



SYMSITES

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

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List of Acronyms

Acronym	Definition
AC	Adsorption column
AI	Artificial intelligence
AMR	Antimicrobial-resistant
AnMBR	Anaerobic membrane bioreactor
BW	Biowaste
CECs	Contaminants of emerging concern
CSTR	Continuous-stirred tank reactor
HRT	Hydraulic retention time
HVNR	High value new resource
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
PHA	Polyhydroxyalkanoates
PVDF	Polyvinylidene fluoride
SRT	Solids retention time
SMCO	Smart Monitoring, Control, and Optimization
VFA	Volatile fatty acid
WW	Wastewater
WWTP	Wastewater treatment plant



Disclaimer

Deliverable D3.4 “Best Practice Guidelines for Public Authorities: needs and solutions for system implementation” is an intermediate deliverable of WP3 “The IT Based regional management platform (ITRMP)” within the SYMSITES project. This deliverable presents the initial structure and content of the guidelines document tailored for Public Authorities, 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. This document will be revised, expanded with new content and further improved during the implementation of the ITRMP at the EcoSites. The updated document will be submitted in May 2026 as deliverable D3.5 “Final report - Best Practice Guidelines for Public Authorities: needs and solutions for system implementation”.

Executive Summary

This guidelines document is tailored for Public Authority 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 is intended to guide through understanding I-US concepts, the benefits for Public Authorities, the structure and functionalities of the ITRMP, and the steps to integrate and govern the necessary data and systems to put the ITRMP at work in real-world I-US contexts.

It also aims to facilitate a smooth adoption and to provide the necessary support for all stakeholders involved in creating smarter, more resilient urban environments.

To this end we encourage to use the ITRMP to bridge the gap between technical implementation and public sector operational needs when coming to I-US conceiving, designing, planning, implementation, management, monitoring and evaluation.

This guideline document serves as a comprehensive roadmap to implement the ITRMP platform effectively, ensuring that industrial-urban symbiosis initiatives are integrated, sustainable, and aligned with both local and EU regulatory frameworks.

The document structure starts facilitating the role of Public Authorities in the rise and success of I-US; secondly, the technologies and architectures needed for I-US functioning are presented; secondly, this guide dedicates a separated statement to ITRM models and at what extend supports better decision making processes to Public Authorities; to continue, , there is a new section devoted to the assessment of Public Authorities, considering legal barriers, or the challenge of stakeholder engagement and coordination. The last sections are addressed to provide a first overview or best practices for implementing ITRMP and finally, guidelines and policy recommendations.

For further details or clarification, please refer to the accompanying technical documentation or contact the ITRMP project team.



1. Introduction

1.1. Purpose and intended audience of the Guidelines

This document aims to provide practical guidance to Public Authorities 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 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 IU-S into resource management and development strategies.

It is especially thought for Public Authority 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 Public Authorities 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 to explore 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.- Map of Content Table

Ch. 2	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 Public Authorities 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. 3	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. 4	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. 5	Addressing the needs of Public Authorities implementing an I-US	Outlines the Public Authorities 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. 6	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. 7	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

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

This chapter provides Public Authorities with an essential understanding of what Industrial-Urban Symbiosis (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.

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

2.1.1. Defining Industrial-Urban Symbiosis

In its most operational definition, industrial-urban symbiosis 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 valorisation 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.



2.1.2. 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, optimise 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 valorisation, hence fostering sustainable urban development over multiple dimensions.

The difference between industrial symbiosis and industrial ecology lies in the focus instead of the scale of the economy. Walmsley et al. (2019) state that the concepts of a circular economy, industrial ecology and Process Integration (Klemeš and Kravanja, 2013) are in line and equally important. However, the emphasis is slightly different, originating from other disciplines (e.g., chemical engineering, ecology, business) and viewing the same “problem” exists at different scales (e.g., processes, industrial, urban, regions).

The relationship between concepts including the circular economy as in (Ellen Macarthur Foundation, 2012), industrial ecology (Frosh and Gallopoulous, 1989), industrial (Jelinski et al., 1992) and urban symbiosis and Process/Total Site Integration is shown in Figure 2-1(own elaboration from Carcamo et al., 2022 ⁽¹⁾).

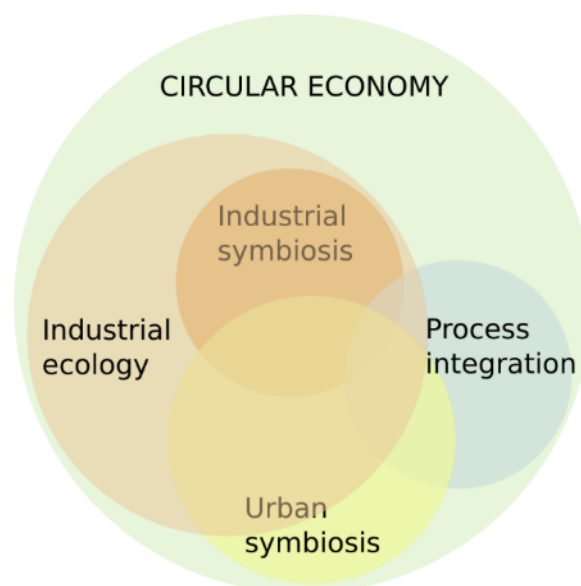


Figure 2-1.- I-US in Context

1 Cárcamo, Efrain A. Boom, and Rita Peñabaena-Niebles. "Opportunities and challenges for the waste management in emerging and frontier countries through industrial symbiosis." Journal of Cleaner Production 363 (2022): 132607. Doi: <https://doi.org/10.1016/j.jclepro.2022.132607>

2.2. 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 Public Authority.

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

- Urban areas providing 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.

2.2.1. Existing (and coming) models of I-US: a brief history and taxonomy

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.

The idea of the Eco-Industrial Park started to take off from the 1990s onwards. EIPs are usually more planned: the main idea is to design and develop industrial areas, either new or existing ones, based on industrial ecology principles, putting businesses together on purpose so that they can exchange resources and share utilities and services. EIP development often comes from a top-down approach, started or supported by government agencies (local, regional or national), development authorities or research institutions.

The governmental launch of the Japanese Eco-Town Programme in 1997 stepped up the evolution towards I-US. The programme, heavily budgeted, tried to solve Japan's problem of not having enough space for rubbish, while improving local economies, especially in areas where traditional industries were in decline, by encouraging environmental industries and recycling.

The Eco-Town Programme encouraged local governments to develop eco-friendly towns by working with local industries and residents: between 1997 and 2006, 26 areas across Japan were chosen as Eco-Towns.



The Eco-Town model directly encouraged of using not only industrial by-products, but also municipal solid waste (MSW) and commercial waste as inputs for industrial processes.

Fraccascia et Al., (2016) outlines the I-U S models from the "value" dimension, examining the concepts of value proposition, value creation, and value capture for "input replacement", "co-products generation", and "new products generation" ⁽²⁾. See **Error! Reference source not found..**

Table 2-1.- I-US Patterns

	Input replacement	Co-product generation	New product generation
Value proposition	Higher production efficiency (lower virgin input to produce output)	Business enlargement	Creation of new business
Value creation	Process innovation	Product innovation Process innovation	Product innovation Process innovation
Value capture	Lower production costs Better reputation from stakeholders	Gains from selling new products	Gains from selling new products

From another point of view, a "polity-centered" analysis of I-US highlights the roles, interests and institutional capacities of public actors (municipalities, regional governments, regulatory agencies and policy networks) in shaping industrial exchange networks. The city (or metropolitan region) becomes itself a political actor with tools - like regulations, incentives, planning mandates - that actively co-design or co-govern how industrial actors co-locate, exchange resources, and close material loops in cities. The focus is primarily on how governance structures, policy frameworks and public-sector capacities enable, constrain or steer urban symbiosis.

The governance criterion can be a pivot for a taxonomy of industrial symbiosis business models, and can be useful for understanding I-US, as in our elaboration from Fraccascia et Al., (2019) ⁽³⁾ in Figure 2-2.

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 potentially incentives (ICLEI Circulars,

2 Fraccascia, Luca, Maurizio Magno, and Vito Albino, "BUSINESS MODELS FOR INDUSTRIAL SYMBIOSIS: A GUIDE FOR FIRMS", Engineering Management, 2016.

3 Fraccascia, Luca, Ilaria Giannoccaro, and Vito Albino, "Business Models for Industrial Symbiosis: A Taxonomy Focused on the Form of Governance", Resources, Conservation and Recycling, Vol. 146, July 2019, pp. 114126.



RISE) ⁽⁴⁾. It will be very 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.

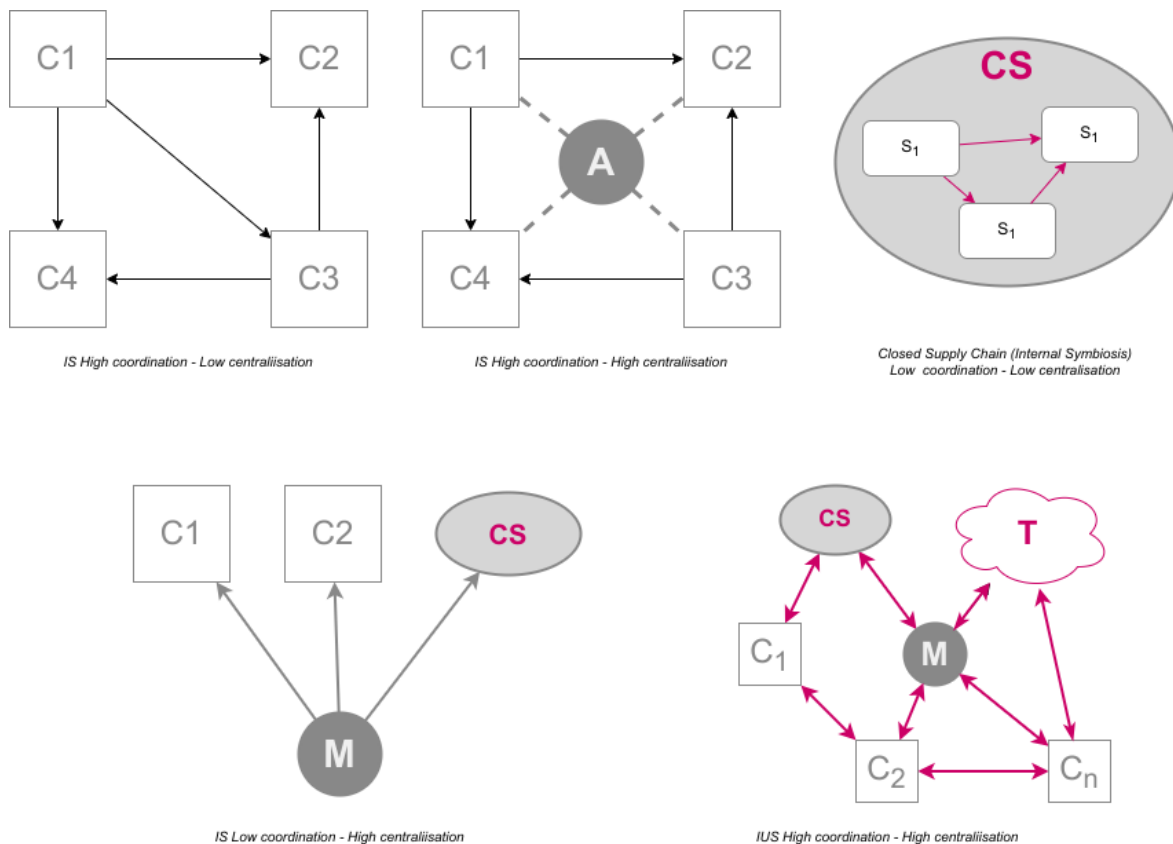


Figure 2-2.- A taxonomy of industrial and I-U S symbiosis business models from the governance dimension (our elaboration from Fraccascia et Al., (2019) ⁽⁵⁾).

2.2.2. The EcoSite I-US model

Technology model

The Symsites EcoSite technology model implements a modular, integrated anaerobic membrane bioreactor (AnMBR) platform designed for small-scale industrial-urban symbiosis. Each of these reactors is equipped with a mesophilic continuous-stirred tank reactor (CSTR) (~23 m³ working volume) that facilitates the co-digestion of mixed wastewater and organic solid waste, in a direct configuration with submerged membrane units for the purpose of biomass-liquid separation. The EcoSite configuration has been demonstrated to decouple hydraulic retention time (HRT) from solids retention time (SRT). This has been shown to maximize biogas yield, whilst simultaneously producing a high-quality permeate stream that is suitable for further reuse.

Key features of the technology model regard:

4 Chrysikopoulos, Stamatios K., Panos T. Chountalas, Dimitrios A. Georgakellos, and Athanasios G. Lagodimos, "Modeling Critical Success Factors for Industrial Symbiosis", Eng, Vol. 5, No. 4, December 2024, pp. 29022919.

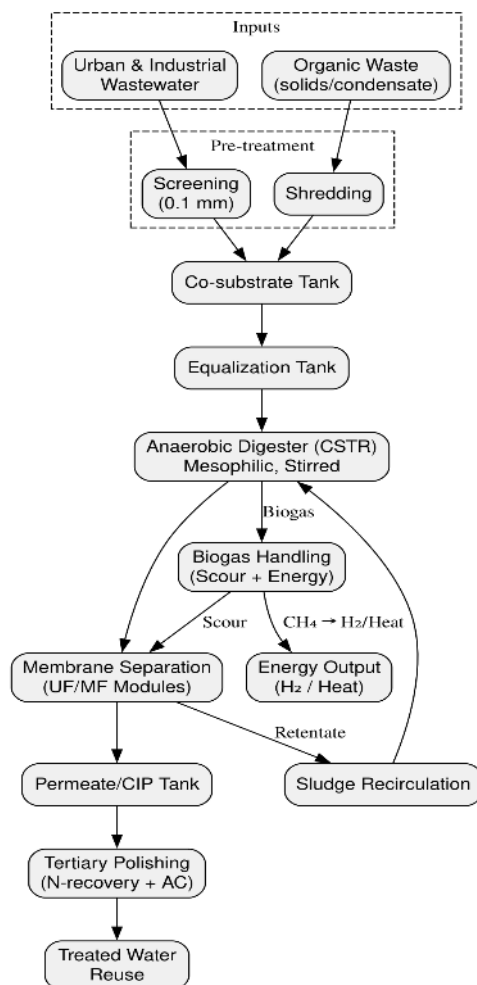


Figure 2-3.- I-US Flow

- Feedstock reception & pre-treatment
- Anaerobic digestion & membrane filtration
- Permeate polishing & biogas management
- Standardized instrumentation & turnkey deployment

An EcoSite accepts a combination of urban and industrial wastewater, plus source-sorted biowaste (e.g. food scraps, blood, brewery effluent, condensates). Raw inputs are first coarse screened via a rotary sieve (0.1 mm mesh) and, where relevant, shredded by a grinder. The resulting slurry is held in a co-substrate tank before being metered into a larger equalization or buffer tank, ensuring stable feed flows into the AnMBR.

The EcoSite maintains temperature ranges that are optimal for fermentation (35-42 °C) via internal heating devices, with continuous mixing and instrumentation for monitoring and control key parameters (pH/redox, temperature, and level). Digestate is recirculated to maintain sludge concentration, while permeate is drawn through submerged ultrafiltration or microfiltration modules (commercial hollow-fiber, tubular ceramic or PVDF - polyvinylidene fluoride flat-sheet ultrafiltration/microfiltration element in a flat-plate configuration) using lobe or spiral pumps.

Permeate is collected in a CIP-equipped tank and then subjected to tertiary treatment: membrane contactors recover ammonium sulphate and dissolved methane;

activated-carbon adsorption removes residual organics and pathogens. The outflows are:

- Clean water that can be recycled for industrial processes, irrigation, or cooling.
- Biogas (60 - 70% CH₄) serves dual purposes
 - as a scour gas in membrane modules to control fouling and
 - as an energy vector, being reformed to green H₂ (Spain), combusted for process heat (Austria/Denmark), or supplemented via dark fermentation for H₂/bioplastics (Greece).

Finally, the hallmark of the EcoSite technology model is standardized instrumentation and turnkey deployment.

The EcoSite model includes a harmonized monitoring plan - tracking COD, TSS, nutrients (NH₄⁺, PO₄³⁻), conductivity, flowrates, and gas composition (CH₄, CO₂, H₂, H₂S) - to ensure stable operations and data comparability.

A standardized instrumentation suite (level probes, flowmeters, pressure gauges, pH/redox probes, and biogas meters) ensures both compliance and performance monitoring.

The modular design (stainless-steel or HDPE tanks, or containerized assemblies like in the Austrian and Danish configuration) enables rapid deployment, scalability and straightforward replication across diverse European contexts.

Different flows

The EcoSite technology model has been designed to process a range of the most recurring urban and industrial waste streams: food waste, urban wastewater, industrial wastewater, industrial sewage from textile production, food production waste (meat processing, olive oil, beer brewing, and similar streams). The model is capable of yielding valuable marketable outputs: digested sludge, bio fertilizer, hydrogen, treated water, and biomethane. This configuration of flows facilitates and enables industrial-urban symbiosis, with inherent strengths in adaptability, environmental impact, and socioeconomic return, fostering a circular economy within an urban centered geographical area.

Technology + flow optimization = more circularity

To summarize from the point of view of the governance of circularity, the key advantage of the EcoSite concept comes from the context-bound configurability allowing synergistic integration of processes capable of handling the distinct characteristics of each input stream and optimizing the production of multiple valuable outputs.

2.3. Benefits of I-US for Public Authorities

Public Authorities 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 industrial-urban symbiosis 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 Public Authority 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 in 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 labour, 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. Public Authorities 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 Public Authorities 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 creates 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 fosters 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 Public Authorities 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, Public Authorities can change waste-related environmental problems into good political opportunities.

2.3.1. 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 Public Authorities 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 Public Authorities 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 Public Authorities 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 Public Authorities 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, Public Authorities 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.

Public Authorities 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, 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.

2.3.2. 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.

Optimizing energy use 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, Public Authorities implementing I-US can establish higher standards for waste and water management, triggering or reinforcing the environmental virtuous circle in the area.

2.3.3. Social and governance benefits

I-US offers significant social and governance benefits for Public Authorities 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 Public Authorities 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 Public Authorities, 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. Public Authorities 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 very 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.

Public Authorities are very 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. Public Authorities 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 Public Authorities with a tool to improve regulatory compliance and effectively achieve national and international sustainability and waste reduction targets.

Public Authorities 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, Public Authorities implementing I-US demonstrate leadership in environmental governance and contribute to achieving climate commitments.

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

Public Authorities 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.

2.4.1. 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.

2.4.2. Public Authorities as I-US coordinators

Public Authorities 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, Public Authorities 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 Public Authorities 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.



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

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

2.5.1. Key EU Policy and Regulatory Drivers

Several key EU policy 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 Public Authorities because it sets binding targets for member states regarding municipal waste recycling and preparing for reuse. Public Authorities, responsible for municipal waste management, are directly tasked with meeting these targets. Promoting I-US, becomes a preferred strategy for Public Authorities 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 Public Authorities 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: Public Authorities 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. Public Authorities 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. Public Authorities 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). Public Authorities can act as applicants, partners, or facilitators in accessing these funds, leveraging them to de-risk investments and accelerate 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.

2.5.2. How EU Frameworks Impact Public Authority Actions

The cumulative impact of these EU policy and regulatory frameworks on Public Authorities 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 Public Authorities.

Directives like the WFD and those on specific waste streams impose legal obligations and targets that Public Authorities 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 Public Authorities with models and guidance for implementing I-US.

Altogether, EU policy and rules have a big influence on how Public Authorities 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.

2.6. Issues on the table of I-US policymakers

Although the advantages of I-US are obvious, Public Authorities 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. Public Authorities 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 Public Authorities 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 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, Public Authorities 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 Public Authorities 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 Public Authorities 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.



3. 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 IUS's life cycle.

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

The SYMSITES project focuses on innovative technologies that enable resource recovery and promote industrial-urban symbiosis (I-US). This section highlights how various cutting-edge processes, such as anaerobic membrane bioreactors (AnMBR), adsorption column (AC) technology, pyrolysis systems, and side stream upgrade, contribute to transforming waste into HVNR.

AnMBR technology plays a fundamental role as an effective method for recovering resources (i.e., energy and materials) from urban wastewater and industrial effluents. SYMSITES improves this technology beyond the current state of the art by incorporating membranes with anti-fouling materials and magnetically induced vibration systems, which significantly improve membrane performance and reduce operating costs. By treating both wastewater (WW) and biowaste (BW), it recovers clean water and produces biogas, directly contributing to the I-US objectives for water reuse and decentralized renewable energy production. Furthermore, the study of new anaerobic metabolic routes, such as those involved in dark fermentation, can be adjusted to simultaneously maximize the yield of hydrogen and different types of volatile fatty acids (VFAs), which can then be valorized for bioplastics production.

The **AC** technology developed in SYMSITES enables the safe reuse of treated water by eliminating antimicrobial-resistant (AMR) bacteria and viruses, and contaminants of emerging concern (CECs). The integration of nano-enabled and biocompatible materials, such as lignin-based nanoparticles or carbon dots, into activated carbon improves compliance with legislative restrictions related to human health and environmental safety, which are critical to sustainable urban and industrial water cycles in I-US. This facilitates the use of treated effluents in urban areas, agriculture and other industries, promoting resource circularity and reducing freshwater extraction.

SYMSITES' **pyrolysis system** facilitates I-US by offering a viable pathway for the treatment and valorization of non-recyclable waste (NRW) streams. By converting complex waste fractions such as textiles into platform chemicals like benzoic acid and activated carbon, this technology closes the material cycle, diverts and avoids the disposal of NRW in landfills. This approach improves the value chain of waste by targeting on obtaining products.

Finally, **upgrading of side streams** is key to how SYMSITES facilitate I-US by transforming flows from AnMBR and pyrolysis into high-value new resources (HVNR):

- **Methane reforming to hydrogen production:** Protonic membrane reformers are designed with planar cells at an intermediate scale to end up in a more durable contact between the



electrode and the current collector and facilitate scaling-up of protonic membrane reforming technology, supporting energy recovery within I-US.

- **Polihydroxyalkanoates (PHA) production:** A two-stage biological process uses mixed microbial cultures to convert acidified fermentation effluents from dark fermentation into PHAs.
- **Nutrient recovery from AnMBR effluents:** Sulfide from AnMBR biogas is oxidized to sulfuric acid in a trickle-bed bioreactor. This acid enables recovery of ammonium sulfate via nanofiltration, generating valuable fertilizers and supporting material recovery within I-US.
- **Platform molecules from pyrolysis gases production:** Platform molecules like benzoic acid are recovered from condensable fractions of pyrolysis via liquid-liquid extraction using optimized solvents. Non-condensable gases (i.e., carbon dioxide, methane, hydrogen) are recirculated as an energy source for pyrolysis.
- **Carbon-rich solid char production:** The solid fraction of pyrolysis is rich in high molecular weight carbonaceous compounds. This char is activated and used for tertiary wastewater treatment, closing the loop between NRW and water systems in I-US.
- **Carbon-based dots production:** Charcoal from incomplete pyrolysis is used to synthesize carbon dots. These carbon dots are embedded in adsorption columns, acting as antibacterial and antiviral agents.

3.2. 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 Industrial-Urban Symbiosis (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.



4. The ITRMP Platform for I-US Implementation

4.1. 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.
- 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, considering economic and environmental aspects.

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

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

The IT Regional Management Platform (ITRMP) offers Public Authorities 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 (k-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.

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

Industrial-Urban Symbiosis represents a paradigm shift towards more sustainable urban, regional and industrial development, and Public Authorities 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.

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

Decision Support Systems (DSS) are digital tools created to help decision-makers navigate complex challenges - the kind that go beyond basic calculations or intuitive decision-making. Their main goal is to make decisions more informed and reliable by using data, smart analysis, and easy-to-use



interfaces. DSS help users compare different options, anticipate possible outcomes, and better understand how various parts of a system interact.

In the specific context of I-US, DSS can help PAs engaged in the following tasks.

- Analyze complex scenarios, that is model the flows of materials, energy, and waste between industrial and urban entities.
- Evaluate multi-dimensional, multivalued impacts, which implies assessing the potential consequences of different I-US strategies across environmental (e.g., emissions, resource depletion), economic (e.g., costs, job creation, market development), and social dimensions (e.g., community well-being, equity, employment conditions).
- Compare policy alternatives, evaluating the trade-offs associated with different site selections, technology choices, incentive structures, or regulatory frameworks.
- Manage uncertainty, exploring the potential outcomes of decisions under various future conditions or assumptions.
- Engage stakeholders, by providing a common platform and data-driven insights to facilitate dialogue and collaboration among diverse stakeholders.

The SYMSITES project's IT Regional Management Platform (ITRMP) DSS is specifically designed to foster and manage I-US implementation at the urban and regional level. It integrates several modules, each providing decision-making tools tailored to different facets of I-US.

A key component demonstrating the DSS capabilities for policymakers within ITRMP is the k-SDSS (Policymaking based on Social Factors) module, explicitly designed to help PAs understand and integrate the often-overlooked social dimension into I-US planning and assessment. It recognizes that I-US decisions occur under "deep uncertainty," where stakeholders may not agree on system workings, future likelihoods, or outcome importance.

Therefore, k-SDSS focuses on **exploratory modelling** using tools like Fuzzy Cognitive Mapping (FCM) and Agent-Based Modelling. It aims to generate plausible hypotheses about the social impacts of I-US proposals rather than providing definitive predictions or prescriptions. The k-SDSS acts as a "knowledge brokerage" tool, helping users interpret evidence, negotiate meaning between social and techno-industrial realms, and explore the consequences of potential interventions related to crucial social decision cases (e.g., facility siting, workforce development, benefit distribution). It empowers the PA user, ensuring they maintain control over decision strategies and ownership of outcomes.

4.2.3. 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, each offering specific functionalities relevant to PA decision-making.

4.2.3.a. IUSM (I-US Potential Map) aiming to supporting strategic planning.

This module serves as a strategic planning tool, enabling PAs to assess the **potential** for I-US development within their cities / regions. It helps evaluate the feasibility of transforming various waste



streams (like biowaste, wastewater, or non-recyclable waste) into High-Value New Resources (HVNR) by considering technological availability, economic viability, and environmental impacts.

IUSM core functionalities are:

1. **Component Library:** stores regional data on potential I-US elements: waste, HVNRs, available technologies, transport options, markets, and existing entities/work centres (categorized by roles like waste generator, technology holder, etc.).
2. **Scenario Configuration:** allows PAs to define and configure specific I-US scenarios for analysis. Scenarios can be based on selecting geographical areas (e.g., municipalities) or specific work centres within the region. Users (politicians, PA officials, planning professionals and researchers) define the roles each entity plays within the scenario (e.g., waste generator, technology holder, HVNR consumer, transport provider).
3. **Potential Analysis:** calculates key indicators for configured scenarios, including environmental impacts (Carbon Footprint, Water Depletion) and overall economic balance. It helps compare different scenarios to identify the most promising strategies and geographical areas for I-US implementation.

4.2.3.b. MATCH (Smart Matchmaking) to facilitating synergies

While primarily aimed at connecting businesses, the MATCH module offers PAs valuable insights into the urban / regional market dynamics and the practical feasibility of forming symbiotic links. It helps to visualize and understand potential collaborations between key actors.

MATCH core functionalities are:

1. **Stakeholder Database:** contains information on verified companies (entities/work centres) that have agreed to participate, detailing their roles, capacities, locations, and potentially pricing for wastes/HVNRs.
2. **Matchmaking Analysis:** enables searches to connect compatible partners based on their roles. Key matchmaking pairs include Waste Generators seeking Technology Holders, and Technology Holders seeking HVNR Consumers (or vice-versa).
3. **Filtering :** users can filter potential matches based on criteria like capacity, material quality (e.g., waste characteristics, HVNR purity), geographical distance, and price.

4.2.3.c. k-SDSS: 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.

k-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.

4.2.3.d. **SMCO (Smart Monitoring, Control and Optimisation): Overseeing Operations**

While primarily designed for the operators of waste/resource valorization facilities, the data and insights generated by SMCO can be indirectly relevant for PAs involved in regulation, compliance monitoring, or performance tracking of I-US related infrastructure, as it provides tools for managing the lifecycle of these facilities.

SMCO core functionalities include tools for registering facility processes, monitoring real-time operational data, process start-up and traceability, setting up alerts for deviations, and using predictive models for optimization.

4.2.4. **Data Governance and Security Considerations and Challenges**

This section provides considerations taken into account in the ITRMP to ensure data quality, consistency, and security.

Data Management Rules

With the aim of ensuring consistent, secure, and reusable practices throughout the data lifecycle, the following considerations are considered:

1. **Develop a data strategy:** A technical data strategy should be established; this allows to define not only the data the system needs for the different stakeholders' needs, but also that how data is managed, structured, and used in existing systems. This strategy should include decisions on data formats, storage structures, integration mechanisms, and basic quality and interoperability criteria. Its main objective is to ensure that data is organized in a consistent manner and is accessible and reusable for different technical and operational processes.
2. **Define data collection procedures:** Detailed procedures should be established for data collection. This involves a complete description of the data collected, including its types, formats, and sources. A structured plan should be developed that defines how data is acquired, retrieved, and stored in a secure and consistent manner.
3. **Define data sensitivity and classification:** A formal classification of data sensitivity should be implemented, categorizing data according to its level of confidentiality (e.g., public or confidential). This classification allows for differentiated treatment and specialized handling procedures, ensuring adequate protection and risk mitigation.
4. **Define data documentation:** Standardized documentation protocols, should be defined to ensure the interpretability and reusability of data. This promotes long-term use and sound governance of data assets.



5. **Establish data storage and security:** Secure storage solutions should be adopted to prevent security breaches, loss, or unauthorized access. This includes encryption, access control, and audit logs to ensure data integrity and availability.
6. **Set data sharing and access policies:** Clear policies should be established on how information is shared, including the use of standardized methods to improve efficiency. Secure communication channels should be defined for data transfer to maintain privacy and integrity. Data exchange mechanisms, especially APIs, should comply with recognized standards such as RESTful APIs, and OPC UA (IEC 62541) for industrial automation. These standards promote interoperability and reproducibility by enabling structured, machine-readable access to data between systems and stakeholders.

Security Measures

Privacy, data security, and data-sharing protocols represent essential cornerstones of digital data management in the ITRMP system. To ensure secure and legally compliant data exchange, the system integrates encryption mechanisms (most notably the use of Hypertext Transfer Protocol Secure) to encrypt the traffic between the front-end and back-end. This approach effectively prevents unauthorized interception and manipulation during data transmission across networks.

Moreover, access to data is strictly managed through Role-Based Access Control security model, supported by standardized delegated access protocols such as OAuth 2.0. These measures help ensure that only authorized personnel, based on predefined roles and responsibilities, can access sensitive information, thereby significantly reducing the risk of unauthorized exposure.

While data ownership is retained by the user, the ITRMP system facilitates structured and controlled data sharing with industrial partners through pre-established agreements. This enables collaborative data use while preserving public accountability and legal compliance.

Challenges

Data governance often arises in environments where digital transformation intersects with complex operational and regulatory environments. The **Error! Reference source not found.** below illustrates some of the key challenges encountered in practice, along with possible approaches addressed within the ITRMP.

Table 4-1.- 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).
Secure delegated access to data	Utilize standardized protocols such as Oauth 2.0 to support delegated access control



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

The ITRMP platform offers Public Authorities 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.

4.3.1. 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 k-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 k-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: k-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.

4.3.2. 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's component library 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 k-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 k-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 k-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 k-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: While the SMO module is primarily for facility operators, if PAs have regulatory access to certain aggregated or anonymized data (e.g., overall resource throughput, emission levels from key facilities), it could provide up to date insights into the



operational health of the regional I-US system, allowing for faster identification of systemic issues requiring PA attention.

4.3.3. 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 k-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 k-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, k-SDSS), and simulation results addressing specific social concerns (k-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 k-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 k-SDSS promotes clearer communication about complex I-US issues, reducing misunderstandings among stakeholders and between PAs and the public.



5. Assessment of Public Authorities' Needs in I-US Implementation

As presented in Section **Error! Reference source not found.**, Public Authorities 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 Public Authorities 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.

5.1. Identification of Key Challenges

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 Public Authorities encounter when implementing I-US projects.

5.2. Technical and Economic Challenges

5.2.1. Lack of real-time data and monitoring tools

Public Authorities 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 Public Authorities 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 Public Authorities to engage in more robust, evidence-based I-US 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.

5.2.2. Economic viability of I-US initiatives

Public Authorities 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 developed 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.

5.3. Legal and Regulatory Barriers

5.3.1. 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.

Public Authorities 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 k-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 k-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.

5.4. Challenges for public engagement and stakeholder coordination

5.4.1. Low Coordination and fragmented communication between Stakeholders

Public authorities 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 public authorities 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 k-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 public authorities and businesses. Through this combined technological and strategic support, the platform contributes to embedding industrial-urban symbiosis into regional development pathways.



5.4.2. 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.

Public authorities 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.

5.4.3. 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.

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

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

Public Authorities 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 k-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.



6. Solutions and Best Practices for implementing the ITRMP

This section will be revised, expanded with new content and further improved during the implementation of the ITRMP at the EcoSites.

This section provides practical solutions for Public Authorities 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

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

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

6.1.1. Defining SMCO's in I-US implementation

In the ITRMP solution, the SMCO module acts as processes monitoring and control system for valorization processes, integrating IIoT sensors and other data sources to collect and analyze data on resource flows such as waste, water and energy. Within the I-US implementation, it is intended for internal use at the facility, improving production traceability, enabling the simulation and optimization of operations, and structuring data to support more effective and informed management.

6.1.2. Why SMCO is important for Public Authorities

The SMCO module provides indirect support to public authorities 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.

6.1.3. Enabling real-time and heterogenous data monitoring and control of industrial processes

SMCO facilitates real-time data integration as well as data gathering from other no-IIOT data sources (i.e. lab. Instruments) and control across industrial systems. While **Error! Reference source not found.** highlights how Public Authorities can benefit through improved oversight and data-driven coordination, the module is ultimately applied at the facility level, where it enables more efficient, responsive, and adaptive process control.

Table 6-1.- 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).
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	Improves the effectiveness of public sector promoted initiatives.



SMCO Feature	Function	Public Sector Benefit
	implementation of solutions driven by public sector initiatives and strategies.	
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.

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

The IUSM module is designed to help users, including Public Authorities, 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.

6.2.1. 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.

6.2.2. 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 Public Authorities 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.

6.2.3. 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 **Error! Reference source not found.** exemplifies how Public Authorities 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 6-2.- 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 public authorities 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 public authorities in decision-making and the proposal of sustainable management strategies.

6.3. Facilitating Smart Matchmaking (MATCH) for Resource Optimization

This section describes how the MATCH module supports Public Authorities 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.

6.3.1. 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.

6.3.2. 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 Public Authorities as it facilitates contact between actors with the potential to carry out I-US activities.



6.3.3. 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, public authorities 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 **Error! Reference source not found.** exemplifies how municipalities can benefit from using MATCH module.

Figure 6-1.- 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.	Helps Public Authorities to identify niche in the industrial and urban symbiosis in a region.

6.3.4. 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.

6.3.5. 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.

Therefore, κ-SDSS is not designed to provide definitive predictions but rather to support exploration and understanding, that is to help ask new, meaningful questions. This is implemented through:



- 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. While not "AI" in the sense of deep learning, these simulation engines 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-U S 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 (labour / employment indicator, value added).

6.3.6. 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 on 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, labour 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 designing I-US projects and accompanying policies that actively promote social equity and contribute positively to the well-being of the entire community.

6.3.7. 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.

6.3.8. 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 below exemplifies how PAs can benefit from using κ -SDSS

Table 6-3.- 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	Analyse 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





κ-SDSS Feature	Function	Public Sector Benefit
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



7. Case Studies and Pilot Applications

This section will be revised, expanded with new content and further improved during the implementation of the ITRMP at the EcoSites.

This version is addressed to present the preliminary key findings in terms of I-US technology processes and in Governance Models, drawing also the transferability potential of SYMSITES' IT solutions.

7.1. 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](#).

7.2. 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. Findings and lessons learned will be tagged as follows:

- **Data Integration and Information Management:** Data interoperability, data quality and reliability of data sharing/collaboration.
- **System Design and Functionality:** User interfaces, scenario planning and simulation capabilities, real-time monitoring, flexibility, adaptability and scalability.
- **Implementation:** Users' engagement and support, feedback from pilot demonstration sites, embedding legal and regulatory frameworks.
- **Unexpected events and factors**

This section will be revised, expanded with new content and further improved during the implementation of the ITRMP at the EcoSites.



7.2.1. Key Findings and Lessons Learned from the 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 non-recyclable waste (NRW) from the textile sector, are valorized to obtain a range of high-value new resources (HVNR), as shown in Figure 7-1. 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 or industrial energy use, treated water for textile dyeing processes or agricultural irrigation, and digested sludge for fertilizer. Additionally, textile waste classified 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 textile industry.

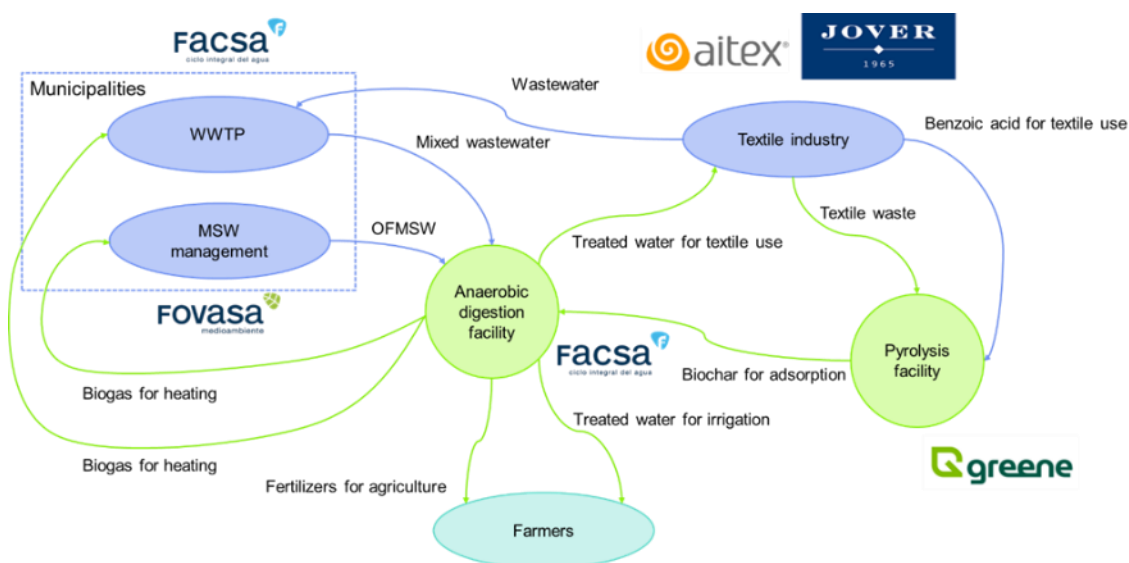


Figure 7-1. Spanish EcoSite diagram: Dark blue represents waste generation⁵

It 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 (AITEK) - Manager of the project
- FRANCISCO JOVER SA (JOV) - Textile industry
- GERMAINE DE CAPUCCINI SAU (GERM) - Cosmetics industry
- KATHOLIEKE UNIVERSITEIT LEUVEN (KUL) MMV - System builder

This section will be updated in a follow up version of this document with the key findings and lessons learned about the ITRMP from the Spanish EcoSite.

⁵ Green indicates waste valorization; light blue denotes consumers. 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.

7.2.2. Key Findings and Lessons Learned from the 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, organic waste from the brewing industry, municipal wastewater, and the organic fraction of municipal solid waste is valorized to obtain a variety of High-Value New Resources, as illustrated in Figure 7-2. The core technology employed is an AnMBR to produce biogas, that has the potential to be used in industrial heating processes, particularly within the brewery. 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 pre-treatment with grinders and filters, biological conversion in bioreactors, and membrane-based filtration systems for water purification.

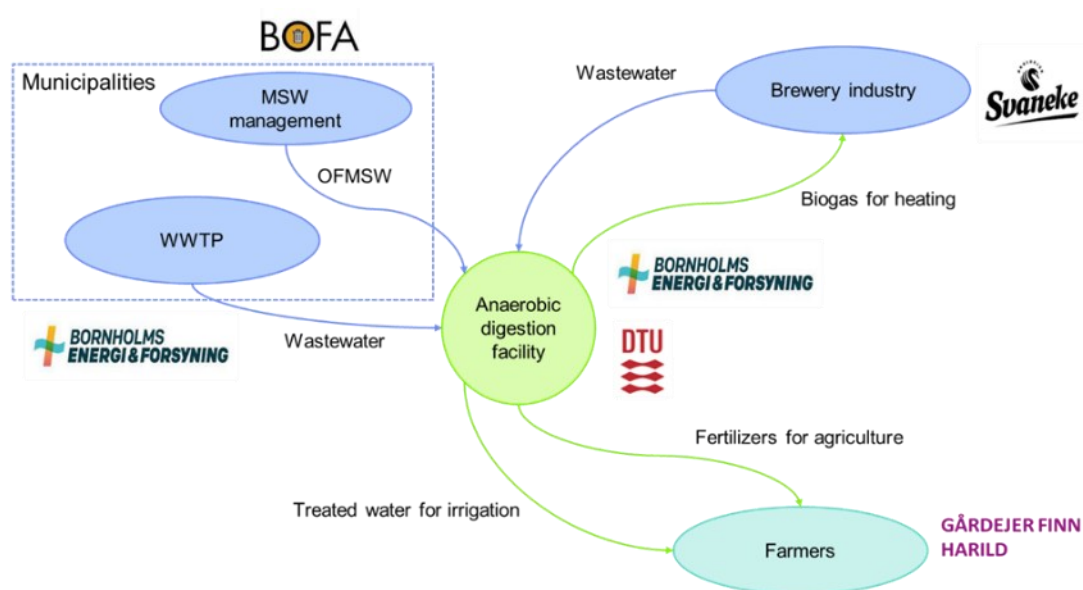


Figure 7-2. Danish EcoSite diagram: Dark blue represents waste generation; green indicates waste valorization⁶

It 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

This section will be updated in a follow up version of this document with the key findings and lessons learned about the ITRMP from the Danish EcoSite.

⁶ Light blue denotes consumers. 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.

7.2.3. Key Findings and Lessons Learned from the EcoSite in Austria

The Austrian EcoSite is in the town of Sieghartskirchen, within the south-eastern Tullnerfeld area. At the pilot plant facility, organic waste from the meat industry and the urban context are valorized through advanced valorization technologies to obtain a variety of HVNR, as illustrated in Figure 7-3. Anaerobic digestion is the main technology used to convert wastewater and biological waste into biogas, which is used as a renewable energy source. Additional processes include flotation for waste pre-treatment and advanced membrane ultrafiltration and nanofiltration for water purification, allowing the treated water to be reused in industrial processes or irrigation. Furthermore, the ammonium presented 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.

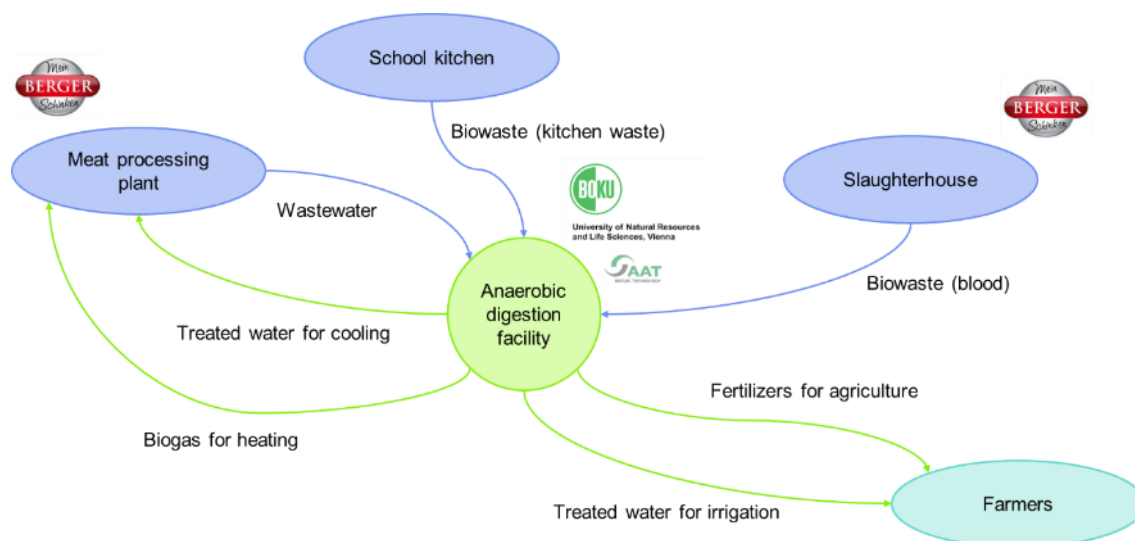


Figure 7-3. Austrian EcoSite diagram: Dark blue represents waste generation⁷

It 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.

This section will be updated in a follow up version of this document with the key findings and lessons learned about the ITRMP from the Austrian EcoSite.

7.2.4. Key Findings and Lessons Learned from the 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 is valorized through advanced recovery technologies to obtain a variety of HVNR, as illustrated in

⁷. Green indicates waste valorization; light blue denotes consumers. In the case that a waste generator is also a product consumer, the diagram highlights their role as a generator.

Figure 7-4. The main technological processes include the pretreatment of food waste using mechanical methods for subsequent dark fermentation and anaerobic membrane bioreaction, which enable the transformation of waste into hydrogen and biogas. Additional processes include membrane filtration to produce treated water and fertilizers suitable for local farmers. Furthermore, olive stone waste is subjected to pyrolysis to produce biochar, which may be used within the adsorption columns for tertiary water treatment.

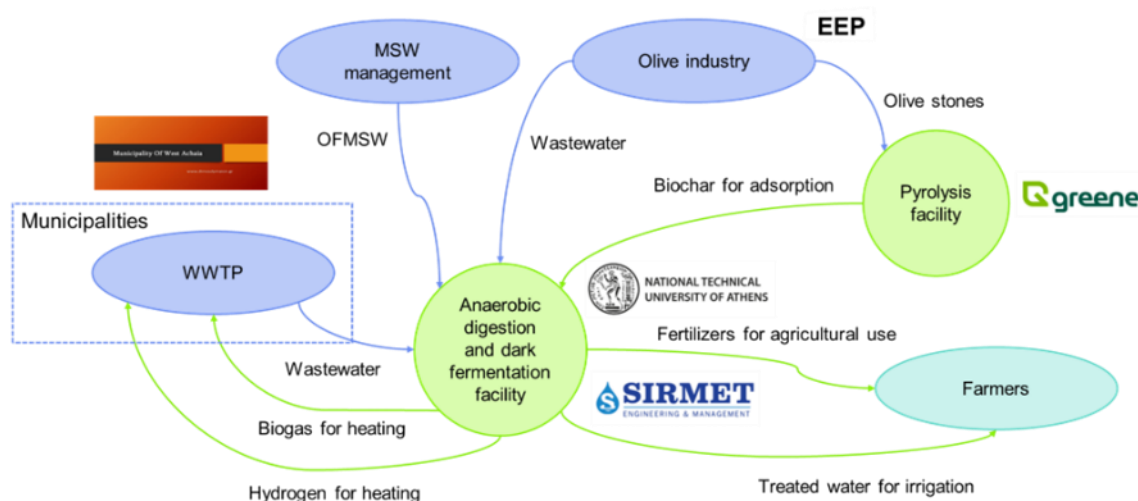


Figure 7-4. Greek EcoSite diagram: Dark blue represents waste generation⁸

It 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

This section will be updated in a follow up version of this document with the key findings and lessons learned about the ITRMP from the Greek EcoSite.

7.2.5. Cross-Site Comparison

This section will provide a comparative analysis between EcoSites, paying attention to the following aspects:

- Key points about the SYMSITES I-US model
- Key points about the SYMSITES technologies
- Key non-technical issues about SYMSITES EcoSites' implementation
- Common challenges faced across EcoSites, along with related solutions and best practices

This section will be revised, expanded with new content and further improved during the implementation of the ITRMP at the EcoSites.

⁸ Green indicates waste valorization; light blue denotes consumers. 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.

7.3. Key Findings in Governance Models and Policy Recommendations

This chapter is intended to provide a basic guide for Public Authorities on how to create effective governance frameworks and policy recommendations that support the implementation of I-US. It is based on the outcomes from the EcoSites implementation practices and experiences.

The focus is on how decision-making frameworks, data governance, and public-private partnerships may be developed, as well as how non-technological barriers and social-parties engagement can be dealt with, focussing on how the ITRMP can be used and contributes to these objectives.

For this reason it will come in the next updated edition.

This part will be shaped to inform best practices from the implementation experiences, advancements and concrete outcomes emerging from field implementations at the EcoSites.

A significant area will be the operationalization and refinement of decision-making frameworks put in place and how and to what end the ITRMP was possibly used as a "compass" for stakeholder coordination and a "scaffold" for transparent governance.

For instance how the EcoSite will have used the ITRMP's capacity to define stakeholder roles, allowing for the creation of adaptive templates that reflect diverse local contexts. Furthermore, the ambition to use ITRMP modules like IUSM and k-SDSS for data-driven policy development will become fully realized when populated with real-world data from the EcoSites. This will allow for more accurate analysis of economic and social impacts, leading to policies that are not just evidence-based in theory but proven in practice.

The development and nurturing of effective Public-Private Partnerships is also a key area for feeding the guidelines with the advancement based on EcoSite learnings, sifting through and capitalising on how different PPP models perform across the varied EcoSite contexts.

For example, the guideline to "offer tax incentives, grants, or subsidies for industries adopting I-US" will be refined by understanding which specific incentives were planned or deemed to most effectively "[encourage] business participation in circular economy" for different types of industries and at different stages of I-US development in each EcoSite. This practical feedback will be included in the guidelines for the design of targeted and efficient decision support.

Furthermore, the call to "facilitate collaborative research and innovation hubs" will gain practical substance through the EcoSites. The experiences from EcoSites will help recognise practices that are not just repositories of intentions but true examples of collaborative innovation, tailored to the specific needs and capacities of the regions.

Finally, getting the knowledge on how the EcoSites adapted to the legal frameworks for resource exchange will be the proving ground for the relevant best practices, highlighting practical challenges and solutions, like liability in shared infrastructure or ensuring fair value distribution in symbiotic exchanges. These on-the-ground experiences will be crucial for developing the practical side of the guidelines, so to make really usable in several diverse contexts as a strong strategic compass public authorities planning and implementing I-US. The real journey begins as the EcoSites generate tangible outcomes, practical experiences, and valuable lessons.





7.4. Transferability of Best Practices to Other Regions

Capitalizing on the experience gathered from the pilot EcoSite demonstration sites, this section will provide a roadmap for municipalities looking to implement or adapt the lessons learned and best practices to their I-US settings. The transferable practices identified will be documented and organized through a simple taxonomy for easy consultation by Public Authorities.

This section will be revised, expanded with new content and further improved during the implementation of the ITRMP at the EcoSites.

