



SYMSITES

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List of Abbreviations and Acronyms

Abbreviation	Definition
AI	Artificial Intelligence
BAT	Best Available Techniques
CAPEX	Capital Expenditure
CE	Circular Economy
CEAP	Circular Economy Action Plan
EDA	Exploratory Data Analysis
EU	European Union
GPP	Green Public Procurement
HVNR	High-Value New Resources
IED	Industrial Emissions Directive
IoT	Internet of Things
IS	Industrial Symbiosis
ITRMP	IT Regional Management Platform
I-US	Industrial-Urban Symbiosis
KPIs	Key Performance Indicator(s)
LCA	Life Cycle Assessment
LRAs	Local and Regional Authorities
MFA	Material Flow Analysis
MSW	Municipal Solid Waste
SMEs	Small and Medium-Sized Enterprises
TRL	Technology Readiness Level
WFD	Waste Framework Directive





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1. Abstract

This report presents the training materials developed within the SYMSITES project to support the understanding and implementation of Industrial-Urban Symbiosis (I-US). The training aims to equip local and regional authorities, industries, and small and medium-sized enterprises (SMEs) with the knowledge, tools, and practical guidance needed to facilitate circular resource exchanges between urban systems and industrial activities.

The training programme consists of ten online modules that guide learners from the basic concepts of the circular economy and I-US to the practical implementation and monitoring of symbiotic initiatives. The first two modules introduce the concept of I-US and relevant European policy and funding frameworks for a general audience. Modules three to seven focus on local and regional authorities, addressing governance, regulatory and economic aspects, stakeholder engagement, resource and waste-stream mapping, strategic planning, and performance monitoring. The final three modules target industries and SMEs, presenting technological solutions for waste valorisation, legislative requirements for wastewater reuse, and digital tools that support monitoring, optimisation, and decision-making in industrial-urban systems.

Together, the training materials provide a comprehensive capacity-building resource that integrates policy context, governance approaches, technical solutions, and digital innovation to equip a vast array of actors to implement I-US in other regions in EU.

2. Executive Summary

This report presents an overview of the training materials developed within the SYMSITES project to support stakeholders in understanding and implementing I-US and the SYMSITES innovations within their regions. I-US is a collaborative approach in which industries, municipalities, utilities, and other local actors exchange materials, energy, water, and by-products so that the output of one process becomes the input of another. The training materials aim to build the knowledge and practical capacities required for both public authorities and industrial actors to initiate and scale symbiotic collaborations within their territories.

The training programme is structured into ten modules that progressively guide learners from conceptual understanding to practical implementation. The first two modules introduce the principles of the circular economy and the concept of industrial and industrial-urban symbiosis, explaining how these approaches address major sustainability challenges while creating economic opportunities. They also present the European policy and funding landscape, highlighting how EU strategies, legislation, and programmes support the development of circular and resource-efficient industrial systems.

Modules three to seven are specifically designed for local and regional authorities, recognising their pivotal role in enabling I-US. These modules explore how municipalities can integrate symbiosis into urban planning and development strategies, mobilise stakeholders, address regulatory and financial challenges, and create supportive governance frameworks. Practical guidance is provided on stakeholder engagement, resource and waste-stream mapping, and the identification of potential synergies between urban services and industrial activities. The training also addresses the operational and technical aspects required to implement I-US initiatives. Modules focus on



developing circular economy strategies, designing governance and business models, and monitoring performance using key indicators and life-cycle assessment approaches.

The last three modules target industries and SMEs, presenting innovative technologies for waste valorisation, methods to convert by-products into high-value new resources, and strategies for integrating recovered materials into markets and supply chains. The programme further covers legislative requirements for wastewater reuse and the importance of risk management and regulatory compliance. Finally, the training highlights the growing importance of digital tools and data integration for managing complex industrial-urban systems. Digital platforms, sensors, and real-time data processing enable improved monitoring of resource flows, predictive decision-making, and adaptive management of symbiotic exchanges. These tools support transparency, operational efficiency, and collaboration between industrial and municipal actors.

Overall, the SYMSITES training materials provide a comprehensive capacity-building resource that combines policy context, governance guidance, technical knowledge, and digital innovation.

3. Objectives

The objective of this deliverable is to present the training materials developed within the SYMSITES project to support the understanding and implementation of I-US. The training aims to build the knowledge and practical capacities of key stakeholders, particularly local and regional authorities, industries, and small and medium-sized enterprises (SMEs), to facilitate the transition toward circular and resource-efficient urban–industrial systems.

More specifically, the training materials pursue the following objectives:

- Increase awareness and understanding of I-US by introducing the principles of the circular economy, industrial symbiosis, and the benefits of integrating urban and industrial resource flows.
- Explain the European policy and regulatory framework relevant to I-US, including strategies, legislation, and funding opportunities that enable circular economy initiatives.
- Strengthen the capacity of local and regional authorities to act as facilitators of I-US by integrating symbiosis into urban planning, economic development, and sustainability strategies.
- Provide practical guidance for implementation, including stakeholder engagement, resource and waste-stream mapping, identification and prioritisation of synergies, and the development of governance and business models.
- Introduce technological and operational solutions for waste valorisation and the production of high-value new resources from industrial and urban by-products.
- Support monitoring, evaluation, and continuous improvement of I-US initiatives through performance indicators, digital tools, and data-driven decision-making.
- Promote the replication and scaling of I-US initiatives by sharing practical examples, methodologies, and tools that can be applied across different regional and industrial contexts.

Through these objectives, the training materials contribute to strengthening stakeholder capacity, enabling more effective collaboration between urban and industrial actors, and supporting the broader transition toward circular, low-carbon, and resilient regional economies.



4. Description of the work

Below is an overview of the content of each module. The training materials, developed as online pdfs, are accessible through the specified links.

Module 1: What is I-US?

Module 1 introduces Industrial-Urban Symbiosis (I-US) and its vital role in advancing the circular economy. It explains how collaboration between industrial sectors and urban systems can optimize resource use, reduce waste, and generate shared environmental, economic, and social benefits. The module is structured into four chapters covering foundational concepts, practical examples, and benefits for stakeholders.

This module can be accessed here: <https://symsites.eu/wp-content/uploads/2026/03/SYMSITES-Training-Material-Module-1.pdf>

Chapter 1.1: Introduction to the Circular Economy

Chapter 1.1 establishes the theoretical and conceptual foundation of the circular economy (CE). It contrasts CE with the traditional linear economic model characterized by the “take-make-dispose” logic, where natural resources are extracted, transformed into products, and ultimately discarded as waste. This linear paradigm has proven environmentally unsustainable and economically inefficient due to its dependence on finite resources and its generation of pollution.

The circular economy is presented as a systemic and regenerative economic model built upon three fundamental principles: eliminating waste and pollution, circulating products and materials at their highest possible value, and regenerating natural systems. Rather than focusing solely on waste management, CE redesigns production and consumption systems to prevent waste generation at the source. It aims to decouple economic growth from resource extraction and environmental degradation while remaining within planetary boundaries. In doing so, CE contributes to resilience, innovation, employment creation, and long-term prosperity.

Several conceptual frameworks support the CE model. The Ellen MacArthur Foundation popularized the Butterfly Diagram, which visually distinguishes between two material cycles. The technical cycle manages non-biological materials through reuse, repair, remanufacturing, and recycling to retain material value. The biological cycle focuses on biodegradable materials that safely return to the biosphere through composting or anaerobic digestion. Together, these cycles illustrate how value retention strategies can significantly reduce resource input and waste output.

Another influential framework is Doughnut Economics, developed by Kate Raworth. This model conceptualizes a “safe and just space for humanity,” bounded internally by social foundations (such as health, education, and equity) and externally by ecological ceilings (such as climate stability and biodiversity preservation). Economic systems must operate within these dual constraints to ensure both social well-being and environmental sustainability.

The chapter also introduces the 9R Framework, which ranks circular strategies according to their effectiveness in preserving value. The hierarchy prioritizes preventive strategies such as Refuse, Rethink, and Reduce, followed by life-extension strategies such as Reuse, Repair, Refurbish, and Remanufacture. Lower in the hierarchy are material recovery options such as Recycling and energy



Recovery. This prioritization underscores that recycling, while important, is less impactful than strategies that prevent material use in the first place.

The circular economy is framed as a strategic response to the Triple Planetary Crisis: climate change, biodiversity loss, and pollution. Current economic systems are exceeding planetary boundaries, destabilizing Earth systems critical for human survival. By redesigning production and consumption patterns, CE offers integrated solutions that address emissions reduction, resource conservation, and ecosystem regeneration simultaneously.

Chapter 1.2: Introduction to Industrial Symbiosis and Industrial-Urban Symbiosis

Chapter 1.2 transitions from macroeconomic theory to applied practice by introducing Industrial Symbiosis (IS). IS is defined as a collaborative business model in which companies exchange resources (such as waste streams, by-products, excess energy, water, or materials) so that the output of one process becomes the input of another. This approach increases resource efficiency and transforms waste management into value creation.

Industrial symbiosis generates multiple categories of benefits. Operationally, it improves process efficiency and logistics coordination. Financially, it reduces disposal costs, lowers raw material expenditures, and can generate new revenue streams. Environmentally, it decreases greenhouse gas emissions, reduces virgin resource extraction, and minimizes landfill use. The growth of IS has been supported by evolving European Union policies, advancements in digital and resource-matching technologies, and increasing corporate sustainability commitments.

The chapter then expands this concept into I-US, which integrates industrial symbiosis within the broader urban ecosystem. Unlike traditional IS, which primarily connects firms within industrial clusters, I-US incorporates municipalities, public utilities, local authorities, and research institutions. This broader integration addresses **territorial metabolism**, the total flow of energy, water, materials, and waste within a defined urban-industrial area.

I-US is characterized by structured multi-actor collaboration. Municipalities play a coordinating role by aligning infrastructure planning, spatial development, and regulatory frameworks. Utilities act as intermediaries connecting industrial processes with urban service systems, particularly in energy and water management. Research institutions contribute technical expertise and innovation capacity. Through these coordinated efforts, I-US enhances resource matching, strengthens local value chains, and maximizes environmental performance.

Importantly, I-US functions not only as a technical mechanism for material exchange but also as a governance model. It fosters resilient local economies by embedding circular principles into urban planning and industrial strategy. This territorial approach ensures that environmental benefits are amplified at scale while economic value remains within the region.

To operationalize collaboration, **I-US Hubs** are introduced as trusted facilitation platforms. These hubs cultivate long-term relationships among stakeholders, build trust, and support matchmaking between resource providers and users. By reducing informational and institutional barriers, hubs enable symbiotic exchanges that might otherwise remain unrealized.

Chapter 1.3: I-US examples



This chapter presents practical examples of I-US from different regions and sectors, illustrating how urban and industrial actors can collaborate to optimize resource flows, reduce waste, and enhance overall efficiency. It includes the well-established case of Kalundborg in Denmark, a global reference for industrial symbiosis, as well as the EcoSites developed under the SYMSITES project. Each EcoSite demonstrates unique approaches to circular resource management, including energy recovery, material reuse, and water recycling, highlighting the diversity of I-US models and their applicability across contexts.

For each EcoSite, the chapter provides a comprehensive overview featuring a schematic image of resource flows, descriptions of the site, and the partners involved in the SYMSITES project. It outlines the challenges faced by the local industries and municipalities, the solutions implemented to enable symbiotic exchanges, and the new added-value products generated, such as biogas, fertilizers, recycled materials, or district heating. The chapter also emphasizes the tangible benefits of I-US, including reduced landfill disposal, lower greenhouse gas emissions, economic gains for participating firms, and enhanced municipal service efficiency.

Chapter 1.4: Environmental, Economic and Social co-benefits for different stakeholders

Chapter 1.4 focuses on the multiple benefits that I-US can generate for different actors involved in urban–industrial systems. Building on the concepts introduced in the previous chapters, this section highlights how collaborative resource management between industries, municipalities, and communities can lead to positive outcomes across environmental, economic, and social dimensions. The chapter emphasizes that these benefits are often interconnected and mutually reinforcing, meaning that improvements in one area (such as resource efficiency) can simultaneously generate economic savings and social advantages.

The chapter first examines the **environmental benefits** associated with I-US initiatives. It explains how symbiotic exchanges can reduce waste generation, lower greenhouse gas emissions, improve resource efficiency, and prevent pollution. Additional environmental advantages, such as reduced demand for virgin raw materials, improved water management, reduced landfill use, and contributions to ecosystem protection, are also discussed. Through these examples, the chapter demonstrates how integrating industrial and urban resource flows can significantly reduce the environmental footprint of both production systems and urban services.

The chapter then explores the **economic benefits** of I-US, highlighting how companies and municipalities can unlock economic value by transforming waste streams into resources. It describes how symbiotic collaboration can reduce operational costs, create new revenue opportunities, improve supply chain resilience, and stimulate regional innovation. The chapter also discusses how I-US initiatives can support the development of new circular economy markets and services, strengthening local industrial ecosystems and contributing to regional economic development.

In addition to environmental and economic advantages, the chapter addresses the **social dimension of I-US**. It outlines how symbiotic initiatives can generate employment opportunities, improve urban liveability through reduced pollution and better resource management, and foster stronger collaboration among stakeholders. The chapter also highlights the role of I-US in raising public awareness of circular economy practices and strengthening the relationship between industry and local communities.



Finally, the chapter introduces **methodologies for assessing the impacts of I-US initiatives**. It presents commonly used approaches for measuring environmental impacts (such as Life Cycle Assessment and Material Flow Analysis), economic outcomes (including cost–benefit analysis and return on investment), and social effects (such as social key performance indicators and stakeholder engagement methods). By outlining these tools, the chapter provides learners with an overview of how the benefits of I-US can be quantified and evaluated, supporting evidence-based decision-making and effective communication of project results.

Module 2: I-US in the European Union

Module 2 introduces learners to the European policy and funding environment that enables I-US. It explains how EU strategies and legislation create the regulatory and strategic conditions for resource-efficient industrial and urban collaboration. The module also presents key funding opportunities, including Horizon Europe, the LIFE Programme, and the Cohesion Fund, which support research, demonstration, and infrastructure projects. Learners gain an understanding of the EU framework’s role in defining opportunities and boundaries for I-US and learn how to identify and access policies and financial instruments to support local implementation.

This module can be accessed here: <https://symsites.eu/wp-content/uploads/2026/03/SYMSITES-Training-Material-Module-2.pdf>

Chapter 2.1: European Framework supporting I-US

Chapter 2.1 explains how the European Union creates the policy conditions that enable I-US to develop across Member States. Although the EU does not directly implement projects on the ground, it plays a decisive role in shaping the regulatory, strategic, and financial environment within which industries, municipalities, and utilities operate.

The EU matters for I-US because it sets long-term direction through political commitments such as climate neutrality by 2050, circular economy transition, and zero pollution. These goals influence markets, investment flows, research agendas, and industrial strategies. The EU also combines non-binding strategies (communications, action plans, policy roadmaps) with binding legislation (directives and regulations). Together, these instruments define what counts as waste or by-products, establish emission limits, structure infrastructure management, and create incentives for innovation. In parallel, EU funding mechanisms support experimentation, pilot deployment, and collaborative networks—critical for the highly contextual and cross-sectoral nature of I-US.

Non-binding Strategies

Several major EU strategies indirectly but strongly support I-US:

- **European Commission’s European Green Deal** – The overarching EU growth and sustainability strategy, targeting climate neutrality by 2050 and promoting circular economy, industrial decarbonisation, and pollution prevention.
- **Circular Economy Action Plan (CEAP)** – Promotes waste prevention, sustainable product design, and resource efficiency, directly aligning with symbiotic resource exchanges.
- **EU Industrial Strategy (2021 update)** – Supports competitiveness while advancing the green and digital transitions, encouraging clean technologies and resilient value chains.



- **Zero Pollution Action Plan** – Encourages systemic links between waste, water, and energy systems, reinforcing cleaner industrial-urban zones.
- **EU Bioeconomy Strategy** – Supports sustainable use of biological resources, enabling symbiosis around biomass, nutrient recovery, and bio-based feedstocks.

These strategies provide strategic direction and policy coherence, even when I-US is not explicitly named.

Binding Legislation

EU directives and regulations translate strategy into enforceable obligations that directly affect I-US initiatives:

- **Waste Framework Directive (WFD)** – Defines waste, by-products, end-of-waste criteria, and establishes the waste hierarchy. It explicitly references industrial symbiosis and enables secondary raw material markets.
- **Industrial Emissions Directive (IED)** – Sets environmental performance standards and requires Best Available Techniques (BAT), pushing industries toward resource efficiency.
- **Fit for 55 Package** – A legislative package aiming to reduce greenhouse gas emissions by at least 55% by 2030, reinforcing industrial decarbonisation.
- **Urban Wastewater Treatment Directive (revised 2025)** – Strengthens water reuse, nutrient recovery, and micropollutant removal, opening pathways for urban-industrial water and resource synergies.
- **REACH Regulation** – Harmonises chemical safety rules, enabling safe material exchanges within symbiotic networks.

Complementary acts (e.g., Renewable Energy Directive, Energy Efficiency Directive, Packaging and Packaging Waste Regulation) further support heat recovery, circular production, and low-carbon transitions.

Overall, the EU framework creates both boundaries (through environmental safeguards) and opportunities (through innovation incentives and clarified resource definitions). Understanding this regulatory landscape is essential for identifying where I-US is permitted, encouraged, or required.

Chapter 2.2: Funding opportunities

Chapter 2.2 focuses on financial instruments and capacity-building opportunities that enable I-US implementation. Financing is identified as a critical enabler, especially given the collaborative, infrastructure-intensive, and innovation-driven nature of industrial-urban systems.

Horizon Europe: Horizon Europe is the EU's flagship research and innovation programme (2021–2027) with a budget of approximately €95.5 billion. Structured around three pillars (Excellent Science; Global Challenges & Industrial Competitiveness; Innovative Europe), it funds collaborative, cross-border projects aligned with EU strategic priorities.

For I-US, Horizon Europe is particularly relevant because it:

- Supports multi-actor consortia (industry, SMEs, municipalities, utilities, research institutions).
- Encourages systemic, cross-sectoral innovation.
- Funds both research (RIA), demonstration and scaling (IA), and coordination activities (CSA).



- Favors territorial ecosystem approaches, aligning well with industrial-urban integration.

Applications require multinational consortia, structured proposals (Excellence, Impact, Implementation), and alignment with specific call topics via the EU Funding & Tenders Portal.

LIFE Programme: The LIFE Programme is dedicated to environment and climate action (2021–2027). It funds demonstration and near-market innovation projects under four sub-programmes (Nature & Biodiversity; Circular Economy & Quality of Life; Climate Mitigation & Adaptation; Clean Energy Transition).

For I-US, LIFE supports:

- Waste-to-value projects
- Wastewater reuse and nutrient recovery
- Heat recovery systems
- Governance and capacity-building initiatives

Unlike Horizon Europe, LIFE focuses more on implementation and replication potential than early-stage research.

Cohesion Fund: The Cohesion Fund supports Member States with GNI below 90% of the EU average, financing environmental infrastructure, circular economy transitions, and sustainable urban development. With around €48 billion (2021–2027), it funds large-scale, place-based investments such as waste-to-value facilities, water infrastructure, and industrial-urban heat networks.

Cohesion policy is managed at national and regional levels, requiring alignment with operational programmes and co-financing rules. It is particularly relevant for municipalities and public utilities implementing infrastructure-based I-US solutions.

Module 3: The role of local authorities and municipalities in I-US

Module 3 of the Training Materials is the first module directed at Local and Regional Authorities (LRAs) and focuses on the pivotal role municipalities and regional administration can play in promoting, facilitating, and sustaining I-US initiatives.

This module can be accessed here: <https://symsites.eu/wp-content/uploads/2026/03/SYMSITES-Training-Material-Module-3.pdf>

Chapter 3.1: Why I-US Matters for Cities and Regions

This chapter highlights the strategic significance of I-US for local governments by linking it to urban sustainability, economic growth, and resource efficiency. It emphasizes that I-US contributes to climate action targets, circular economy objectives, and sustainable urban planning by enabling the systematic exchange of materials, energy, and by-products among urban industries and public infrastructure. The chapter details the economic advantages of I-US, including job creation, cost savings, investment attraction, and industrial diversification, alongside environmental and social benefits such as reduced waste, lower emissions, enhanced urban resilience, improved public health, and strengthened community cohesion. It also underscores the importance of integrating I-US into broader local and regional strategies, including climate action plans, circular economy frameworks, economic development strategies, and urban planning, with practical tips for authorities



to map industrial flows, foster multi-stakeholder collaboration, develop incentives, and monitor outcomes.

Chapter 3.2: Roles of Local Authorities in I-US Initiatives

Local authorities play a critical role in fostering I-US by enabling collaboration between industries, businesses, and communities. This chapter explores five key roles they can take:

- *Mobilize*: Bring together stakeholders, facilitate partnerships, and create a shared vision for I-US.
- *Educate*: Raise awareness and provide knowledge on the benefits and implementation of I-US.
- *Incentivize*: Develop financial and regulatory incentives that encourage symbiotic collaborations.
- *Manage*: Support infrastructure planning, resource mapping, and the integration of I-US within urban and industrial development plans.
- *Regulate*: Implement policies, zoning regulations, and environmental standards that promote I-US while ensuring compliance with sustainability goals.

Chapter 3.3: I-US examples across Europe – experiences from local authorities and municipalities

This chapter presents real-world examples of European cities and regions that have successfully implemented I-US, specific practical case studies illustrating successful local authority-led initiatives. Examples include:

- **West Midlands, UK**: WMCA implements an Industrial Symbiosis programme across manufacturing, construction, and food waste sectors to support circular economy and net-zero by 2041.
- **Fécamp & Tréport, France**: ANCRE 76 fosters port-based industrial symbiosis through shared energy, waste heat, and water initiatives, led by local stakeholders.
- **Bornholm, Denmark**: BOFA in the SYMSITES project educates students and engages businesses and citizens in co-creating symbiotic resource exchanges for sustainable local development.
- **Arnsberg, Germany**: The state of North Rhine Westfalia subsidises manufacturing and public/private actors to use industrial waste heat in heating networks, promoting decarbonisation.
- **Helsingborg, Sweden**: Local companies run an operational I-US network using waste streams and energy flows for recycling, heating, and cooling, avoiding significant CO₂ emissions.

These cases demonstrate diverse material typologies of I-US (energy exchange, material reuse, and water symbiosis) highlighting critical success factors such as strong municipal leadership, cross-stakeholder collaboration, infrastructure investment, and knowledge sharing. Together, the chapter



shows that local authorities are central to embedding I-US into urban and regional systems, enabling cities to achieve environmental, economic, and social sustainability goals.

Module 4: Regulatory Challenges and Economic Considerations in I-US

Module 4 provides local and regional authorities with an in-depth understanding of the regulatory, economic, and business dimensions critical for implementing I-US. Learners can explore how to navigate complex legal and bureaucratic barriers, and examine economic considerations, including municipal cost savings, revenue generation, financing strategies, and investment sequencing, alongside practical business models for reclaimed resources, energy sharing, and material reuse. Additionally, the module highlights the strategic use of Green Public Procurement and complementary policy tools to stimulate market demand for circular solutions. By the end of this module, participants will gain practical knowledge, actionable strategies, and decision-making frameworks to ensure the financial viability, regulatory compliance, and long-term sustainability of I-US projects in their jurisdictions.

This module can be accessed here: <https://symsites.eu/wp-content/uploads/2026/03/SYMSITES-Training-Material-Module-4.pdf>

Chapter 4.1: Navigating Regulatory Barriers in I-US

This chapter addresses the legal and bureaucratic challenges that municipalities and industrial actors face when implementing I-US. Key regulatory obstacles include fragmented legislation across waste management, energy, water, and land-use domains, as well as conflicting provisions in cross-regional or cross-border projects. System-blind regulations—particularly the classification of materials as “waste”—can prevent technically feasible exchanges, while unclear ownership and liability in shared infrastructure or materials create additional legal uncertainty. Governance continuity is also highlighted as a structural challenge, where staff turnover, management changes, or political shifts can disrupt hub stability.

The chapter emphasizes proactive strategies to overcome these barriers:

- **Regulatory facilitation:** Assigning dedicated hub facilitators or legal intermediaries to liaise with authorities, translate regulations into practical guidance, and provide ongoing support.
- **Documentation and policy advocacy:** Recording blocked exchanges and foregone environmental benefits to support legislative improvements at national or EU levels.
- **Regulatory sandboxes:** Controlled testing of innovative exchanges to generate data for future policy adjustments.
- **Clear ownership and liability frameworks:** Formal agreements specifying responsibilities for materials, permits, compliance, and infrastructure use.
- **Embedding hubs into broader governance structures:** Aligning objectives with regional and sectoral strategies and engaging multiple organizational levels to reduce dependence on individual champions.

Overall, effective navigation of these regulatory barriers enables compliance, reduces legal risk, accelerates industrial collaboration, strengthens investor confidence, and supports the long-term resilience of circular industrial hubs



Chapter 4.2: Economic Considerations for Local Governments

This chapter explores the economic rationale and financial strategies for municipalities engaging in I-US. Circular hubs can generate both direct and indirect benefits: reducing municipal solid waste (MSW) and wastewater (WW) management costs, producing local energy and water resources, and enhancing industrial resilience, regional attractiveness, and citizen well-being. The “**black box**” **model** is introduced, treating municipal facilities as unified systems with defined inputs (MSW, WW) and outputs (biogas, recycled water, compost, low-carbon products), which enables authorities to assess both material and economic balances.

Economic opportunities extend beyond energy and water, including circular loops for cardboard, wood, agricultural waste, and bio-based materials, which can be reintegrated into municipal services or local markets.

A structured financing strategy is outlined for municipalities:

1. **Align funding with organizational profile and use of funds:** R&D, CAPEX, OPEX, and network/coordination activities.
2. **Select financial instruments:** Grants (low-risk, non-repayable), debt financing (loans/bonds for infrastructure), equity or quasi-equity (higher-risk growth), and blended finance (combining multiple instruments).
3. **Map the financing landscape:** EU/national programs, promotional banks, advisory hubs (i.e., JASPERS).
4. **Assess costs, trade-offs, and sequencing:** Early-stage projects may rely on grants, mid-stage projects on equity, and mature hubs on debt or balance-sheet financing.
5. **Leverage advisory support:** Partnerships with experienced entities or consortia can address capacity constraints and enhance project bankability.

Early integration of economic considerations, careful sequencing of funding, and strategic use of advisory support are essential for the financial sustainability of circular hubs.

Chapter 4.3: Financing I-US and Business Models

This chapter examines the financial and operational frameworks required to make I-US sustainable. Viable business models are crucial for reclaimed water, energy sharing, and material reuse, balancing public and private interests while stabilizing supply and demand. Across Europe and Asia, successful models combine joint investment, shared infrastructure, service-based contracts, and market-based pricing to lower barriers for smaller enterprises and municipalities.

Key mechanisms for stabilizing and de-risking I-US projects include:

- **Offtake and long-term agreements:** Ensuring predictable demand for reclaimed resources or energy.
- **Subsidies:** Incentivizing adoption of recycled water or low-carbon materials.
- **In-situ usage and local symbiosis:** Reducing logistics costs and fostering trust through local collaboration.
- **Pre-design and co-design:** Optimizing resource quality and usability.



- **Shared investment:** Spreading costs across multiple actors, from industrial plants to public authorities.
- **Carbon credits and green finance mechanisms:** Supporting CAPEX/OPEX balance and incentivizing environmental benefits.

The chapter also highlights financing barriers such as information gaps, limited administrative capacity, perceived risks, and weak business cases. Mitigation strategies include engaging advisory services, partnering with consultancies or regional authorities, and aligning financing instruments with technology readiness levels (TRLs). Early-stage technologies typically rely on grants, mid-stage technologies attract equity, and mature technologies leverage debt financing.

Hub business models vary according to governance and operational scope:

- **Operational hubs:** Own/manage infrastructure; models can be defensive (regulatory focus) or accommodative (environmental and social objectives).
- **Managerial hubs:** Facilitate collaboration, redesign waste value chains, and support climate-neutral business models.
- **Hybrid hubs:** Combine operational and managerial functions.

Revenue streams include membership fees, service fees, commissions on synergies, infrastructure usage fees, and energy management contracts. Strategic alignment between governance, operational ambition, and financial structure is critical, with public funding used strategically to de-risk early phases, demonstrate viability, and attract private investment. Over time, a mixed revenue model enhances resilience, scalability, and long-term circular transformation.

This chapter also includes a video to an online training session organized by H4C ECoP for the SYMSITES project partners in February 2026 explaining key financial mechanisms for I-US.

Chapter 4.4: Green Public Procurement and Policy Tools for I-US

This chapter demonstrates how municipalities can leverage **Green Public Procurement (GPP)** and complementary policy tools to promote I-US. GPP integrates environmental and circular economy criteria into public tenders, influencing market demand and stimulating industrial collaboration. Public procurement accounts for approximately 14% of EU GDP, making it a powerful instrument for directing investment toward circular and symbiotic products, services, and infrastructure.

By embedding circularity into procurement, municipalities can:

- Create predictable demand for secondary raw materials, recycled products, and modular infrastructure components.
- Stimulate local circular markets, supporting resource recovery, energy reuse, and material upcycling.
- Encourage supplier innovation aligned with industrial symbiosis principles.
- Align municipal investment with broader sustainability goals, integrating infrastructure, utilities, and urban development.

GPP criteria are applied across sectors relevant to I-US, including construction, utilities, materials, food services, and ICT. Implementation approaches include specifying environmental and circular standards in tenders, using subsidies to offset initial costs, ensuring regulatory alignment, and leveraging knowledge platforms for procurement officers. European case studies highlight



measurable outcomes, such as increased use of recycled construction materials, energy exchange contracts, and local industrial partnerships.

GPP is a strategic lever to convert public purchasing power into systemic impact, supporting market development, industrial collaboration, and long-term implementation of I-US while reinforcing environmental and resource efficiency objectives.

Module 5: Understanding the industrial landscape

Module 5 introduces LRAs to the industrial landscape. Learners will explore how to identify and engage key stakeholders, ranging from industries and utilities to local administrations and research institutions, while navigating the challenges of multi-actor collaboration. They will also learn how to map local resources and waste streams, analyse material and energy flows, and identify opportunities for symbiotic exchanges. By the end of the module, learners will understand how to connect stakeholder engagement with technical resource mapping to design effective, scalable, and collaborative I-US initiatives.

This module can be accessed here: <https://symsites.eu/wp-content/uploads/2026/03/SYMSITES-Training-Material-Module-5.pdf>

Chapter 5.1: Stakeholder Identification and Engagement

In this chapter, the emphasis is placed on stakeholder identification and engagement as a foundational condition for I-US. Since symbiosis and circular economy approaches inherently rely on cooperation across sectors, the chapter highlights that effective implementation cannot be achieved by isolated actors but requires structured collaboration between municipalities, industries, utilities, research institutions, multiplier organisations, and civil society. Stakeholder engagement is presented not only as a technical coordination task but also as a social process aimed at building trust, aligning incentives, and fostering long-term collaboration. Different perspectives are explored, including the roles of public administrations as facilitators and coordinators, utilities as system integrators, companies as resource-optimising actors, and hubs as convening platforms. The chapter outlines common challenges in multi-stakeholder processes (such as limited resources, misaligned incentives, lack of trust, difficulty moving from discussion to implementation, and sustaining long-term engagement) and provides practical mitigation strategies, including structured facilitation, clear agenda-setting, prioritisation matrices, pilot projects, and transparent communication.

The chapter further introduces structured stakeholder mapping as a practical tool to categorise relevant actors (e.g., industry, public utilities, local administration, academia, CSOs) and to prioritise them based on relevance and interest. It presents a step-by-step approach covering objective definition, tool selection (from simple spreadsheets to advanced network analysis tools), GDPR considerations, iterative data population, and subsequent prioritisation. Building on this mapping, the chapter explains how to design effective engagement strategies that are intentional yet flexible, linking identified stakeholders to specific objectives and engagement formats. Various engagement formats are discussed: formal (steering committees, advisory boards), co-creative (workshops, innovation labs), networking-oriented (industry roundtables, site visits), and digital, emphasising the importance of selecting formats aligned with stakeholder capacity, maturity of the initiative, and desired outcomes.



Chapter 5.2: Mapping Resources and Waste Streams

Chapter 5.2 shifts the focus to mapping resources and waste streams as the analytical backbone of I-US initiatives. It introduces methodologies for identifying and quantifying material and energy flows (such as water, energy, by-products, waste, and utilities) within defined territorial boundaries. The importance of defining a clear scope is highlighted, including thematic orientation, geographic focus, and prioritised value chains, in order to translate strategic ambition into operational and measurable action. The chapter stresses that scoping should be evidence-based and context-sensitive, taking into account economic structures, environmental pressures, policy frameworks, and stakeholder readiness. Incremental development is encouraged, noting that many successful initiatives began with a limited number of exchanges and expanded over time as trust and infrastructure developed.

A value-chain-based approach is presented as a systematic way to operationalise symbiosis opportunities by analysing inputs, outputs, inefficiencies, and substitution potentials across production stages. The process includes internal company mapping of subprocesses, quantification of material and energy flows, visualisation through flowcharts or Sankey diagrams, and identification of cross-company synergies. Detailed data collection (covering volumes, composition, temporal availability, logistics, costs, and infrastructure) is described as essential for feasibility assessment. The chapter also underscores the importance of secure data management and acknowledges organisational and behavioural complexities that arise when transitioning from theoretical opportunities to real collaborations. Finally, Material Flow Analysis (MFA) is introduced as a key methodological tool to quantify and visualise resource flows, providing an empirical basis for prioritising exchanges and supporting decision-making.

Module 6: From Vision to Implementation

This module guides local authorities through the practical steps needed to turn I-US concepts into operational initiatives, by showing how to identify and prioritize synergies, and exploring the development of circular economy and site-specific strategies that embed I-US within broader urban, economic, and energy planning. It also examines governance and business models, highlighting how formal structures, multi-actor participation, and iterative funding or service approaches can stabilize, scale, and sustain I-US initiatives over time, ensuring that symbiotic exchanges evolve from isolated experiments into integrated, resilient systems.

This module can be accessed here: <https://symsites.eu/wp-content/uploads/2026/03/SYMSITES-Training-Material-Module-6.pdf>

Chapter 6.1: Identifying and Prioritizing Synergies

To move from concept to execution, this chapter highlights that synergies (the symbiotic exchanges of materials, energy, water, or services between urban and industrial actors) need to be assessed using structured methodologies to ensure they deliver maximum economic, environmental, and social value. Key evaluation methods include:

- Input–Output and Material Flow Analysis to quantify resource flows and assess technical feasibility and logistical constraints.



- Multi-Criteria Decision Analysis (MCDA) for scoring opportunities based on economic, environmental, and social indicators, allowing authorities to rank priorities.
- Readiness and Risk Assessment Tools, including Symbiosis Readiness Level matrices to identify actionable opportunities and minimize implementation risks.

Prioritization involves aligning opportunities with broader policy objectives, distinguishing between “quick wins” and long-term strategic projects, and engaging stakeholders to validate and refine selections. The chapter also introduced the **SYMSITES IT Regional Management Platform (ITRMP)**, a digital tool that supports I-US planning by mapping potential synergies, automating matchmaking, monitoring resource flows, and integrating social, economic, and environmental data. ITRMP enhances structured decision-making, scenario modelling, and multi-stakeholder collaboration.

Chapter 6.2: Embed I-US in Local Strategies

Chapter 6.2 explored how long-term strategies provide direction, legitimacy, and continuity for I-US initiatives. I-US rarely emerges spontaneously; strategies help translate political and organizational ambitions into concrete priorities, align departments and actors around shared goals, and create an environment conducive to collaboration, experimentation, and investment.

Strategies can vary in focus and scale:

- **Circular Economy Strategies:** Often the most common entry point, these strategies aim to retain resources in use, valorize by-products, and encourage cross-sector collaboration. They explicitly embed I-US as a lever for achieving circularity objectives.
- **Urban Planning and Spatial Strategies:** Integrate I-US by considering co-location of industries and utilities, protecting land for circular infrastructure, or planning networks for heat, water, and materials.
- **Economic Development and Innovation Strategies:** Strengthen industrial clusters, support pilot projects, and attract investment in resource valorization technologies.
- **Energy and Climate Strategies:** Focus on waste heat recovery, renewable integration, or industrial decarbonization, providing additional leverage for I-US adoption.

Concrete examples were presented: Munich’s Circular Economy Strategy, Vitoria-Gasteiz 2030 Strategy to Drive the Circular Economy and its Action Plan 2024–2027 and Päijät-Häme (Finland) demonstrate a long-term regional approach linking industrial symbiosis to economic development and innovation. These cases illustrate that strategies do not need to follow a single template; their value lies in creating a shared framework, connecting sectors, and institutionalizing I-US over time.

Additionally, the chapter emphasized **site-specific strategies** for hubs, eco-industrial parks, or pilot projects, and includes a structured reflection exercise for the learner.

Chapter 6.3: Governance and Business Models for I-US

This chapter examined how governance structures and business models enable long-term collaboration and scaling of I-US initiatives. Governance provides the framework necessary to turn isolated exchanges into stable, repeatable systems. Because I-US is context-specific, multiple governance models exist, including industrial symbiosis hubs, eco-industrial parks, clusters, ports,



digital platforms, and formal or informal networks. Common to all is the goal of reducing transaction costs, coordinating stakeholders, and providing continuity.

Formal governance brings several advantages: it clarifies responsibilities, builds trust, attracts participants, and enables scaling. Effective governance structures rely on a mix of actors—public authorities, utilities, companies, facilitators, and research organizations—each contributing complementary capability.

Business models underpin governance structures by ensuring sustainability and operational continuity. The chapter covered multiple models:

- **Project-based funding:** Supports experimentation but may lack continuity.
- **Public funding:** Provides stability and aligns with policy objectives, though it may be politically dependent.
- **Fee-based or membership models:** Encourage stakeholder commitment but can exclude smaller actors.
- **Service- or performance-based models:** Link income to value delivered, scalable but potentially volatile in early phases.
- **Private funding or sponsorship:** Flexible and fast, but may be subject to individual interests and short-term priorities.

The chapter stressed that developing a business model is iterative. Tools like business model canvases and scenario exercises help stakeholders clarify value propositions, align on shared goals, and gradually evolve from project-based setups into more stable, diversified structures.

Then this chapter explores how circular hubs create, deliver, and capture value through operational, managerial, or hybrid business models, linking infrastructure, facilitation services, and knowledge networks to sustainable revenue streams.

This chapter also includes a video to an online training session organized by H4C ECoP for the SYMSITES project partners in February 2026 explaining key governance models for I-US.

Module 7: Monitoring and Evaluating I-US Progress

Module 7 focused on two closely connected dimensions of I-US: first, how to measure sustainability performance through robust key performance indicators (KPIs), and second, how to use these results to enable policy feedback and continuous improvement. Together, these final chapters provide local and regional authorities with both the analytical framework and governance mechanisms required to assess, refine, and scale I-US systems.

This module can be accessed here: <https://symsites.eu/wp-content/uploads/2026/03/SYMSITES-Training-Material-Module-7.pdf>

Chapter 7.1: Performance Indicators for I-US

This chapter introduces key performance indicators (KPIs) as a framework for assessing I-US initiatives. The chapter emphasizes that EcoSites, which integrate wastewater treatment, energy recovery, and by-product valorisation, are complex multifunctional systems that require



multidimensional evaluation. To capture their full sustainability impact, the assessment covers **environmental, economic, and social dimensions**, using Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (SLCA), respectively.

Environmental KPIs focus on greenhouse gas emissions, particulate matter formation, eutrophication, ecotoxicity, and resource use. Economic KPIs include total life cycle costs, operational expenditure, revenue from resource recovery, and avoided disposal costs. Social KPIs capture worker health and safety, fair salary compliance, governance risks, and broader community impacts. Aggregated single scores can summarize performance while highlighting trade-offs across dimensions.

The chapter presents results from the SYMSITES EcoSites in Austria, Denmark, Greece, and Spain, comparing each to a conventional benchmark system. While initial assessments show higher environmental and economic impacts than benchmarks, climate change impacts and resource efficiency improved over time, demonstrating significant optimization potential. Social risks were mostly linked to electricity consumption and governance factors. Benchmarking with functional units allows municipalities to evaluate progress objectively and identify areas for improvement.

Finally, the chapter highlights that KPIs are not just technical metrics but strategic tools for municipalities. Regular monitoring enables authorities to adjust operational parameters, refine incentives, optimize processes, and provide evidence for policy and investment decisions, supporting the scaling of I-US initiatives in a measurable, accountable way.

Chapter 7.2: Policy Feedback and Continuous Improvement

Chapter 7.2 focuses on integrating performance data into adaptive governance structures to enable continuous improvement of I-US systems. It stresses that policy feedback loops are essential because I-US environments are dynamic, involving multiple stakeholders and evolving resource flows. Feedback allows authorities to detect deviations, identify regulatory bottlenecks, refine incentives, and support evidence-based scaling.

The chapter illustrates how SYMSITES implemented an IT Regional Management Platform (ITRMP) and associated decision-support tools to monitor performance in near-real-time. These digital systems enable authorities to evaluate ecological, economic, and social outcomes, and to adjust regulations, planning codes, and operational guidance accordingly. Stakeholder engagement, including forums and surveys, ensures that feedback reflects technical, social, and governance perspectives, enhancing legitimacy and effectiveness.

Iterative regulatory design and adaptive incentive schemes are presented as core mechanisms for policy improvement. Regulations should include review clauses and thresholds that trigger reassessment, while subsidies or performance-based incentives are recalibrated according to measured outcomes. Cross-departmental coordination, inter-jurisdictional working groups, and annual performance reviews support this adaptive governance approach.

Finally, the chapter emphasizes the strategic importance of scaling I-US models. Systematic documentation, standardisation of technical and regulatory practices, and regional policy harmonisation allow successful EcoSites to be replicated efficiently. Combined, performance monitoring and adaptive governance transform I-US from experimental projects into resilient, scalable, and sustainable urban-industrial systems.



Module 8: Technological Solutions to achieve I-US from SYMSITES

This Module is the first of the series directed to Industries and SMEs. Through this module, participants will explore both the technical and commercial aspects of turning industrial and urban by-products into high-value new resources (HVNRs), gaining practical insights into the full cycle from waste identification to market integration. Learners can understand the composition and potential of waste streams, explore innovative technologies for waste valorization, learn how to convert recovered resources into HVNRs, and acquire practical knowledge for market integration.

This module can be accessed here: <https://symsites.eu/wp-content/uploads/2026/03/SYMSITES-Training-Material-Module-8.pdf>

Chapter 8.1: Understanding Waste Streams in Industrial–Urban Symbiosis

This chapter provides a foundational understanding of the various waste streams generated by urban and industrial activities, emphasizing their potential as resources rather than disposal challenges. Waste is reframed as a potential resource rather than a disposal problem, highlighting the value embedded in industrial by-products and urban organic materials. The chapter outlines methods for mapping and characterizing these flows, including chemical composition, physical form, and seasonal variability. Understanding these factors is essential for designing symbiotic exchanges where waste from one sector becomes feedstock for another.

The chapter also focuses on nutrient and water cycles, showing how industrial and urban systems contribute to flows of nitrogen, phosphorus, carbon, and water. It explains how recovered nutrients from wastewater, biosolids, and organic waste can be reintegrated into agricultural production or industrial processes, closing material loops. Then it introduces the methodologies developed in the SYMSITES project for classifying and quantifying waste flows. By the end of this chapter, SMEs and industrial actors are encouraged to analyse their own waste streams in detail, including variability, contamination risks, and regulatory classification. This understanding forms the basis for selecting appropriate recovery technologies and identifying potential symbiotic partners.

Chapter 8.2: Innovative Technologies for Waste Valorisation

This chapter shifts the focus from understanding waste to actively transforming it through technology. It introduces technologies that transform waste into usable resources, highlighting how innovation enables the circular use of materials in industrial settings. It presents a range of approaches, including membrane separation, advanced oxidation, anaerobic digestion, pyrolysis, and thermal hydrolysis, showing how these technologies recover nutrients, energy, and high-value intermediates from industrial and urban waste streams. The focus is on efficiency, scalability, and regulatory compliance, guiding SMEs in selecting the best solutions for their specific waste profiles.

The chapter emphasizes process integration, ensuring that recovery technologies are compatible with existing production flows. SYMSITES examples demonstrate successful applications, such as nutrient extraction from wastewater streams for fertilizer use or energy recovery from organic residues. Practical considerations for industries include assessing energy balances, emissions profiles, and modularity to match variable production scales.



By providing a clear overview of technical options, this chapter equips companies with the knowledge to choose and implement technologies that maximize value from waste while contributing to environmental sustainability and compliance with EU regulations.

Chapter 8.3: From Waste to High-Value New Resources (HVNR)

This chapter focuses on converting recovered waste into High-Value New Resources (HVNR), highlighting the economic and environmental potential of I-US. HVNR includes secondary raw materials, bio-based chemicals, alternative fuels, and other products that can replace virgin inputs in industrial processes. This chapter provides guidance on how waste-derived materials can be processed to meet quality standards and achieve marketable value.

It explains how industries can convert waste streams into secondary raw materials, renewable fuels, bio-based chemicals, or soil amendments, highlighting the potential for both environmental and financial gains. This chapter reinforces the idea that waste can become a strategic asset rather than a liability.

SYMSITES case studies illustrate practical examples: food processing residues converted to biogas and digestate for agricultural use, industrial effluents processed to recover high-purity nutrients for chemical manufacturing, and pyrolysis outputs turned into biochar for soil improvement. The chapter stresses the importance of quality standards, purity, and process economics, ensuring that HVNRs are compatible with market demands and regulatory frameworks.

By understanding how to generate HVNRs, SMEs and industries can identify new business opportunities and enhance resource efficiency. The chapter encourages strategic thinking about product applications, market demand, and revenue models to make waste recovery financially viable and environmentally beneficial.

Chapter 8.4: Market Integration and Product Applications for Recovered Resources

Chapter 8.4 addresses the final step in the symbiosis process: turning recovered resources into marketable products. While technology can convert waste into valuable products, commercial success requires careful planning to ensure recovered materials reach the right markets. The chapter emphasizes the importance of understanding market demand, identifying potential buyers in sectors like agriculture, construction, chemicals, and energy, and defining a clear value proposition that highlights environmental benefits, quality, and cost competitiveness.

The chapter also addresses regulatory compliance and quality assurance, noting that HVNRs must meet legal standards and industry certifications to gain market acceptance. Businesses need to establish robust testing, documentation, and traceability systems to ensure their products are safe, consistent, and trusted by buyers. Certifications and sustainability labelling can further enhance credibility and differentiate recovered resources from conventional alternatives. It also discusses business model design, supply chain planning, and stakeholder engagement. Companies must organize logistics, distribution, and contractual frameworks to ensure efficient delivery while clarifying responsibilities for quality and performance. Engaging proactively with regulators, industry partners, and end-users strengthens confidence in HVNRs and supports uptake. By integrating these considerations, businesses can transform recovered materials into viable products, capturing both economic and environmental value.



Module 9: Legislative requirements and risk management for wastewater reuse

This one-chapter module presents the regulatory and operational foundations necessary for industries and SMEs to safely implement wastewater reuse within I-US projects. The chapter explains that reclaimed water can become a strategic industrial input, reduce freshwater dependency and enhance resource efficiency, but only if legal, environmental, and health safeguards are fully respected. It positions wastewater reuse not only as a sustainability measure but also as a regulated activity requiring structured compliance and accountability.

The chapter outlines the European legislative context governing reuse, with particular reference to Regulation (EU) 2020/741 (Water Reuse Regulation) and its risk-based approach. Although originally developed for agricultural irrigation, its principles (minimum quality requirements, monitoring obligations, permitting procedures, and mandatory risk management) are highly relevant for industrial reuse schemes. The chapter also highlights the interaction with broader EU water legislation, such as the Urban Wastewater Treatment Directive and the Water Framework Directive, emphasizing the need for companies to understand both EU-level and national regulatory requirements when designing reuse systems.

A core focus of the chapter is the application of structured risk management in line with the framework developed by the Joint Research Centre (JRC). It explains how industries should map their reuse systems, identify hazards (microbiological, chemical, and operational), assess exposure risks, and implement preventive and corrective control measures. The importance of documented monitoring systems, quality assurance procedures, and clear allocation of responsibilities is emphasized as essential for regulatory approval and operational reliability.

Finally, the chapter addresses monitoring, verification and quality control systems. It underscores that industries must plan for variability in water quality and availability, integrate contingency measures, and maintain transparent communication with regulators and symbiosis partners.

This module can be accessed here: <https://symsites.eu/wp-content/uploads/2026/03/SYMSITES-Training-Material-Module-9.pdf>

Module 10: Digital Integration and visualization for I-US

Module 10 introduces the digital infrastructure required to monitor, manage, and optimize I-US systems for industries. It explains how integrated data platforms, interoperable communication standards, and user-cantered dashboards transform raw sensor data into operational intelligence. Learners will understand how system integration frameworks (linking IoT sensors, industrial equipment, and municipal databases) enable structured, secure, and semantically consistent data exchange. Participants will gain practical insight into exploratory data analysis, data quality assurance, and the deployment of predictive models within integrated platforms such as ITRMP.

This module can be accessed here: <https://symsites.eu/wp-content/uploads/2026/03/SYMSITES-Training-Material-Module-10.pdf>

Chapter 10.1: Data analysis and system integration



Chapter 10.1 presents the digital backbone of I-US by focusing on system integration, interoperability, and user-centered visualization within the SYMSITES ecosystem. It explains how digital platforms (particularly the ITRMP environment and its SMCO module) act as operational bridges between physical infrastructure (sensors and actuators) and decision-making interfaces. Sensors collect physical, chemical, or operational parameters, while actuators translate digital commands into physical control actions, enabling dynamic and responsive management of resource flows. The chapter emphasizes that seamless integration of industrial and municipal data streams is fundamental for optimizing exchanges in I-US systems.

A key theme is interoperability, both technical and semantic. The chapter explains how semantic interoperability, aligned with guidance from the National Institute of Standards and Technology (NIST), ensures that resource-related terms and data retain consistent meaning across different systems. This prevents ambiguity and reduces integration errors when data moves between industrial control systems, municipal databases, and digital platforms. It further highlights the importance of communication standards such as OPC UA (Open Platform Communications Unified Architecture), which provides secure, platform-independent industrial communication, and REST APIs, which enable scalable web-based data exchange across heterogeneous systems. Together, these technologies allow structured, secure, and reliable information sharing between machines, sensors, and enterprise software in industrial-municipal partnerships.

The second part of the chapter focuses on user interface design and data visualization, stressing that digital tools are only effective if they are accessible and actionable. The development of user-friendly dashboards within the SMCO module allows operators and managers to track real-time data, visualize trends, and monitor KPIs in an integrated environment. By embedding KPIs into interactive dashboards, companies can detect deviations early, compare performance over time, and improve decision-making efficiency. Robust system integration combined with intuitive visualization tools enhances operational transparency, strengthens collaboration between industrial and municipal actors, and supports data-driven optimization of I-US exchanges.

Chapter 10.2: Incorporating Real-Time Data Processing Tools

This last chapter of the training material builds upon system integration by introducing real-time data processing, advanced analytics, and AI-driven tools as mechanisms for adaptive management in I-US. It explains how IoT-enabled infrastructures generate continuous streams of operational data, which, when processed in real time, enable early detection of inefficiencies, predictive maintenance, and proactive compliance management. The chapter frames real-time analytics as a shift from reactive monitoring to anticipatory and adaptive decision-making.

The chapter first introduces Exploratory Data Analysis (EDA) as a foundational method for understanding sensor and process data before applying formal models. Rooted in John Tukey's statistical philosophy, EDA allows users to visualize trends, detect anomalies, and refine KPI selection dynamically. It also addresses data reliability challenges, outlining structured approaches to handle missing or inconsistent data through imputation, interpolation, validation rules, and calibration procedures. These practices ensure that derived KPIs and analytics outputs remain robust and trustworthy which is an essential condition for industrial applications and regulatory reporting.



A significant component of Chapter 10.2 is the integration of AI models for predictive and adaptive planning, referencing insights from the Joint Research Centre (JRC) AI Watch report on AI uptake in manufacturing. The chapter explains how AI systems can forecast resource demand, optimize capacity allocation, and simulate feasible operating regions by integrating multi-source production data. Within the SMCO module of ITRMP, users can develop or integrate AI-based models that operate in real time, ingesting structured sensor data to generate predictive outputs. The inclusion of external analytical tools, such as Python libraries (NumPy, Pandas, and Scikit-learn), is presented as a practical pathway for industries seeking more advanced modelling capabilities.

Finally, the chapter addresses monitoring and regulatory compliance, emphasizing that real-time data processing supports a proactive compliance framework. Continuous monitoring, automated alerts, and closed-loop control mechanisms ensure that industrial processes remain within regulatory thresholds while adapting dynamically to operational changes. By combining monitoring, predictive analytics, and automated response systems, companies can reduce risk, document compliance, and enhance resource efficiency in line with the objectives of the EU Circular Economy Action Plan.

5. Conclusion

The SYMSITES training materials present a comprehensive framework for understanding and implementing I-US as a practical pathway toward circular and sustainable urban-industrial systems. Through ten interconnected modules, the training guides learners from foundational concepts of the circular economy and industrial symbiosis to the practical steps required to design, implement, monitor, and scale symbiotic exchanges. The modules collectively demonstrate that effective I-US initiatives require an integrated approach combining policy alignment, stakeholder collaboration, technological innovation, and data-driven decision-making.

A key message emerging from the training is the central role of collaboration among diverse actors. Local and regional authorities, industries, utilities, research institutions, and communities each contribute specific capabilities that enable the creation of circular resource flows. By facilitating stakeholder engagement, aligning strategies, and providing supportive regulatory and financial frameworks, public authorities can create the conditions necessary for successful I-US ecosystems. At the same time, industries and SMEs play a crucial role in identifying waste valorisation opportunities, adopting innovative technologies, and integrating recovered resources into production processes, all the while managing wastewater reuse through exchanges with LRAs and citizens.

The training also highlights the importance of structured methodologies and digital tools for identifying synergies, assessing feasibility, monitoring performance, and ensuring regulatory compliance. Approaches such as material flow analysis, life-cycle assessment, and key performance indicators provide a robust evidence base for decision-making, while digital platforms – such as the SYMSITES ITRMP – and real-time data processing enable continuous optimization of resource exchanges. Together, these tools support adaptive governance and help transform experimental projects into stable, scalable systems.

Ultimately, the training materials demonstrate that I-US is a systemic approach to regional development that strengthens environmental sustainability, economic competitiveness, and social well-being. By equipping stakeholders with the knowledge, tools, and practical examples needed to implement I-US, the SYMSITES training contributes to accelerating the transition toward circular, resilient, and climate-neutral urban-industrial ecosystems across Europe.

