (as detailed in its domain knowledge taxonomy). By simulating potential social impacts, PAs can proactively identify and mitigate risks, aligning I-US development with broader social regulations and ESG principles.
- **Compliance monitoring support.** As mentioned, access to relevant operational data via SMCO could potentially aid PAs in monitoring whether specific I-US facilities are operating within their permitted environmental limits, although this depends heavily on data sharing agreements and regulatory frameworks.

ITRMP contribution to fostering public trust comes from:

- **Evidence-based rationale.** Being a comprehensive platform, ITRMP provides a clear, data-driven rationale for I-US policy decisions. PAs can point to the analyses conducted within IUSM and κ -SDSS to explain why certain strategies were chosen over others, making the decision-making process more objective and defensible.
- **Enhanced communication.** The outputs from ITRMP - such as potential maps (IUSM), scenario impact comparisons (IUSM, κ -SDSS), and simulation results addressing specific social concerns (κ -SDSS) - can be used as communication tools. They provide concrete evidence to share with the public and stakeholders, explaining the expected benefits and trade-offs of I-US initiatives.
- **Transparency in considering social factors.** The structured approach of κ -SDSS, including its explicit vocabulary and ontology, makes the process of considering complex social impacts more transparent. Even if specific simulations are confidential, the framework itself demonstrates a systematic effort to integrate social dimensions into planning.
- **Reduced ambiguity.** The use of defined terminology and ontological structures within κ -SDSS promotes clearer communication about complex I-US issues, reducing misunderstandings among stakeholders and between PAs and the public.



4. Public Authorities' Needs and Challenges in I-US Implementation

As presented in Section 1.3, PAs play a crucial role in promoting and supporting the implementation of I-US. Nevertheless, fulfilling this role comes with various challenges that should be addressed. This section provides a needs assessment to help PAs better understand the obstacles they may face in implementing I-US. These challenges can be of different natures, including technical, economic, legal and social aspects. To support decision-making, this assessment also presents initial ideas for potential solutions that align with the capabilities of the ITRMP.

This section provides an overview of the most frequent inefficiencies in waste collection, resource utilization, and environmental impact; so, it is described the technical, economic, and operational barriers that PAs encounter when implementing I-US projects.

4.1. Challenges for public engagement and stakeholder coordination

4.1.1. Low Coordination and fragmented communication between Stakeholders

PAs play a pivotal role in fostering the implementation of industrial-urban symbiosis, particularly in regions where stakeholder coordination is low and awareness among businesses and citizens is limited. Fragmented communication, institutional silos, and the absence of shared objectives often hinder the development of collaborative initiatives between industries, municipalities, and communities.

The ITRMP platform directly addresses these challenges by offering an integrated digital environment where stakeholders can access tools to assess, connect, and plan I-US initiatives. The IUSM module supports PAs in mapping territorial resources, evaluating development scenarios, and identifying viable symbiosis configurations. The MATCH module further enhances coordination by facilitating automated resource matchmaking, enabling industries, municipalities, and other actors to discover potential collaborators for waste valorization, resource sharing, or joint innovation efforts. In addition to technological support, regulatory simplifications can motivate hesitant stakeholders to engage in symbiotic practices. Embedding symbiosis principles into regional planning frameworks and economic development policies ensures that circularity becomes a structural component of long-term territorial strategies. In regions with historically low coordination, these actions not only unlock untapped potential but also build resilience, strengthen local economies, and pave the way for an integrated and sustainable industrial-urban ecosystem. The ITRMP platform directly supports this transformation by providing decision-makers and stakeholders with integrated tools to align technical, economic, and policy dimensions of symbiotic development. The κ-SDSS module facilitates scenario-based simulations to assess the long-term impacts of regulatory and planning measures, helping identify policy levers with the greatest systemic benefit. Simultaneously, the IUSM module enables the evaluation of various symbiosis configurations under different development conditions, fostering informed dialogue among PAs and businesses. Through this combined technological and strategic support, the platform contributes to embedding I-US into regional development pathways.

4.1.2. Low Awareness among Businesses and Citizens

Low awareness among businesses and citizens is a significant barrier to the successful implementation of industrial-urban symbiosis, particularly in regions where circular economy practices are still emerging. Without a clear understanding of the benefits and opportunities that I-US can bring, such as cost savings, new revenue streams, and environmental improvements, many actors remain disengaged.



PAs have a key role in raising awareness through targeted communication campaigns, public events, and educational programs that explain the principles of circularity and showcase success stories. The ITRMP, through the IUSM module, offers a powerful framework for supporting data-driven decision-making in the context of I-US at the regional level. By integrating data linked to the activities of the stakeholders, the IUSM module can generate scenarios that simulate various symbiosis configurations between industrial and urban actors. These scenarios help identify potential waste valorization opportunities and collaboration pathways across different sectors. In addition, the module generates I-US potential maps representing possible opportunities for symbiosis between the actors considered and possible cooperation actions. These maps serve as intuitive tools to communicate the concept of symbiosis to both technical and non-technical stakeholders, including local governments, businesses, and community members. The IUSM module also delivers key performance indicators, both economic and environmental. Such indicators provide a solid foundation for assessing the feasibility and impact of proposed symbiosis strategies.

4.1.3. Lack of Industry Participation

Businesses are often hesitant to invest in I-US without clear evidence of technical and economic viability. This reluctance stems from the inherent risks associated with long-term urban infrastructure investments, including market uncertainty, complex regulatory environments, and the difficulty in forecasting returns under different development conditions. To address this, the ITRMP Solution offers a digital platform designed to support stakeholders in evaluating the potential of I-US initiatives. Central to this platform is the IUSM module which enables the simulation and analysis of multiple development scenarios. By providing transparent, data-driven insights into feasibility and expected outcomes, the IUSM module helps reduce investment risk and encourages greater participation from industry and private investors in I-US strategies.

4.1.4. Complexity of analysis and broader effects of introducing an I-US on the regional territory

Implementing I-US goes far beyond simple waste exchange; it involves reconfiguring regional economic, environmental, and social systems.

PAs are tasked with overseeing these transitions, requiring them to balance a complex array of policy objectives. Environmental goals like waste reduction and emissions control must be weighed alongside economic considerations such as industrial competitiveness and job creation.

Depending on the relative size and inter-twinning between urban and industrial domains, I-US initiatives also trigger significant social effects impacting working conditions (e.g., job quality, safety, skills demand), living conditions (e.g., housing, access to services, health impacts), and overall community development (e.g., social cohesion, equity, population dynamics). PAs must navigate these interconnected domains, making decisions whose broader effects are difficult to predict using traditional, often siloed, analytical methods. The real-world social context is not a controlled laboratory: direct experimentation with policies affecting communities is often impractical and ethically fraught.

The ITRMP platform is designed precisely to address this complexity, offering tools that allow for a more integrated analysis of I-US impacts. While modules like IUSM provide insights into environmental and economic potential, the κ-SDSS module specifically tackles the intricate 'social side' of I-US policymaking. It adopts a 'social perspective,' explicitly focusing on the social concerns that stakeholders bring to the I-US decision-making table. It provides a structured framework, to systematically consider dimensions like employment quality, human rights integration, health and safety, diversity, habitat quality, inequality, and community cohesion within the I-US context.



With the ITRMP, PAs can run "what-if" scenarios and model specific interventions, to test hypotheses about their impacts, and identify potential unintended negative consequences to compare the performance of different policy options in a complex system where real-world experimentation is infeasible.

4.2. Legal and regulatory barriers

4.2.1. Limited Public Procurement policies for I-US

Public procurement represents a powerful lever for driving market transformation towards sustainability and circularity, yet current legal frameworks, including those in the EU, often lack specific, tailored provisions explicitly designed for procuring the outputs of I-US.

PAs wishing to use their purchasing power to stimulate local symbiotic exchanges - such as buying heating/cooling services derived from industrial waste heat, procuring construction materials made from recycled regional waste streams, or specifying the use of water reclaimed through I-US processes - face challenges in designing tenders that are both effective in promoting I-US and compliant with existing procurement laws (which emphasize competition, non-discrimination, and transparency).

The ITRMP platform, however, offers valuable capabilities to help PAs navigate this complex landscape by enabling them to understand, model, and simulate the potential impacts of policy adjustments aimed at integrating I-US flows into procurement strategies before implementation.

To this end, the ITRMP platform serves as an essential tool for PAs to explore and de-risk potential procurement strategies that favor I-US. The IUSM module allows PAs to quantitatively assess the regional potential for specific symbiotic flows - identifying the types, volumes, locations, and environmental/economic characteristics of potential waste-to-resource streams (HVNRS). This provides the necessary evidence to understand what could potentially be procured and the scale of the opportunity. Furthermore, PAs can use IUSM to model scenarios where public entities act as anchor consumers for these HVNRS, assessing the viability and impact. The MATCH module complements this by providing insights into the market landscape, identifying potential local suppliers (technology holders, waste generators) who could respond to tenders incorporating I-US criteria. This combined information allows PAs to design procurement specifications that are compliant and grounded in regional reality and market capacity.

The κ -SDSS module allows PAs to move beyond purely technical or economic assessments and simulate the social consequences of different procurement policy adjustments. PAs can design experiments within κ -SDSS to model interventions such as introducing specific green public procurement (GPP) criteria that favor I-US outputs, incorporating social value clauses rewarding suppliers who participate in local symbiotic loops, setting up frameworks for innovative procurement targeting I-US solutions, or even simulating the effects of direct public demand for specific HVNRS. By running simulations using FCM and ABM, PAs can explore the potential impacts of these adjustments on key social indicators like local employment dynamics (job creation/quality), economic equity (distribution of benefits), community development, and working conditions within the affected industries. This simulation capability allows PAs to anticipate unintended consequences, refine policy design iteratively, and build a stronger case for procurement strategies that are not only legally compliant and environmentally beneficial but also socially responsible, ultimately finding "lawful and smart" ways to leverage public spending for fostering sustainable I-US ecosystems.

4.3. Technical and economic challenges

4.3.1. Data governance and IT integration challenges

Even with a platform designed for flexibility, PAs will encounter real IT and data governance challenges when implementing the ITRMP. Understanding these in advance helps PAs plan adoption more effectively



- **Outdated municipal IT systems** can limit direct integration. The recommended approach is to transition progressively to modular, cloud-based architectures that support API-based connections, rather than attempting full system replacement upfront.
- **Incompatible data formats across agencies** slow data consolidation. Adopting standardized exchange protocols (JSON, OPC UA) across departments from the outset reduces this friction significantly.
- **Cybersecurity requirements** in public sector environments, particularly for systems touching energy or water infrastructure, require alignment with frameworks such as ISO/IEC 27001 and, where applicable, the NIS-II Directive.
- **Delegated data access between a PA and its industrial partners** must be governed by formal data-sharing agreements before ITRMP integration can deliver its full value. Establishing these agreements early - ideally during the I-US planning phase - avoids delays at the implementation stage.

Addressing these challenges is manageable and well-supported by the ITRMP's architecture. The key is to anticipate them in the project planning timeline rather than encounter them mid-implementation.

4.3.2. Lack of real-time data and monitoring tools

PAs often find it hard to manage the movement of resources in and out of cities and regions, especially waste, water and energy from industrial activities. A big problem is that there is no central system that collects all the data. This means that information is often kept in different parts of different companies, in different formats, and is often reported after the event, if at all. This makes it hard to keep track of what is happening, to look at how things are changing, and to deal with problems quickly.

The ITRMP platform, especially the SMCO (Smart Monitoring, Control and Optimization) module designed for industrial facilities, offers a way to overcome this. When industries use these tools, they start to create real-time, organized, and trackable data about their processes, material inputs (like water and energy), waste outputs, and product lifecycles (through internal batch traceability). This means that we can get a clearer, more accurate and quicker view of how materials are used in industry. But this only works if PAs can get the right information through the platform (and or via the industrial stakeholders involved who use the platform).

Access to this structured, updating data, fundamentally changes the capacity of PAs for monitoring and management. Instead of relying on infrequent surveys, estimations, or delayed self-reporting, PAs could potentially tap into a dynamic data stream reflecting actual resource consumption and waste generation patterns across participating industries. This enables a shift from reactive problem-solving to proactive monitoring, allowing for the early identification of emerging trends, potential environmental hotspots (e.g., unexpected surges in specific waste types or water usage), or deviations from expected norms. Furthermore, the structured and traceable nature of the data significantly enhances the accuracy of regional material flow analyses and environmental accounting, providing a more reliable basis for understanding the region's overall resource efficiency and environmental footprint. This improved visibility (and accountability) also aids PAs in identifying and verifying potential I-US opportunities flagged by the system, such as consistent, high-volume waste streams suitable for valorization technologies documented in the IUSM module.

The availability of reliable, structured, and traceable industrial data empowers PAs to engage in more robust, evidence-based I-U S policy development and strategic planning. Traceable data on material flows and process inputs/outputs, facilitated by SMCO-like functionalities, allows for a more accurate



assessment of the environmental impacts associated with different industrial activities and supports the design of targeted circular economy policies. Real-time insights into water and energy consumption patterns can directly inform regional resource management strategies and infrastructure planning (e.g., optimizing water treatment capacity or energy grid management). Moreover, having a clearer, data-backed understanding of baseline conditions and actual flows allows PAs to design more effective regulations and incentives (e.g., for waste reduction or water conservation) and, crucially, to better evaluate their impact over time, fostering a positive cycle of continuous improvement in urban / regional resource governance.

4.3.3. Economic viability of I-US initiatives

PAs often struggle to make I-US investments financially viable thanks to difficulties such as fragmented decision-making processes, limited access to real-time operational data, the difficulty of quantifying social and environmental co-benefits, etc. To address these issues, the ITRMP digital platform provides a suite of modules designed to enhance both operational efficiency and strategic planning. The SMCO module supports real-time data collection and process optimization, reducing operational costs and improving service delivery. The IUSM module offers detailed assessments of economic feasibility, enabling more informed investment decisions. Complementarily, the κ -SDSS module allows users to simulate policy scenarios and evaluate long-term social impacts.



5. Solutions and Best Practices for implementing the ITRMP

This section provides practical solutions for PAs to implement I-US initiatives using the ITRMP tools. It offers guidance on leveraging the platform's modules to improve waste management, stakeholder coordination and policy planning.

5.1. Implementing Smart Monitoring, Control, and Optimization (SMCO)

This section explains the role of SMCO in I-US and provides guidelines on how PAs can benefit from the use of SMCO by facilities that are part of a region thanks to its monitoring, control, and optimization capabilities.

5.1.1. Defining SMCO's in I-US implementation

In the ITRMP solution, the SMCO module functions as a decision-support tool for valorization process lines. Within the I-US implementation, it is conceived for internal use at the facility level, enhancing production traceability, enabling the simulation and optimization of operations, and structuring data to support more effective, informed, and evidence-based management. To this end, the SMCO is structured into a set of conceptual sections that group related functionalities according to their role within the system, as described below:

- **Process configuration:** It groups the functionalities related to the definition and formalization of the physical and logical structure of the process. It includes the registration of process assets such as equipment, and sensors, the graphical representation of the process flow to describe its configuration, the depiction of process blocks and their spatial layout within the plant and the establishment of an inventory of the materials used and produced in the valorization process.
- **Process operation:** It encompasses the functionalities associated with the supervision and data acquisition of the valorization lines. It integrates operational data obtained from IoT-compatible sensors and other heterogeneous data sources, as well as data generated during experimental activities aimed at testing process improvements and exploring new exploitation pathways involving resource flows such as waste, water, and energy. It also supports remote monitoring through IoT capabilities and the definition of alerts to facilitate process control.
- **Process modelling:** It groups the functionalities related to the analytical and predictive representation of the process. It supports the use of models of different natures, including mechanistic and AI-based models, adapted to the specific characteristics of the process. These models enable the execution of simulation scenarios to analyze “what-if” scenarios and the optimization of selected variables, allowing the identification of combinations of operating conditions and resource flows that lead to the most favorable valorization scenarios.

5.1.2. Why SMCO is important for Public Authorities

The SMCO module provides indirect support to PAs by enabling facilities to monitor, control, and optimize their valorization processes as well as the performance of innovative I-US treatment processes. This enables both not only the early detection of inefficiencies in waste and water management, but also to know the I-US processes performance, even comparative analysis, and helps enforce policies, ensuring that industries comply with environmental regulations.



5.1.3. Enabling real-time and heterogeneous data monitoring and control of industrial processes

SMCO enables real-time monitoring and control of industrial processes by facilitating the integration of heterogeneous data sources. In addition to data streams originating from IIoT-enabled devices, it supports data acquisition from non-IIoT sources such as laboratory instruments. The module is ultimately deployed at the facility level, where it enhances process support by enabling more efficient, responsive, and adaptive operational management.

To effectively exploit SMCO for the promotion of inclusive and sustainable I-US implementation, facility managers and operators may follow the structured procedure outlined below:

1. *Identification of key process parameters*
Identify the relevant process parameters to be monitored, as well as the required stages and flow units necessary to formally define and construct the process.
2. *Identification of associated physical elements*
Identify the physical assets involved in the process, including equipment, systems, their grouping, and spatial arrangement within the facility.
3. *Definition and registration of experiments*
Design, execute, and register experimental activities, ensuring that data generated throughout these experiments are systematically collected and stored.
4. *Simulation and optimization analyses*
Perform analyses using the available simulation and optimization tools in order to assess alternative operating conditions and evaluate potential process improvements.
5. *Configuration of valorization lines*
Select the most successful experimental configurations and configure the corresponding valorization lines, defining the materials used and produced and ensuring full traceability.
6. *Process monitoring and control*
Connect data from the different devices and databases to the configured valorization lines to enable continuous and real-time monitoring and control.
7. *Reporting and compliance assurance*
Provide the appropriate and relevant information required to demonstrate compliance with established standards and constraints, thereby supporting quality assurance and adherence to safety and environmental limits defined by the competent PAs

Although the SMCO module is primarily applied at the facility level, Table 5-1 highlights how PA can also benefit from its implementation through improved oversight capabilities and enhanced data-driven coordination derived from facility-level SMCO deployment.

Table 5-1. Features of SMCO and its beneficial impact on the public sector.

SMCO Feature	Function	Public Sector Benefit
Waste flow monitoring	Real-time tracking of urban and industrial waste flows at facility level.	Assist in gathering information for reporting for official communications, such as the European Pollutant Emission Register (EPER).



SMCO Feature	Function	Public Sector Benefit
Water quality monitoring	Tracking of pollutant levels in wastewater and/or treated water at the facility level (before discharge).	Ensures compliance with EU Water Framework Directive.
Operation process simulation	Modelling operational processes to improve efficiency and resource consumption in the implementation of solutions driven by public sector initiatives and strategies.	Improves the effectiveness of public sector promoted initiatives.
Data analytics	Allows facility owners to access recorded data to detect and analyze historical trends.	Facilitates the study and reporting of non-compliance cases to the relevant public sector authorities.
Production traceability	Collects detailed information on the materials, operating conditions, equipment, and infrastructure used during production.	Ensures transparency and accountability in communications with the public sector.
Planning experiments	Helps the design and execution of controlled experiments.	Facilitates evidence-based decision-making for innovation that can affect the public sector.
Production control	Supports the management and optimization of valorization processes through IIoT and a web platform that is easily accessible from any location.	Improves control of processes that may affect the environment and public health, allowing industrial operations to adjust quickly.

5.2. Leveraging I-US Potential Mapping (IUSM) for Strategic Planning

The IUSM module is designed to help users, including PAs, identify and optimize symbiosis opportunities at the regional level. It enables authorities to assess environmental and economic impacts before implementing symbiotic strategies to support decision-making processes.

5.2.1. Defining IUSM in I-US implementation

The IUSM module uses various data sources, including information about industrial activities, urban waste management, product flows and potential consumptions, to create a map of potential symbiosis opportunities. This visualization not only facilitates better decision-making but also promotes sustainable practices by encouraging the circular use of resources, reducing waste, and lowering environmental impacts.

5.2.2. Why IUSM is important for Public Authorities

The IUSM module supports urban and regional planning by identifying the potential for the creation of EcoSites. It helps PAs pinpoint regions that are suitable for developing EcoSites. In this way, the IUSM module provides a data-driven approach that supports the promotion of EcoSites, enabling authorities to strategically plan for circular economy practices, prioritize actions, and foster collaboration among local industries and communities.



5.2.3. Identifying symbiotic opportunities and optimizing resource distribution with IUSM

The IUSM module facilitates the recognition of symbiotic opportunities by analyzing resource flows and identifying areas where industrial and urban activities can collaborate effectively. IUSM helps ensure that resources are allocated in the most effective way possible, minimizing waste and maximizing economic and environmental benefits. Best practices for using IUSM data to support long-term urban planning.

The Table 5-2 exemplifies how PAs can use the IUSM to identify potential symbiosis opportunities, allocate resources efficiently, and integrate circular economy practices into their urban planning processes, ensuring long-term environmental and economic benefits.

Table 5-2. IUSM and Public Authorities benefits.

IUSM Feature	Function	Public Sector Benefit
Resource flow mapping	Identifies waste sources and potential users.	Help authorities plan waste-to-resource exchanges.
Actors mapping	Identify the different stakeholders, their relationship with resource flows, waste recovery, and product consumption through the roles assigned to each stakeholder.	Help PAs provide a tool to the stakeholders involved in each region, fostering greater industrial and urban symbiosis.
EcoSite identification	Suggests potential for locations for I-US facilities.	Supports circular economy zoning policies.
Scenario analysis	Simulates different I-US development models.	Provides data-driven insights for urban planning.
Scenario comparison	Comparison of real or fictional industrial and urban symbiosis frameworks.	Help PAs in decision-making and the proposal of sustainable management strategies.

5.3. Facilitating smart matchmaking (MATCH) for resource optimization

This section describes how the MATCH module supports PAs in creating connections between waste generators industries or industries that can valorize these waste streams within a defined geographical area. Additionally, MATCH supports resource matching by suggesting optimal flows and identifying synergies between different sectors.

5.3.1. Defining MATCH in I-US implementation

The MATCH module functions as a marketplace for waste-to-resource transactions, connecting waste producers with technology holders capable of transforming waste into valuable products and industries or communities that consume the products obtained. Thus, the MATCH module acts as an agent that automatically identifies opportunities for material exchange between urban and industrial actors, facilitating the reuse of by-products. By enabling these exchanges, MATCH supports the development of a circular economy, reducing waste and fostering sustainable practices across sectors.



5.3.2. Why MATCH is important for Public Authorities

MATCH helps actors to access raw materials at lower costs, fostering local economic development and improving resource efficiency across industries. By streamlining the exchange of materials between waste producers, those with the necessary technologies and the consumers, MATCH supports the rationalization of resources, reduces environmental impacts, and enhances the competitiveness of local economies. This makes MATCH an essential asset for PAs as it facilitates contact between actors with the potential to carry out I-US activities.

5.3.3. Matching resource surpluses with industrial needs to foster circular economy practices

The MATCH module allows for customization of searches to meet the specific needs of industries and other users. By defining the importance given to factors such as the quality and quantity of the waste or product involved, the distance between stakeholders, and the buying and selling prices, the module can optimally match resource surpluses with industrial needs. This level of customization ensures that material exchanges are compatible and efficient, aligning with the requirements of the industries involved and fostering effective resource utilization within the circular economy framework. Additionally, the module enables circular economy practices by bringing together actors with compatible needs. Through this approach, PAs can foster the contact of available actors and adjust policy strategies to further improve sustainability and resource efficiency in their regions. Using MATCH to optimize resource flows and reduce waste.

The MATCH module optimizes resource use and reduces waste by providing matchmaking based on the preferences and needs of stakeholders. By allowing municipalities to define key criteria such as material quality, quantity, distance, and price, MATCH ensures that resource surpluses are efficiently allocated to industries or businesses that require them. This tailored approach facilitates the reduction of waste, enhances resource reuse, and supports local economic development. The Table 5-3 exemplifies how municipalities can benefit from using MATCH module.

Table 5-3. MATCH uses by Public Authorities.

MATCH Feature	Function	Public Sector Benefit
Overview of stakeholders' information	Allows a first approach to matchmaking potential in a region.	Help PAs to identify niche in the industrial and urban symbiosis in a region.

5.4. Policymaking based on social factors (κ-SDSS)

The κ-SDSS module within the ITRMP platform is the specialized DSS module designed to empower PAs and other stakeholders to navigate the complex social dimensions inherent in I-US implementation. Recognizing that I-US projects profoundly impact communities beyond purely environmental or economic metrics, κ-SDSS provides tools to analyze, simulate, and understand potential social consequences before decisions are finalized. It facilitates socially inclusive decision-making by offering insights derived from computational modeling techniques, helping policymakers craft strategies that are not only efficient and environmentally sound but also equitable, just, and beneficial to the community fabric.

5.4.1. Defining κ-SDSS in I-US implementation

κ-SDSS functions as a sophisticated analytical toolset tailored for the social complexities of I-US. It operates on the understanding that social systems are intricate and often unpredictable,



characterized by "deep uncertainty" where stakeholders may hold differing views on how systems work or the importance of various outcomes.

κ -SDSS is designed to support exploration and understanding that is to help ask new, meaningful questions (not to provide definitive predictions). It comes with

A laboratory to model social effects

κ -SDSS acts as a virtual laboratory where PAs can construct, and test models of the social system affected by an I-US initiative. Users define a "Decision Case Study" relevant to their policy concerns, establish a "do-nothing baseline" representing the current social context (using structured data input, via questionnaires), and then configure specific "interventions." These interventions represent potential policy changes, project configurations, or external shocks whose social effects the PA wishes to explore. This setup allows for systematic experimentation without the risks and costs associated with real-world trials. The platform provides a structured environment to ensure consistency and clarity in defining these models and experiments.

An AI-driven simulator for social outcomes

at its core, κ -SDSS employs computational modeling techniques - specifically Fuzzy Cognitive Mapping (FCM) and Agent-Based Modelling (ABM) - to simulate the potential outcomes of the defined interventions on the social side. These simulation engines (a simple, transparent kind of AI) provide computationally driven insights, allowing PAs to explore a range of plausible social futures resulting from their policy choices.

- *FCM simulation*
this approach models the complex web of influences between various social factors (e.g., employment rates, housing affordability, community trust, environmental quality perception). PAs can adjust the strength of these influences or introduce changes to specific factors (representing the intervention) and simulate how these changes propagate through the network, revealing potential impacts on key social dimension indicators (related to employment, living conditions, and community development).
- *ABM simulation*
this technique models the behavior of actors in the I-US based on predefined rules and their interactions with each other and their environment. PAs can configure interventions that alter the agents' environment or behavioral rules and simulate how these changes affect aggregate social outcomes (labor / employment indicator, value added).

5.4.2. Why κ -SDSS is important for Public Authorities

The capabilities of κ -SDSS directly address core needs of PAs responsible for guiding I-US development in a socially responsible and sustainable manner.

One of the most difficult things for PAs is trying to predict the often indirect or delayed social results of complex projects like I-US. κ -SDSS can help with this. By running simulations during the planning phase and before management decisions are finalized, PAs can explore how different social indicators might be impacted. These indicators include things like job creation, quality and wage distribution, housing stress, access to services, social mobility, and community cohesion. This helps to spot potential problems or risks to society early on, so they can be dealt with before they become a major issue. It helps answer questions like "*What might happen to local jobs if we choose to encourage inter-firms' quick short term symbiotic contracts instead of long term publicly backed framework contracts?*" or "*How might different ways of sharing profits affect things like how the municipality can invest in local community development programs?*"

The topic of environmental justice affects I-US too, in terms of social equity. Sustainability requires balancing environmental, economic, and social pillars. κ -SDSS empowers PAs to explicitly consider social equity, justice, and inclusion when evaluating I-US options.



The module allows PAs to model how different I-US configurations (e.g., technology choices, scale of operations, type of materials), associated policies (e.g., workforce development programs, local procurement rules), and operational aspects impact the existing social fabric. By simulating effects on exchanges, labor and value-added indicators or analyzing impacts on indicators like the gender gap or access to services for deprived groups, PAs can assess whether a proposed I-US initiative is likely to exacerbate existing inequalities or distribute benefits fairly.

This understanding helps design I-US projects and accompanying policies that actively promote social equity and contribute positively to the well-being of the entire community.

5.4.3. Integrating social data to support social-aware, informed policy decisions

Effective social impact analysis requires relevant data. κ -SDSS facilitates the integration of social data into the decision-making process in several ways:

- **Structured data input**
the platform guides users in providing necessary baseline data, through structured questionnaires covering key social dimensions relevant to I-US (employment characteristics, living conditions metrics, community development indicators). This ensures that simulations are grounded in a representation of the actual or hypothesized local context.
- **Linking interventions to data**
when configuring interventions, PAs link policy choices or project parameters to specific changes in the model's variables or agent rules, making the connection between action and potential social outcome explicit within the simulation framework.
- **Generating actionable insights**
the simulation outputs - changes in FCM concept values, changes in indicators over time in ABM aggregate behaviors, comparisons between baseline and intervention scenarios - represent integrated social information. Instead of raw data points, κ -SDSS provides insights into dynamics and potential consequences. This processed information is more directly usable for informing policy decisions than trying to interpret disparate social statistics alone.
- **User control and interpretation**
 κ -SDSS emphasizes user control allowing PAs to bring their contextual knowledge to interpret the simulation results, combining the model's outputs with their understanding of local nuances to arrive at social-aware, informed decisions. The platform supports, rather than replaces, expert judgment and stakeholder dialogue.

5.4.4. Guidelines on leveraging κ -SDSS insights for inclusive and sustainable I-US policy choices

To effectively use κ -SDSS for promoting inclusive and sustainable I-US, PAs can follow these steps.

1. *Define clear social objectives*
Start by explicitly defining the social sustainability and inclusion goals for the I-US initiative (e.g., maximize local quality job creation, minimize displacement, and improve access to services for disadvantaged groups). Use these goals to frame the "Decision Case Studies" and focus questions explored within κ -SDSS.
2. *Engage diverse stakeholders in defining baselines and interventions*
While PAs operate the tool, involving community representatives and local businesses in defining the baseline social conditions and potential policy interventions can make the simulations more relevant and build buy-in for the outcomes.
3. *Use simulations for comparative analysis*
The primary value lies in comparing different scenarios. Simulate multiple policy alternatives or project configurations to understand their relative social advantages and disadvantages. Identify trade-offs between social goals and other objectives (economic, environmental).



4. *Focus on distributional impacts*

Pay close attention to how simulated impacts affect different variables in the system analyzed. Use ABM results to explore how diverse I-U S mechanisms may affect overall employment and value added.

5. *Identify potential social risks and mitigation needs*

Use simulation results to proactively identify potential negative social outcomes (e.g., increased strain on housing, skills mismatches leading to unemployment, erosion of social cohesion). This allows for the design of targeted mitigation strategies or complementary policies (e.g., affordable housing programs, tailored job training, community benefit agreements) as part of the overall I-US plan.

6. *Inform communication and consultation*

Use the insights and visualizations generated by κ -SDSS (appropriately contextualized) to communicate the potential social impacts (both positive and negative) of proposed I-US initiatives to the public and stakeholders, fostering more informed dialogue and transparency.

7. *Adopt an iterative approach*

Treat κ -SDSS insights as inputs into an ongoing, iterative policy design process. Use simulation results to refine policy options, then potentially re-simulate to assess the effectiveness of the refinements. Always acknowledge the exploratory nature of the simulations and combine insights with other forms of evidence and stakeholder feedback.

The Table 5-4 below exemplifies how PAs can benefit from using κ -SDSS.

Table 5-4. κ -DSS and Public Authorities benefit.

κ -SDSS Feature	Function	Public Sector Benefit
Simulation of social impacts of I-US configurations	Explores how I-US diverse implementation policies may affect social dimensions	Develop socially aware planning.
Explore and compare I-US impact on employment and wages	Analyze I-US investments from a social cost-benefit point of view	Include social cost when justifying investment decisions.
Explore and compare I-US impact on communities	Explore benefits and critical weaknesses of urban thread triggered by I-US	Identify sensitive drivers to switch positive development and anticipate potential threats
Explore I-US final equilibrium states from the employment and working conditions, living conditions, and community development dimensions	Development of (long term) equilibrium scenarios	Support EU sustainability targets.
Probe the most reactive points of intervention	Find most promising intervention points	Improve effectiveness of policymaking for I-US
Co-model the social performances of a I-US	Co-model and collaborative simulation	Include multiple views in I-US policy design and assessment



6. Case Studies and Pilot Applications

6.1. Overview and purpose of SYMSITES' EcoSites

The SYMSITES project has established four EcoSites across Europe to demonstrate how I-US principles can be applied in real-world settings. These EcoSites, located in Spain, Denmark, Austria and Greece, serve as testing grounds for ITRMP integration, waste valorization technologies and policy frameworks. Each site provides valuable insights into the challenges and opportunities of I-US implementation, fostering innovation and sustainable resource management.

An EcoSite can be envisioned as a geographically limited area where various stakeholders, such as municipalities, industries, agricultural entities and urban infrastructure, collaborate to maintain and optimize interconnected resource flows, driving economic development and environmental sustainability. Each EcoSite is planned around urban wastewater treatment plants and other key facilities, creating a regional hub that collects and processes wastewater, biowaste and non-recyclable waste from both urban and industrial sources.

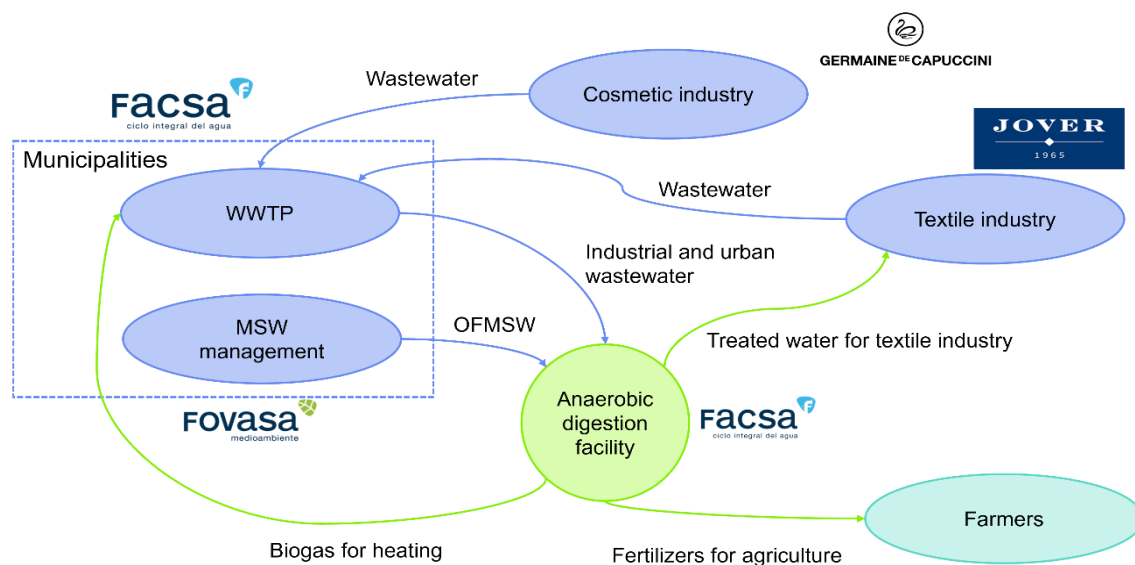
Within this framework, an advanced co-treatment system is implemented to transform waste into valuable resources. This includes the production of clean water, energy (in the form of biogas or hydrogen), biochar and upcycled high-value products, such as platform molecules, fertilizers and polyhydroxyalkanoates (PHA). These products are generated for reuse within the local economy, supporting the principles of circularity and sustainability. More detailed information about the EcoSites can be found in the [SYMSITES EcoSite book](#).

6.1.1. EcoSite in Spain

The Spanish EcoSite is located at the wastewater treatment plant (WWTP) in Alcoy, within the Valencian Community. The I-US scheme covers an area of approximately 8 km², spanning the municipalities of Muro de Alcoy, Alcoy and Cocentaina in the province of Alicante. At the facility, organic waste from municipal and industrial sources, including wastewater from the WWTP, the organic fraction of municipal solid waste and NRW from the textile sector, are valorized to obtain a range of HVNR.

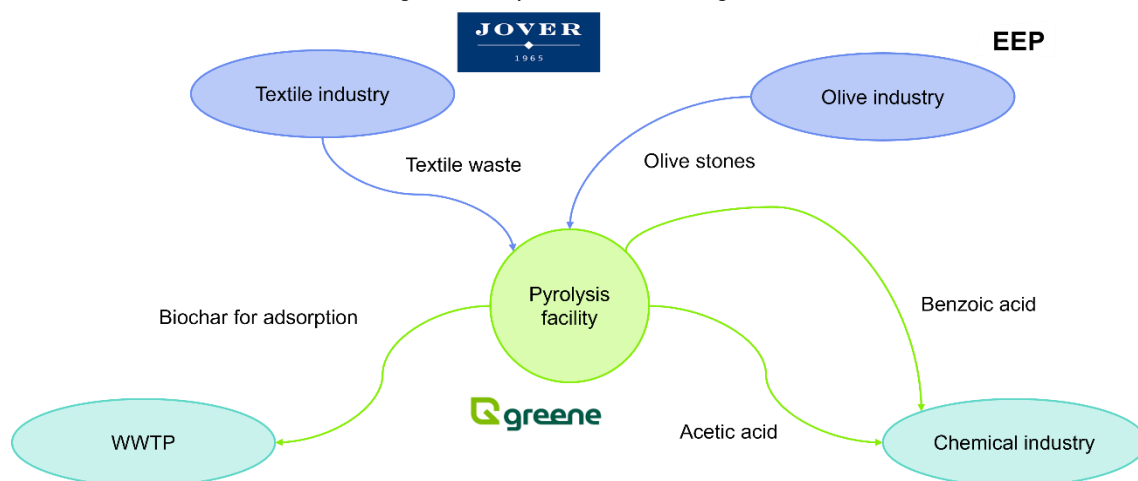
The core technology employed is an anaerobic membrane bioreactor (AnMBR), supported by tertiary treatment, which enables the conversion of these waste streams into products such as biogas for municipal energy use, treated water for textile dyeing processes and digested sludge for use as fertilizer by local farmers, as illustrated in Figure 6-1. Additionally, textile waste classified as NRW is subjected to pyrolysis, yielding biochar for adsorption applications within the EcoSite and benzoic acid from the condensable gases, which can be reused in the chemical industry, as presented in Figure 6-2.





Dark blue represents waste generation; green indicates waste valorization; light blue denotes consumers.¹

Figure 6-1. Spanish EcoSite diagram.



Dark blue represents waste generation; green indicates waste valorization; light blue denotes consumers.¹

Figure 6-2. Pyrolysis line diagram.

The Spanish EcoSite involves the following public and private partners:

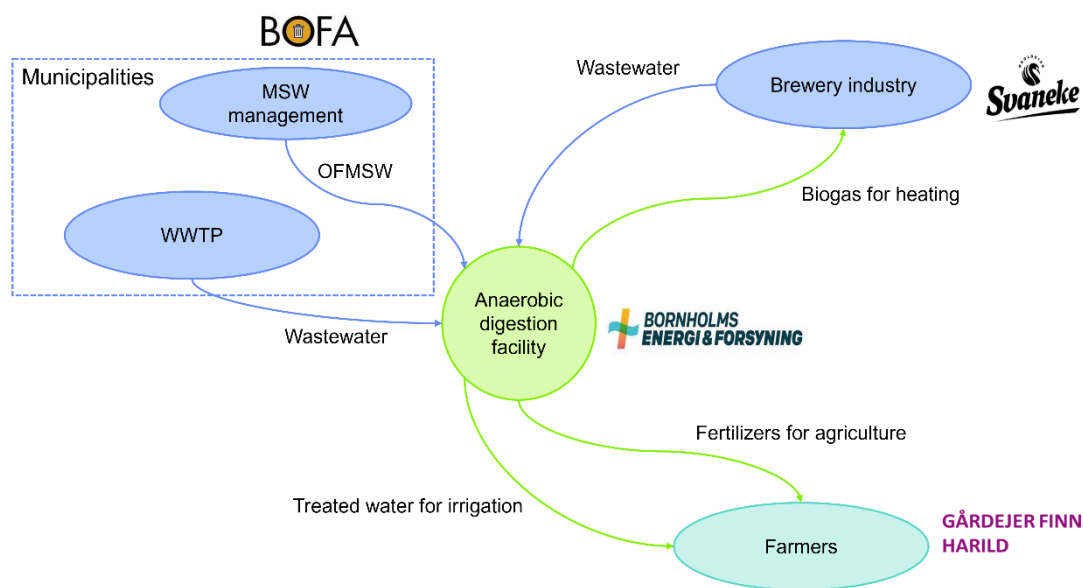
- SOCIEDAD DE FOMENTO AGRICOLA CASTELLONENSE, S.A. (FACSA) - Manager of the EcoSite
- FOMENTO VALENCIA MEDIOAMBIENTE SL (FOVASA) - Waste collection company
- ASOCIACIÓN DE INVESTIGACIÓN DE LA INDUSTRIA TEXTIL Y COSMÉTICA (AITEC) - Manager of the project
- FRANCISCO JOVER SA (JOV) - Textile industry
- GERMAINE DE CAPUCCINI SAU (GERM) - Cosmetics industry

¹ In the case that a waste generator is also a product consumer, the diagram highlights their role as a generator. Definition of acronyms: MSW – municipal solid waste; OFMSW – organic fraction of municipal solid waste; WWTP – wastewater treatment plant.

- KATHOLIEKE UNIVERSITEIT LEUVEN (KUL) MMV - System builder

6.1.2. EcoSite in Denmark

The Danish EcoSite is located on the island of Bornholm in the Baltic Sea, in and around the small town of Svaneke. The town has a population of 1,100 people and covers an area of about 6 km². At the pilot plant facility, wastewater from the brewing industry, municipal wastewater Figure 6-3. The core technology employed is an AnMBR to produce biogas, which has the potential to be used in industrial heating processes, particularly within the brewery industry. In addition to biogas, treated water and digested sludge are also obtained; the former is analyzed for reuse in agricultural irrigation in accordance with regulatory standards, while the latter may serve as fertilizer for local farming activities, provided it meets quality criteria. The valorization process is supported by a series of integrated operations, including mechanical pretreatment with grinders and filters, biological conversion in bioreactors, and membrane-based filtration systems for water purification.



Dark blue represents waste generation; green indicates waste valorization; light blue denotes consumers.²

Figure 6-3. Danish EcoSite diagram.

The Danish EcoSite involves the following public and private partners:

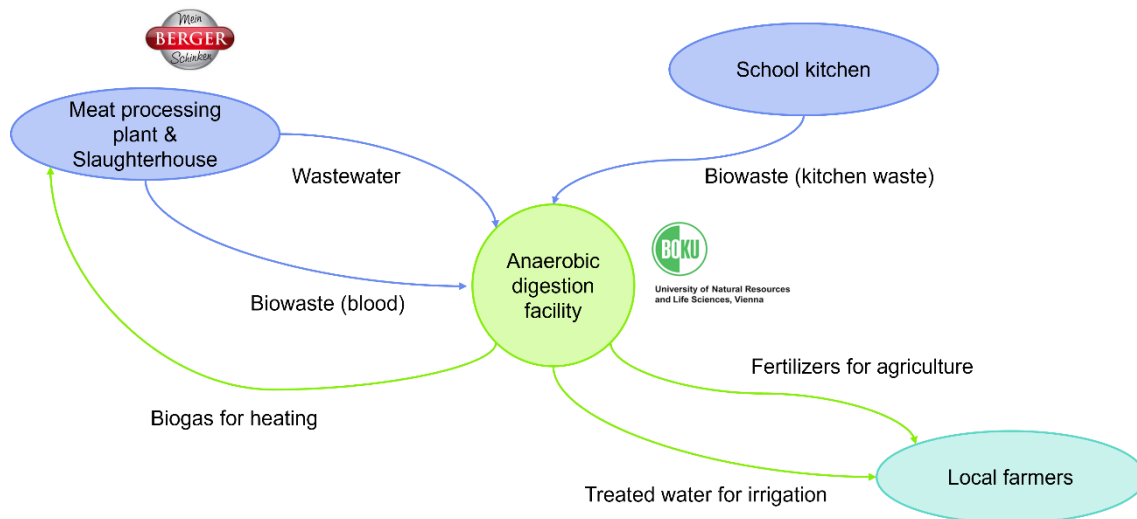
- BORNHOLMS SPILDEVAND A/S (BEOF) - Wastewater treatment plant and manager of the EcoSite
- SVANEKE BRYGHUS (BRYG) - Local brewery
- FINN HARILD (GARD) - Local farmer
- BORNHOLMS REGIONSKOMMUNE (BOFA) - The municipal waste handling Company

6.1.3. EcoSite in Austria

The Austrian EcoSite is located in the town of Sieghartskirchen, within the southeastern Tullnerfeld area. At the pilot plant facility, organic waste from urban sources and organic waste such as blood from the meat industry, together with industrial wastewater, are processed through advanced

² In the case that a waste generator is also a product consumer, the diagram highlights their role as a generator. Definition of acronyms: MSW – municipal solid waste; OFMSW – organic fraction of municipal solid waste; WWTP – wastewater treatment plant.

treatment technologies to obtain a variety of HVNR, as illustrated in Figure 6-4. Anaerobic digestion is the main technology used to convert these streams into biogas, which is used as a renewable energy source. Additional processes include flotation for waste pretreatment and advanced membrane ultrafiltration and nanofiltration or reverse osmosis for water purification, allowing the treated water to be reused for irrigation. Furthermore, the ammonium present in the effluent extracted with sulfuric acid (produced from the hydrogen sulfide contained in the biogas) forms ammonium sulfate fertilizers, which can be used by local farmers.



Dark blue represents waste generation; green indicates waste valorization; light blue denotes consumers.³

Figure 6-4. Austrian EcoSite diagram.

The Austrian EcoSite involves the following public and private partners:

- IFA TULLN, BOKU UNIVERSITY (BOKU) - Manager of the EcoSite
- FLEISCHWAREN BERGER GESMBH (BER) - Meat processing industry
- GEMEINDEABWASSERVERBAND SÜDÖSTLICHES TULLNERFELD (GST) - Wastewater treatment
- SPITZER GESMBH (SP) - Membrane technology
- AAT ABWASSER AND ABFALLTECHNIK GMBH (AAT) - Biogas pilot plant installation.

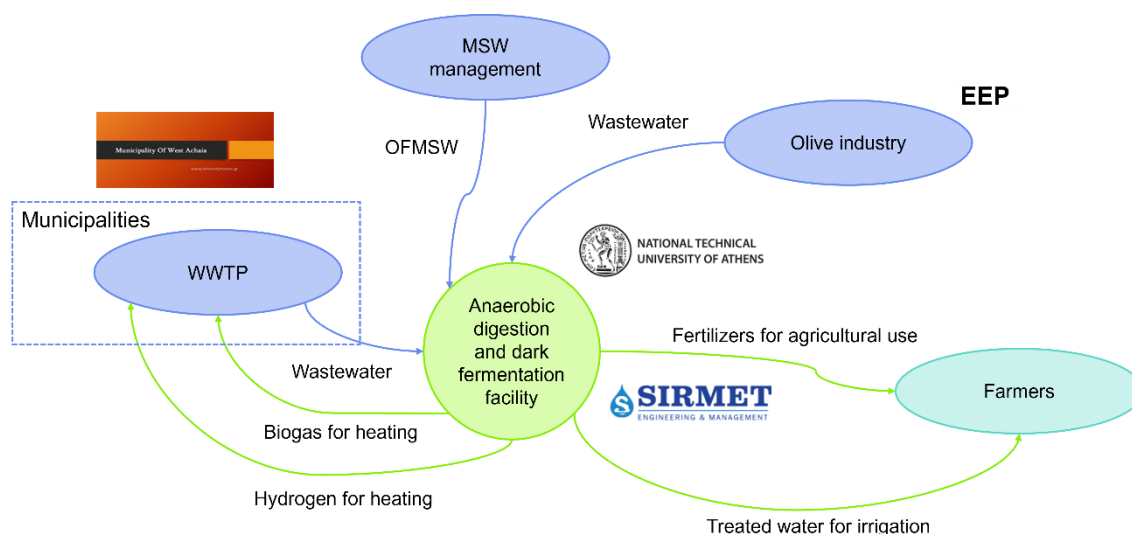
6.1.4. EcoSite in Greece

The Greek Ecosite is located at the WWTP in the municipality of Western Achaia. The I-US scheme extends over an area of approximately 13.5 km², encompassing Ano Alissos, the industrial zone, and the WWTP. At the pilot plant facility, waste originating from the olive oil industry, municipal wastewater treatment, and the organic fraction of municipal solid waste from the urban context are valorized through advanced recovery technologies to obtain a variety of HVNR, as illustrated in Figure 6-5. The main technological processes include the pretreatment of food waste using mechanical methods, followed by dark fermentation and anaerobic membrane bioreaction, which enable the transformation of these streams into hydrogen and biogas. These processes also support the production of treated water and fertilizers suitable for local farmers. Furthermore, olive stone waste is subjected to pyrolysis to produce biochar, which may be used within adsorption columns

³ In the case that a waste generator is also a product consumer, the diagram highlights their role as a generator.



for tertiary water treatment, as well as acetic acid for use in the chemical industry, as shown in Figure 6-2.



Dark blue represents waste generation; green indicates waste valorization; light blue denotes consumers.⁴

Figure 6-5. Greek EcoSite diagram.

The Greek EcoSite involves the following public and private partners:

- NATIONAL TECHNICAL UNIVERSITY OF ATHENS (NTUA) - Manager of the EcoSite
- SIRMET S.A. (SIRMET) - Developer of the Ecosite
- MUNICIPALITY OF WESTERN ACHAIA (MWA) - Operator of the WWTP
- ELAIOURGIKES EPIHEIRISEIS PATRON S.A. (EEP) - Olive oil industry

6.2. Key Findings from the Application of ITRMP at the EcoSites

This section will highlight the key takeaways and lessons learned about the ITRMP implementation in SYMSITES's demonstration sites in Spain, Denmark, Austria and Greece. The content reflects the practical experience gained throughout its deployment and use in diverse territorial and institutional contexts.

The findings and lessons relate to the way information was structured, managed, and exchanged among stakeholders, including aspects affecting data consistency and coordination. They also address elements associated with the configuration and practical functioning of the digital solution in planning and management processes. In addition, they encompass issues linked to implementation processes, such as stakeholder involvement and institutional embedding, as well as the influence of contextual or unforeseen factors encountered during its application.

6.2.1. Application of Smart Operation: SMCO

The application of the SMCO across different EcoSites validated it as a flexible and transversal framework for supporting monitoring, analysis, and process optimization under real operating conditions. Its deployment across the Spanish, Danish, Austrian, Greek, and Pyrolysis pilots demonstrated adaptability to diverse operational environments, waste and product streams, and

⁴ In the case that a waste generator is also a product consumer, the diagram highlights their role as a generator. Definition of acronyms: MSW – municipal solid waste; OFMSW – organic fraction of municipal solid waste; WWTP – wastewater treatment plant.

technological configurations, including wastewater treatment, anaerobic digestion, and pyrolysis conversion processes.

Across the pilots, the SMCO was deployed as a facility-level tool to support data acquisition and monitoring, process traceability, and process modelling, while allowing specific configuration of system functionalities. The deployment highlighted the importance of several implementation factors - data integration, user interaction, and operational alignment - and provided practical feedback that informs the best practices set out below.

Lesson 1: Standardize data integration from the outset

Experience across the EcoSites showed that combining data from online sensors and laboratory analyses works best when standardized integration methods are established early. Where different data origins and structures were harmonized within a common information management framework from the start, data consistency improved and cross-pilot comparison became more reliable.

Best practice: define data formats, units, and collection protocols before deployment, not after.

Lesson 2: Align measurement scales and time resolution across all data sources

Differences in units, measurement scales, and temporal resolution can limit the reliability of trend analysis and operational assessment. Implementing data homogenization processes - including unit standardization and temporal alignment - proved essential for meaningful long-term monitoring.

Best practice: apply validation protocols and systematic temporal alignment as a standard operational procedure from day one.

Lesson 3: Build sensor supervision and quality control into the monitoring plan

Continuous monitoring depends on appropriate sensor calibration and maintenance. Across the EcoSites, data quality analysis and inconsistency detection mechanisms were implemented to support sensor supervision, enabling early identification of anomalies before they affected downstream analysis.

Best practice: include sensor maintenance schedules and automated inconsistency detection in the facility monitoring plan, rather than treating quality control as a reactive measure.

Lesson 4: Monitor all input and output streams through a single integrated system

Operating several input and output streams through separate management systems limits overall process understanding. Implementing a single integrated monitoring and control system across different waste and product streams improved process overview and coordination between streams and associated equipment.

Best practice: configure the SMCO to cover all valorization streams from the outset, rather than adding streams incrementally.

Lesson 5: Use predictive modelling to manage variability in feedstock supply

Variations in the quantity and composition of feedstock inputs are a normal feature of I-US operations and can be effectively managed with the right tools. Predictive models based on feedstock characteristics and operational parameters were applied across the EcoSites to support production planning under variable input conditions, allowing output projections to be adjusted to changing feeding scenarios.

Best practice: deploy SMCO simulation tools proactively for production planning, not only for troubleshooting.



Lesson 6: Use centralized data storage to maintain operational continuity

Extreme environmental events and external disturbances can disrupt pilot operation and affect data availability. Storing pilot data in a centralized, remote system proved effective in protecting information and maintaining operational resilience during unexpected events.

Best practice: ensure all SMCO data is backed up to a centralized, remotely accessible system as a standard infrastructure requirement.

Lesson 7: Adapt monitoring strategies to capture seasonal variation

Seasonal changes in waste feedstock characteristics affect both operational behavior and data interpretation. Across the EcoSites, data collection and monitoring strategies were adapted to better reflect seasonal conditions, improving the representativeness of results over time.

Best practice: design monitoring protocols with seasonal variability in mind from the start, including planned adjustments to sampling frequency or parameters at seasonal transitions.

6.2.2. Application of Smart Business: MATCH

The application of the MATCH module across the economic activities represented at the EcoSites validated it as a flexible and transversal framework for supporting stakeholder identification, matchmaking, and interaction facilitation under real-world territorial conditions. Its implementation within the textile, brewery, meat, olive oil refining, and cosmetic industries demonstrated adaptability to diverse industrial contexts, levels of network maturity, and resource exchange configurations, including urban systems, wastewater treatment value chains, anaerobic digestion networks, and thermal conversion environments.

MATCH was deployed as a strategic planning and facilitation tool to support stakeholder mapping, compatibility assessment, and the identification of potential I-US connections. It enabled structured matchmaking between waste generators, technology providers, and HVNR consumers.

Continuous feedback loops allowed the refinement of actor databases, the improvement of compatibility criteria, and the adjustment of facilitation strategies to better reflect actual market conditions and institutional settings. The lessons below capture what this experience revealed about effective MATCH implementation.

Lesson 1: Map the full local industrial ecosystem before launching the tool

A key finding from implementation is that the value of MATCH depends directly on the comprehensiveness of the actor database. Where relevant industrial or urban actors were not initially included in the system, the tool's visibility and early-stage uptake were limited.

Best practice: conduct a thorough stakeholder mapping exercise - covering both obvious and less visible actors in the local industrial ecosystem - before populating the MATCH database and use targeted engagement strategies to ensure comprehensive representation from the outset.

Lesson 2: Invest in robust, detailed data on waste streams, technologies, and resource flows

The quality of MATCH outputs is directly determined by the quality of its input data. Across several EcoSites, information on waste streams, available technologies, and HVNR flows was incomplete, inconsistent, or insufficiently detailed, which affected the accuracy of compatibility assessments and matchmaking results.

Best practice: establish clear data collection protocols and reporting standards for all participating actors before system launch, specifying the minimum data resolution required for reliable matchmaking.

Lesson 3: Keep actor, resource, and technology data continuously up to date

Static databases quickly become unreliable in dynamic industrial environments. Changes in industrial processes, resource availability, or technological capacity that are not reflected promptly in the system lead to outdated matches and eroded user trust.



Best practice: implement continuous data updating mechanisms and schedule periodic validation routines - at least annually, or when significant changes occur at participating facilities - to ensure the MATCH database accurately reflects current territorial conditions.

Lesson 4: Track and update the status of interactions between actors

The matchmaking process does not end when a connection is identified - the evolution of that relationship matters too. Across the EcoSites, the status of contacts, collaborations, and negotiations was not always systematically updated, creating discrepancies between recorded and actual interaction states.

Best practice: implement structured follow-up procedures and feedback loops so that the MATCH system reflects the real state of ongoing and emerging relationships within the network, maintaining its reliability as a facilitation tool over time.

6.2.3. Application of Smart Social Decision Making: IUSM

The application of the IUSM module across the EcoSites validated it as a flexible and transversal framework for supporting I-US potential analysis and identifying urban-industrial symbiosis opportunities under real-world territorial conditions.

Its implementation across the Spanish, Danish, Austrian, Greek, and Pyrolysis line EcoSites demonstrated adaptability to diverse geographical contexts, planning systems, and industrial configurations - including urban-industrial interfaces, agro-industrial territories, wastewater treatment areas, and regions hosting thermal conversion facilities.

IUSM was deployed as a strategic planning tool to support comparative I-US territorial analysis, enabling the identification of spatially explicit synergies between waste generation points, processing infrastructures, and resource demand areas. Continuous refinement of input data and iterative validation of territorial assumptions improved scenario robustness and mapping accuracy over time.

The lessons below reflect what this experience revealed about effective IUSM implementation.

Lesson 1: Prioritize data integration and standardization before running scenarios

A consistent finding across EcoSites was that the robustness of IUSM outputs depends directly on the quality and consistency of input data. Information on economic activities, industrial sectors, infrastructure, and resource flows is often fragmented or not harmonized across sources, which affects the reliability of potential mapping and scenario results.

Best practice: invest in data integration and standardization as a prerequisite step before configuring IUSM scenarios, because incomplete or inconsistent inputs produce outputs that are difficult to defend in planning or investment decisions.

Lesson 2: Harmonize and georeference all datasets before spatial analysis

Integrating multiple datasets with different formats, resolutions, and spatial references is one of the most common operational constraints in territorial I-US analysis. Differences between administrative, environmental, and industrial datasets can limit comparability and reduce analytical accuracy if not addressed systematically.

Best practice: apply data harmonization and georeferencing procedures to all input datasets before loading them into IUSM, ensuring that every source can be consistently integrated within a unified spatial planning framework.

Lesson 3: Establish mechanisms for continuous updating of territorial data

The relevance of IUSM outputs depends on the currency of the underlying data. Changes in industrial development or infrastructure expansion that are not reflected promptly in the system lead to discrepancies between modelled scenarios and actual territorial conditions, undermining the credibility of planning outputs.



Best practice: put continuous updating mechanisms and periodic validation of spatial datasets in place from the outset, treating the IUSM data layer as a living resource rather than a one-time input.

Lesson 4: Embed IUSM outputs formally in planning and policy processes from the start

Across some EcoSite contexts, IUSM scenario and mapping outputs were produced but not systematically connected to official spatial planning or policy-making processes, limiting their direct influence on decisions. The analytical value of IUSM is only fully realized when its results are formally embedded in the governance processes they are designed to inform.

Best practice: establish from the outset how IUSM outputs will feed into specific planning instruments, zoning procedures, or investment decisions, defining the institutional pathway for results before the analysis begins, not after.

6.2.4. Application for Smart Social Decision Making: κ -SDSS

The κ -SDSS module was applied across all four EcoSites to support social impact analysis and policy simulation in real I-US planning contexts. Its two complementary tools (Fuzzy Cognitive Mapping - FCM, which explores how different interventions affect a broad set of social conditions, and Agent-Based Modelling - ABM, which simulates how I-US network configurations affect labor and employment outcomes over time) were implemented following a consistent protocol across all sites, ensuring cross-site comparability while accommodating the significant differences in industrial context, settlement scale, and social baseline between Spain, Denmark, Austria, and Greece.

The EcoSite implementations confirmed that the κ -SDSS delivers meaningful governance value in diverse real-world settings. The lessons below reflect what this experience revealed about effective and impactful use of the module.

Lesson 1: Run social baseline analysis before making I-US design decisions

Across all four EcoSites, the FCM baseline survey - mapping the current state of social conditions across key dimensions including employment, living conditions, community cohesion, health, and equity - revealed that local social starting points differ substantially and directly determine which intervention strategies are most effective. What worked in Austria was not the right approach for Greece, and vice versa.

Best practice: conduct the κ -SDSS FCM baseline survey as a standard first step before finalizing I-US site configurations, technology choices, or governance strategies. The baseline is quick to administer and provides an evidence trail demonstrating that social consequences were considered, which is an increasingly important requirement in EU-funded projects.

Lesson 2: Use simulation to identify the most effective social intervention points

FCM simulations across Austria, Spain, Denmark, and Greece consistently showed that when the local social fabric is under stress, such as declining employment quality, weakening social cohesion, or deteriorating health and safety conditions, multiple intervention types tend to activate the same sensitive variables simultaneously, producing convergent positive outcomes. This means that targeted action on a small number of key levers can generate broad social benefit.

Best practice: use FCM simulations to identify the two or three social variables that function as the most reactive entry points in the local context, then design incentives, training programs, or governance structures around them, rather than spreading effort across all dimensions equally.

Lesson 3: Combine governance-led and community-led strategies

Neither strategy alone is sufficient. FCM experiments across all four EcoSites converged on two recurring and complementary strategy types. Governance-led approaches, like public-private partnerships, regulatory alignment, digital infrastructure, produced stronger effects on living conditions and social innovation potential. Community-led approaches, like awareness campaigns, citizen engagement, participatory training, produced stronger effects on employment quality and social networking. Neither type alone delivered the full range of social benefits.



Best practice: use κ -SDSS FCM simulations to determine which strategy type is most needed given the local baseline, and how to sequence or combine the two to achieve broad and lasting social benefit across all three dimensions (employment, living conditions, and community development) simultaneously.

Lesson 4: Act early, because the formative phase of an I-US network is the highest-leverage moment

ABM simulations across all four EcoSites revealed a consistent structural pattern: a critical threshold appears at around 10÷20 participating companies, after which an I-US network's social performance trajectory becomes self-reinforcing and difficult to redirect. Networks that settle into a lower-performing path at this stage tend to remain there regardless of subsequent growth.

Best practice: use κ -SDSS ABM to identify this formative window in the specific regional context, and concentrate governance investments (early institutional frameworks, deliberate actor recruitment focused on complementarity, public-private partnership formation) before the threshold is reached. Acting after this point requires substantially greater effort for smaller returns.

Lesson 5: Prioritize the quality and complementarity of network actors over network size

ABM simulations confirmed that the social performance ceiling of an I-US network is determined more by the complementarity of its waste streams and resource exchanges than by the number of participating actors. The optimal network size varied considerably across EcoSites, spanning from around 6÷8 firms in Svaneke to 40÷60 in Tullnerfeld, reflecting the different industrial mix and exchange potential of each context. A simple growth strategy is not reliable.

Best practice: use κ -SDSS ABM to identify the right scale and actor composition for the regional context before designing participation frameworks or expansion policies. Quality of fit between actors matters more than quantity.

Lesson 6: Use co-modelling to build shared understanding among stakeholders

Both ABM and FCM results across all EcoSites pointed to the same conclusion: passive or market-driven I-US network development is insufficient. A strategic facilitator, that is a public or public-private body able to monitor network sustainability, curate the actor mix, and intervene before negative trajectories become entrenched, is needed for durable performance. The κ -SDSS co-modelling function supports this role directly, enabling PAs, industrial partners, and community stakeholders to run simulations together in a shared environment.

Best practice: use κ -SDSS co-modelling sessions as a governance instrument and don't limit it to analytical tasks. This will build common understanding of trajectory risks, align stakeholder expectations, and create the shared analytical reference that effective and durable I-US policy design requires. The complementary exploratory and analytical functions of the social decision making component of the ITRMP (κ -SDSS) have been applied across the EcoSites to produce a unified feature matrix to support social decisions in I-US policy making. The Agent-Based Modelling component simulates how I-US network configurations affect labor outcomes over time, and the Fuzzy Cognitive Mapping component allows to model and explore how different intervention strategies affect a wider set of social conditions in a given I-US setting.

Together these two approaches help policy makers interested on the social dimensions to link I-US planning and/or coordination to different set of decisions (Table 6-1).

Table 6-1. κ -SDSS features and supported policy decisions.

Feature	PA Decision Supported
Simulate social impacts of I-US configurations	Select and compare configuration options before committing to a design
Explore the labor intensity effects (L-IUSI)	Incorporate social cost-benefit analysis into investment



Feature	PA Decision Supported
indicator)	justification
Explore community impacts across 30+ social variables	Identify vulnerable social dimensions; anticipate threats to social legitimacy
Model long-term equilibrium states	Assess alignment with EU employment and sustainability targets
Probe reactive points of intervention	Improve timing and targeting of policy measures
Co-model with stakeholders	Integrate multiple viewpoints in I-US design; build shared analytical reference

6.3. Governance Models and Policy Recommendations

Where Section 6.2 distills the operational lessons from deploying each ITRMP module at the EcoSites, this section addresses a distinct and higher-order question: *how should Public Authorities embed the ITRMP and its insights into their formal governance systems?*

Lessons from pilots are fully realized when they are translated into institutional practice, into data-sharing agreements, planning procedures, investment frameworks, and governance structures that persist beyond the project cycle.

The recommendations below are organized by governance function, reflecting the cross-cutting nature of the decisions PAs must make.

6.3.1. Establish data-sharing frameworks as a governance prerequisite

The most consistent enabling condition across all four EcoSites was the availability of structured, reliable, and continuously updated data. Without it, none of the ITRMP modules can operate at full effectiveness. PAs should treat data access as a governance decision that must be made upfront, because it is not a technical detail that can be resolved during implementation.

Before launching an I-US initiative, PAs should establish formal data-sharing agreements with industrial operators covering the minimum data flows required for SMCO compliance monitoring, IUSM territorial mapping, and MATCH actor registration. These agreements should specify data formats, update frequency, access rights, and the permissible uses of shared information. Embedding these requirements in permitting conditions or public funding criteria is the most reliable way to ensure compliance across the I-US network.

6.3.2. Institutionalize ITRMP scenario analysis in formal planning cycles

A recurring gap observed at the EcoSites was that ITRMP outputs like potential maps, scenario comparisons, social simulations, were produced but not systematically connected to official planning and investment decisions. The analytical value of the platform is only fully realized when its outputs are given a defined role in formal governance processes, which are in turn only fully effective when they are implemented consistently and at the right level.

PAs should institutionalize IUSM scenario analysis as a standard step in circular economy strategy revisions, regional development plans, and waste management program updates, ensuring that I-US options are evaluated alongside conventional approaches every planning cycle. Similarly, the K-SDSS FCM baseline survey should be established as a routine social impact assessment instrument, required before finalizing any significant I-US configuration or scaling decision. To convert the ITRMP from a research tool into a governance instrument these steps should be embedded in formal planning procedures rather than leaving them to project-by-project.



6.3.3. Use ITRMP evidence to ground investment decisions and public procurement

Public investment in I-US infrastructure is most defensible face to oversight bodies, elected representatives, and the public, when it is backed by quantified, comparable evidence. Similarly, I-US-friendly public procurement is legally most sustainable when grounded in documented proof that competitive local supply exists.

Investment sponsoring committees (including funders, regulators, planners, elected) should require IUSM scenario comparison outputs as standard supporting documentation for I-US infrastructure proposals, using the calculated carbon footprint, water depletion, and social and economic performance indicators to rank competing configurations objectively. For procurement, MATCH market intelligence - mapping verified local suppliers, their capacities, and pricing signals - should be used to demonstrate supply-side readiness before drafting tender specifications that favor recovered resources. This shifts both investment and procurement decisions from assertion to evidence, strengthening accountability and reducing legal challenge risk.

6.3.4. Leverage SMCO traceability to underpin compliance and build public trust

Environmental permitting and public acceptance are two of the most persistent governance challenges for I-US. SMCO process traceability addresses both simultaneously, but only if PAs actively incorporate it into their oversight and communication strategies rather than leaving it as an internal facility tool.

PAs responsible for environmental permitting should require I-US operators to share relevant SMCO outputs through pre-agreed protocols, enabling a shift from periodic self-reporting to continuous, evidence-based compliance monitoring. At the same time, aggregated and anonymized SMCO traceability data, documenting that recovered materials meet quality and safety standards, should be used proactively in public communication and, where appropriate, incorporated into certification or labelling schemes. This transparency is particularly important for materials entering public supply chains, such as reclaimed water, digestate, or biomethane.

6.3.5. Use κ -SDSS to make social governance explicit and evidence-based

The most significant cross-cutting governance finding from the EcoSites is that positive environmental and economic outcomes do not automatically generate positive social outcomes. Health, social cohesion, and habitat quality declined in do-nothing baseline simulations even when economic indicators improved. This means that social governance must be designed deliberately and cannot be simply assumed.

PAs should use the κ -SDSS FCM component as a standard planning instrument to make hidden social dynamics visible before committing to I-US configurations (retrospective assessment is useless). FCM simulations should directly inform the design of complementary social policies (workforce development programs, community benefit agreements, equity-focused incentive structures) that accompany I-US infrastructure decisions. The κ -SDSS ABM should be used to justify the timing and scale of governance investment, demonstrating to decision-makers that early intervention at the formative phase of an I-US network delivers social returns that later-stage governance cannot recover.

6.3.6. Assign and resource the orchestrator role within the governance structure

Both the FCM and ABM analyses across all four EcoSites converged on the same conclusion that passive or market-driven I-US network development is insufficient for durable social and economic performance. It is need to make sure the network can continue to exist, that the different people and organizations involved work well together, and that is steered right before things go wrong. This role of the orchestrator cannot be left to develop naturally, taking the risk that it deviates from the goal. It needs to be assigned formally, given the necessary resources, and supported.

Regional governance frameworks for I-US should explicitly designate an orchestrating body - whether a PA department, a dedicated agency, or a public-private governance structure - and equip



it with access to ITRMP data flows and co-modelling capability. The κ -SDSS co-modelling function should be used as a regular governance instrument, enabling the orchestrator to run collaborative simulations with industrial partners and community stakeholders, build shared understanding of trajectory risks, and maintain the adaptive capacity needed to respond to changing market conditions, actor dynamics, and social pressures. The resources and mandate for this role should be secured for timescales that exceed individual political cycles, since the highest-leverage governance moments in I-US network development occur early and cannot be retrospectively addressed.

6.4. Transferability of best practices to other regions

Where Section 6.2 distils operational lessons from deploying the ITRMP at the EcoSites, and Section 6.3 translates those lessons into governance recommendations for institutionalizing the platform, this section addresses the question: *how can a PA in a region with no existing I-US infrastructure and potentially a different regulatory, industrial, or social context, adapt and adopt what SYMSITES has demonstrated?*

The four EcoSites were deliberately chosen to span substantially different conditions, going from a small island community (Svaneke, Denmark), a textile-industrial basin (Alcoy, Spain), an agri-food processing area (Tullnerfeld, Austria), and an olive-oil and wastewater context (Western Achaia, Greece). This diversity was designed precisely to stress-test transferability. Indeed, the cross-site evidence confirms that the ITRMP platform and the governance insights it generates hold across all four, which means they can be smartly replicated with proper adaptation elsewhere.

The recommendations below are organized in the order that a new-adopter region is likely to follow, namely assessing starting conditions, building the minimum data foundation, identifying where to begin, designing the right incentives and governance structures, and sequencing social readiness work. Readers from regions that already have I-US governance in place should focus on sections 6.4.3 and 6.4.5, which address scaling and social risk management.

6.4.1. Start with a fair assessment of the as-is situation.

The most common mistake in I-US adoption is assuming that a model that worked elsewhere can be transplanted directly. The EcoSite evidence shows clearly that what worked in Austria was not the right approach for Greece, and that the optimal network scale, actor composition, and governance strategy differ substantially across contexts. Before selecting tools, strategies, or partners, a new-adopter region needs a clear picture of its own starting point across three dimensions.

Before engaging with any ITRMP module, PAs should map three things:

- *the state of the local data infrastructure (is monitoring report-based or real-time?);*
- *the structure of the local industrial ecosystem (concentrated or dispersed? mature or nascent?); and*
- *the social baseline (is the community socially stressed, resilient, or stable?).*

The κ -SDSS FCM baseline survey and IUSM component library population are both low-cost instruments for this diagnostic step and should be treated as prerequisites to the I-US planning process.

6.4.2. Use SMC0 as the entry point where data infrastructure is weak

One of the most consistent barriers to I-US adoption in new contexts is the absence of reliable, structured data on waste flows, energy consumption, and water quality. Without this foundation, neither strategic planning nor matchmaking nor social simulation can function reliably. The EcoSite experience confirms that this barrier is real and that SMC0 provides a practical, low-risk entry path that does not require a pre-existing regional digital platform.



Regions with limited or report-based monitoring infrastructure should prioritize SMCO deployment at one or two pilot facilities as a first step, before attempting to run IUSM scenarios or MATCH analyses at regional scale. A single SMCO-enabled facility creates structured, traceable process data immediately usable for baseline calibration, investment justification, and regulatory dialogue. The standardized instrumentation approach validated across four different national regulatory contexts makes this entry path replicable with limited customization and the compliance data it generates is directly usable to build the case for regulatory modernization, replacing precautionary blanket restrictions with outcome-focused permitting standards.

6.4.3. Use IUSM to identify where to start, not just what to do

Regions new to I-US typically face two related problems: they do not know *where in their territory symbiotic exchanges are most feasible*, and they lack the analytical basis to justify the choice of a starting site to elected bodies and funding institutions.

IUSM addresses both. Its georeferenced potential mapping, scenario configuration, and comparative indicator outputs are designed precisely for this pre-investment analytical phase, as shown across the four EcoSite contexts.

PAs in new-adopter regions should use IUSM scenario comparison to evaluate carbon footprint, water depletion, and economic performance across alternative configurations as the primary instrument for site selection and investment prioritization. In regions where I-US is politically novel, embedding IUSM outputs in official planning documents creates a documented record of evidence-based decision-making that supports funding applications and reduces the political vulnerability of departing from established practice. The component library structure is also directly usable as a template for building regional data standardization frameworks, regardless of whether a formal I-US initiative is yet underway.

6.4.4. Use MATCH to overcome actor fragmentation before making infrastructure commitments

A structural obstacle that is likely to be more severe in new-adopter regions than at the EcoSites is the fragmentation of potential I-US actors, often dispersed across a territory, unaware of each other's resource flows, and with no established channels for collaboration. In peripheral EU regions and in many non-EU contexts with dispersed agri-food, textile, meat-processing, or manufacturing sectors, this fragmentation means that infrastructure investment made before actor compatibility is confirmed carries high risk of underutilization.

PAs considering I-US adoption should use MATCH to map actor compatibility and identify viable symbiotic pairs before committing infrastructure budgets. This intelligence directly reduces the cost and uncertainty of stakeholder engagement and allows facilitation resources to be directed toward the connections most likely to succeed, rather than promoting I-US participation uniformly. For incentive design specifically (subsidies, tax reductions, procurement criteria, feed-in tariffs) MATCH market intelligence reveals which resource flows have sufficient volume and pricing viability to sustain formal exchange, preventing the common failure mode of incentives designed for a market that does not yet exist at the assumed scale.

6.4.5. Calibrate social engagement strategy to the local baseline before launching

The EcoSite evidence on social dynamics is the most directly transferable governance finding in the entire project, precisely because it reveals that standard approaches do not travel. Communities that are socially stressed need different interventions from those that are stable or already high-performing. Applying the wrong strategy - no matter how well-intentioned - produces negligible or counterproductive results.

PAs in new-adopter regions should use the κ -SDSS FCM baseline survey and do-nothing simulation before committing to a social engagement or communication strategy. This diagnostic step is low-cost, requires no prior ITRMP deployment, and directly determines which strategy type - governance-



led, community-led or both - is likely to be most effective in the local context. It also identifies which social variables are most reactive to intervention, allowing resources to be concentrated on the levers with the greatest leverage rather than spread evenly. For regions where I-US is being introduced for the first time, the κ -SDSS ABM adds a further critical insight: the formative phase of network development is the window of highest governance leverage, and public investment in actor curation and institutional framework-setting at this stage delivers social returns that retroactive intervention cannot recover.

6.4.6. Sequence adoption incrementally as the ITRMP is designed for it

A final transferability principle that runs across all four modules is that the ITRMP does not require full deployment to deliver value. Each module can be adopted independently and at the pace that regional capacity allows. This modularity is a design feature that makes the platform accessible in lower-resource regulatory environments and in regions where political or institutional commitment to I-US is still being built.

New-adopter regions should sequence ITRMP adoption in line with their readiness: SMCO first to build the data foundation; IUSM next to support strategic siting and investment decisions; MATCH once actor data is sufficiently populated to support reliable matchmaking; and κ -SDSS from the earliest planning stage, since its FCM baseline survey is one of the lowest-cost and highest-return instruments available. Regions that attempt full simultaneous deployment without the underlying data infrastructure typically find that the outputs are too uncertain to be useful or defensible. Starting small, demonstrating value, and expanding incrementally is the approach that the EcoSite experience consistently validates.



7. Conclusion and Future Directions

This document provides PAs with a comprehensive roadmap for understanding, planning, and implementing I-US through the SYMSITES IT Regional Management Platform. Starting from the foundational concept of I-US as a mutually beneficial exchange of resources between urban areas and industrial facilities, and its integral alignment with EU Circular Economy Action Plan objectives, the guidelines have demonstrated how the ITRMP translates this strategic ambition into operational reality.

The four platform modules - SMCO for facility-level monitoring and optimization, IUSM for territorial potential mapping and scenario analysis, MATCH for resource matchmaking and market intelligence, and κ -SDSS for social impact simulation and policy support - together constitute an integrated decision support system that addresses the full governance lifecycle of I-US: from initial feasibility assessment and stakeholder engagement, through infrastructure planning and investment justification, to ongoing operational oversight and adaptive policy development.

The four EcoSites in Spain, Denmark, Austria, and Greece have validated this integrated approach under genuinely diverse industrial, social, and regulatory conditions, confirming that the platform delivers meaningful governance value across different European contexts.

The implementation of the ITRMP at the EcoSites generated a set of cross-cutting findings with direct implications for governance practice. Three stand out as particularly significant.

- (a) The **social dimension of I-US** cannot be assumed to emerge automatically from environmental or economic performance: configurations that maximize recycling rates or value-added flows can simultaneously allow health, social cohesion, and habitat quality to deteriorate, and PAs may benefit greatly from using the κ -SDSS to design I-US initiatives with deliberate social intent rather than assuming benefits will follow from technical efficiency alone.
- (b) **Network formation dynamics** are path-dependent and non-linear. A structural fork appears at around 10 to 20 participating firms, after which trajectories become self-reinforcing, making the formative phase of an I-US initiative the highest-leverage window for public policy intervention.
- (c) **Industrial mix quality**, that is the complementarity of waste streams and resource needs among participating actors, **determines the social performance ceiling** more decisively than network scale, meaning that curated, quality-focused network development consistently outperforms passive growth strategies.

These findings hold across all four EcoSites and across both the FCM and ABM simulation approaches, lending them robust empirical grounding that planners in other regions can draw on.

Looking ahead, the key priority for PAs wishing to act on these guidelines is to embed the ITRMP systematically into existing planning and governance cycles rather than treating it as a stand-alone project tool. Concretely, this means:

1. Investing in the **data infrastructure** prerequisite, that is populating the IUSM component library with verified regional data on waste streams, technologies, and actors, and establishing data-sharing agreements with industrial operators that give SMCO-generated operational data a defined role in environmental compliance reporting.
2. Institutionalizing IUSM **scenario analysis** as a standard step in circular economy strategy revisions and spatial planning processes, ensuring that I-US options are evaluated systematically alongside conventional approaches.
3. Using the κ -SDSS FCM baseline survey as a routine instrument for **assessing social readiness** before launching new I-US initiatives or significantly scaling existing ones.



4. Building the **multi-stakeholder co-governance structures** that the EcoSite evidence identifies as a prerequisite for durable I-US performance. The orchestrator role that monitors network sustainability, curates actor composition, and prevents lock-in into sub-optimal trajectories should be formally assigned within regional governance frameworks, supported by the co-modelling capability of the κ -SDSS, and adequately resourced over timescales that exceed individual political cycles.

The evidence from the EcoSites shows that the ITRMP works across genuinely different European contexts, and the governance insights it generates are transferable. Public Authorities that engage with it systematically, embedding its modules into planning cycles, establishing data-sharing agreements, and using it to inform both investment decisions and stakeholder dialogue, will be better positioned to deliver I-US initiatives that are technically sound, economically viable, and socially durable.

The platform is ready to step up with institutional commitment.



A Research and Innovation Agenda

This box is addressed to researchers, technical developers, and project evaluators. It summarizes open questions and development priorities identified through the SYMSITES EcoSite implementations. Public Authority readers focused on practical adoption may proceed directly to probe the ITRMP on their real world scene.

Monitoring and data infrastructure. EcoSite implementations highlighted persistent challenges in integrating heterogeneous data sources, ensuring sensor reliability, and managing seasonal variability in waste feedstocks. Continued investment in standardized IIoT protocols and AI-assisted anomaly detection within the SMC0 framework would substantially reduce these operational burdens for future adopters.

Territorial analysis and stakeholder matchmaking. Challenges were identified regarding the availability, consistency, and continuous updating of territorial, market, and stakeholder data, as well as the effective integration of analytical outputs into planning and decision-making processes. Strengthening data harmonization practices, improving data coverage, and ensuring systematic updating mechanisms are critical to enhancing the robustness and practical usability of the IUSM and MATCH modules.

Social simulation validation. The FCM and ABM components of κ -SDSS currently model social dynamics at a single point in time or over a defined simulation horizon. Longitudinal validation of simulated trajectories against actual social outcomes at the EcoSites as they mature would significantly strengthen the evidential basis for using these tools in high-stakes investment decisions.

Transferability beyond the EU regulatory context. The ITRMP was designed and validated within a European regulatory framework. Future development should prioritize adaptations that make the platform accessible in lower-resource regulatory environments, including simplified data entry pathways, multilingual interfaces, and modular deployment options that allow regions to adopt individual components incrementally.

Next-generation I-US models. As I-US evolves beyond its current industrial bias - towards city-led, community-centered symbiotic networks - the ITRMP will need to incorporate new actor typologies, urban metabolism data streams, and governance frameworks that reflect the growing role of municipalities as active co-designers and co-beneficiaries of circular resource flows at the urban scale.

