

Module 7: Monitoring and Evaluating I-US Progress

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Module Overview

In this module, the focus is on how to monitor and evaluate I-US initiatives and use evidence to improve policy frameworks over time. Building on the implementation and governance concepts discussed in earlier modules, this module introduces practical tools for assessing environmental, economic, and social outcomes of I-US hubs, and then exploring how monitoring results can feed into policy feedback and adaptive governance,

- [Chapter 7.1: Performance Indicators for I-US](#)
- [Chapter 7.2: Policy Feedback and Continuous Improvement](#)





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Chapter 7.1: Performance Indicators for I-US

This chapter introduces key performance indicators (KPIs) for I-US, covering environmental, economic, and social metrics. Measuring resource efficiency, cost savings, and emissions reductions allows municipalities to quantify the impact of their initiatives and adjust strategies accordingly.

- Target audience: Local Authorities and Municipalities
- Estimated time: 15 minutes
- Includes: Explanations Case Studies

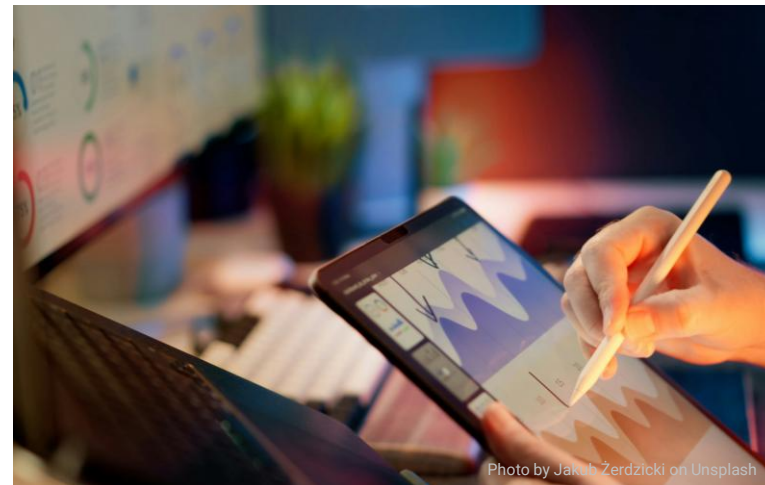




Performance Indicators for I-US

Industrial–Urban Symbiosis (I-US) represents a systemic approach to transforming urban and industrial infrastructure. By connecting resource flows such as wastewater, organic and industrial waste, energy, by-products, and infrastructure, I-US hubs aim to maximize resource efficiency while creating environmental, economic, and social value.

For municipalities and regional authorities, the strategic value of these hubs depends not only on operational implementation but also on **monitoring, measurement, and evaluation**.





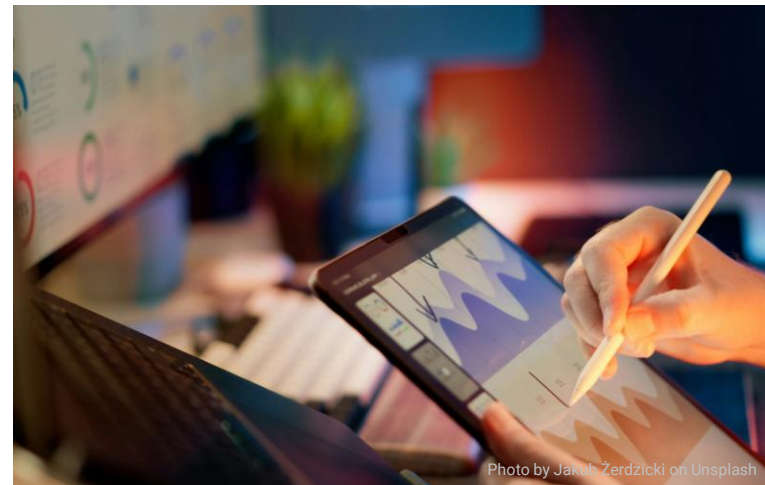
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Performance Indicators for I-US

The **objectives of an I-US hub** are typically formulated in terms of:

- **Environmental improvement** – reducing emissions, minimizing waste, and conserving resources.
- **Economic competitiveness** – generating revenue, lowering operating costs, and creating investment opportunities.
- **Resilience** – ensuring stable operations under changing conditions and resource availability.
- **Social value creation** – promoting employment, fair labor practices, and community well-being.

Monitoring provides the empirical foundation for assessing whether these objectives are being achieved. Evaluation enables adaptive management and course correction, ensuring that interventions are evidence-based and outcomes are continuously optimized.





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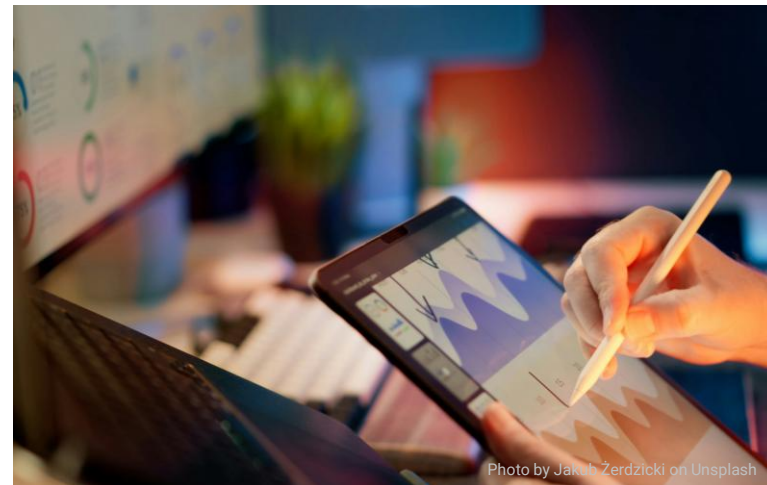
Performance Indicators for I-US

Without structured monitoring, benefits of industrial symbiosis remain largely anecdotal, limiting learning, replicability, and access to funding or investment. Quantified KPIs also strengthen the hub's legitimacy and visibility, demonstrating tangible outcomes such as avoided emissions, reduced waste, increased turnover, or new employment to public authorities, investors, and participating firms.

1. The Importance of Monitoring and Evaluation

Monitoring I-US hubs is essential for both **operational and strategic purposes**. It provides evidence to support decision-making, informs policy adjustments, and helps prioritize investments. Key benefits of robust monitoring include:

- **Accountability** – demonstrating progress to stakeholders and funding bodies.



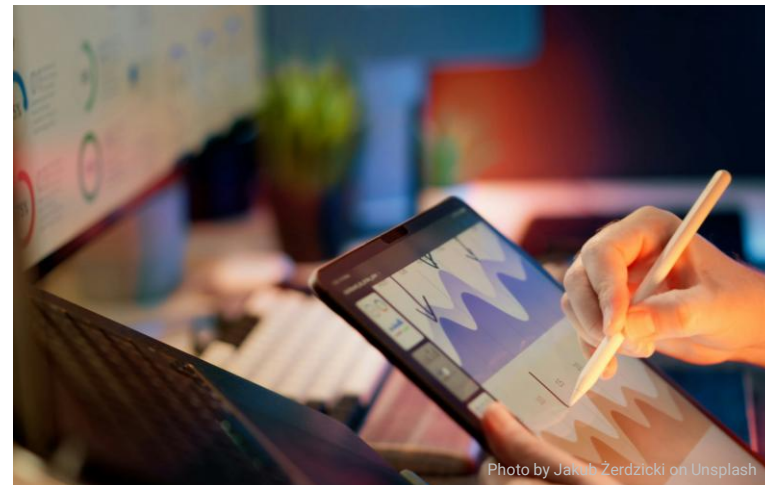


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Performance Indicators for I-US

- **Optimization** – identifying inefficiencies and improvement potential in resource flows and processes.
- **Learning and replication** – enabling other municipalities or industrial clusters to replicate successful models.
- **Legitimacy and visibility** – showing the environmental, economic, and social benefits of the hub to external audiences.

However, the selection of KPIs must be context-specific. They depend on the technologies deployed, resource flows managed, value chains involved, and local governance structures. There is no “one-size-fits-all” KPI set; each hub must adapt indicators to its operational and strategic context. Existing literature and EU project outputs provide structured guidance to design a comprehensive monitoring framework while allowing customization for local circumstances.





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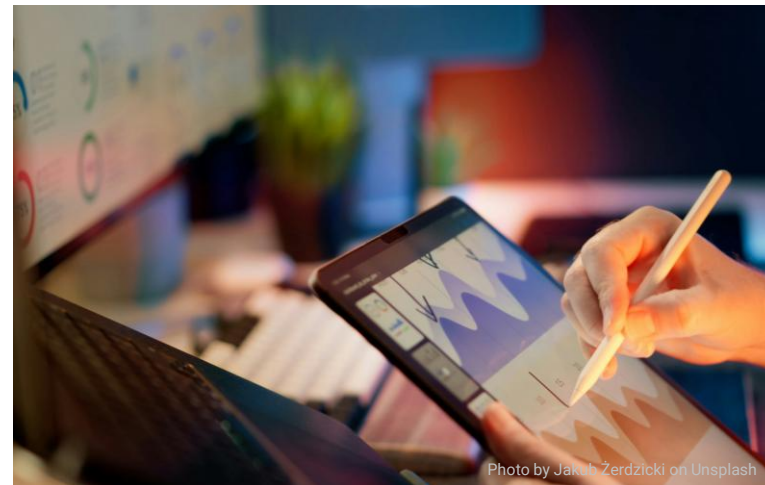
Performance Indicators for I-US

2. What Should Be Monitored

Monitoring in an I-US hub should reflect three dimensions of sustainability (environmental, economic, and social) while also capturing structural and governance-related aspects of the hub itself. Industrial symbiosis systems consume resources (financial, human, material, energy, water, land) and generate outputs that include both tangible and intangible impacts.

Effective monitoring considers:

- **Input-related indicators** – financial investments, labor hours, energy and water consumption, material throughput, and land use.
- **Output-related indicators** – treated wastewater, recovered energy or nutrients, avoided emissions, cost savings, revenue from by-products, jobs created, and social benefits.
- **Process and governance indicators** – stakeholder engagement, coordination efficiency, regulatory compliance, and adaptive management practices.





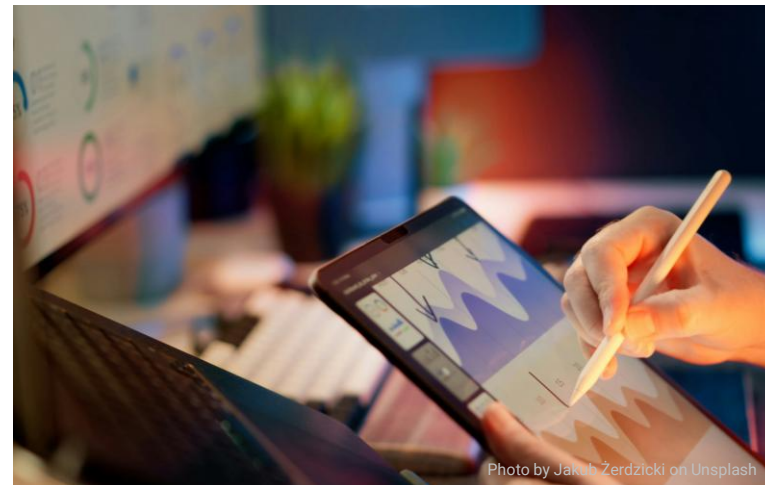
Performance Indicators for I-US

By combining input, output, and governance indicators, municipalities can obtain a holistic view of hub performance that supports strategic decisions, policy adaptation, and long-term sustainability planning.

KPIs are structured metrics designed to quantify the performance of I-US hubs. They allow municipalities to evaluate, compare, and communicate outcomes. While KPIs must be tailored to each hub, the following framework captures the essential dimensions:

Environmental KPIs – measure ecological impacts and resource efficiency:

- Greenhouse gas emissions (CO₂-eq avoided or reduced)
- Particulate matter formation
- Freshwater and marine eutrophication
- Freshwater ecotoxicity
- Resource consumption (energy, water, raw materials)
- Waste reduction and diversion from landfill





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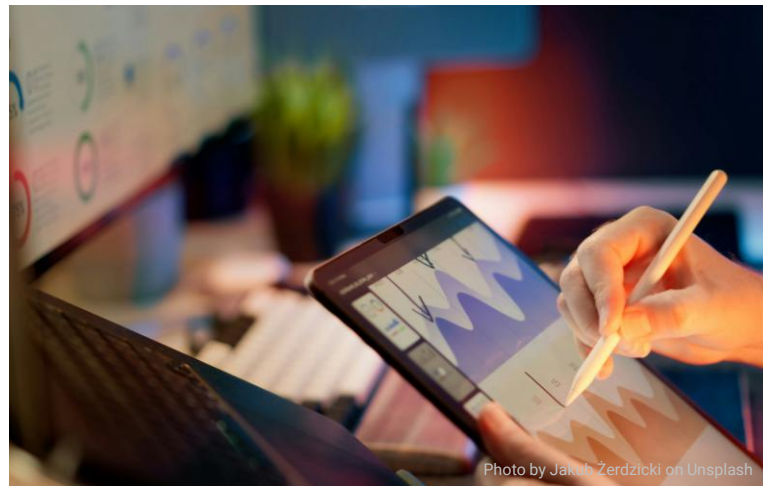
Performance Indicators for I-US

Economic KPIs – assess financial and operational performance:

- Total life cycle costs (capital, operational, maintenance)
- Revenue from recovered materials or energy
- Avoided disposal costs and resource substitution benefits
- Net Present Value (NPV), Internal Rate of Return (IRR), or payback periods
- Cost per functional unit (e.g., €/m³ of treated wastewater or €/kg of recovered material)

Social KPIs – capture social outcomes and governance:

- Worker hours at risk and occupational health and safety metrics
- Compliance with fair wage and labor standards
- Job creation and local employment impacts
- Community engagement and stakeholder participation
- Governance and regulatory compliance indicators, including risk of corruption or exclusion



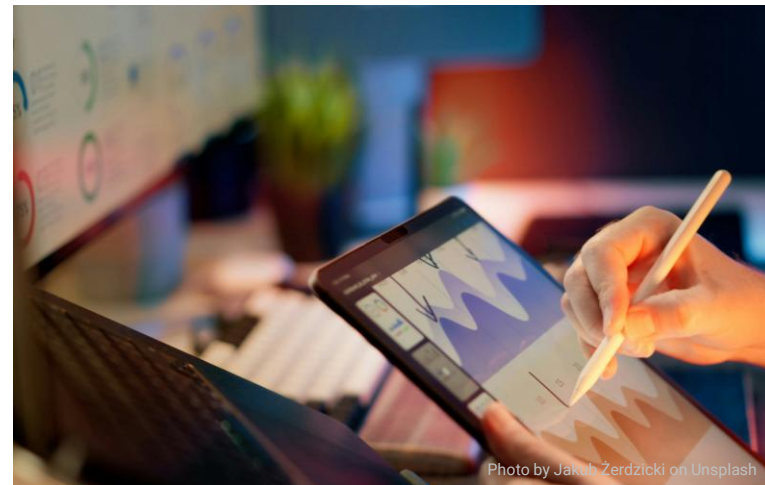


Performance Indicators for I-US

Composite and single-score KPIs can aggregate these dimensions for high-level reporting. For instance, normalized and weighted indicators may allow authorities to compare EcoSites, assess improvements over time, or communicate outcomes to funding bodies. However, aggregated scores should always be complemented with sub-indicator analyses to retain transparency and highlight trade-offs between dimensions.

3. Benchmarking and Functional Comparisons

Effective KPI analysis requires benchmarking against conventional systems or comparable reference scenarios. Because I-US hubs are multifunctional, comparison typically relies on a **functional unit**, such as treating a defined volume of wastewater while producing specified quantities of biogas or recovered materials.





Performance Indicators for I-US

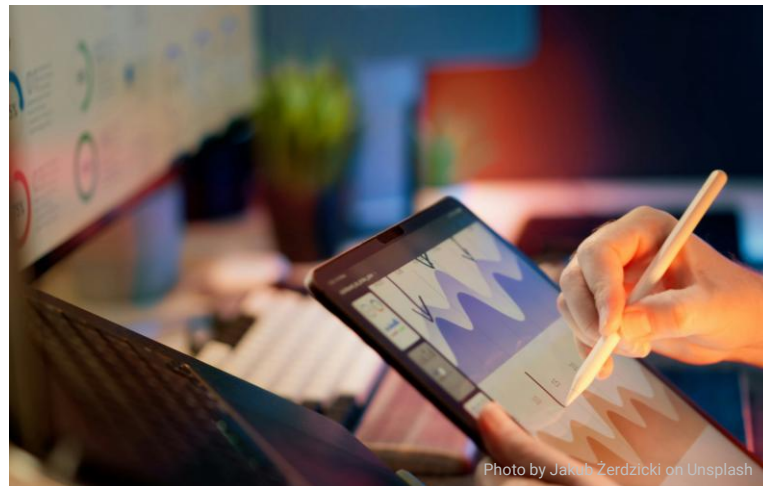
The **system expansion method** accounts for multiple outputs, ensuring that all benefits and trade-offs are reflected in the comparison. Benchmarking enables municipalities to:

- Identify operational and sustainability gaps
- Demonstrate added value relative to conventional systems
- Justify policy or regulatory adjustments
- Inform scaling and replication strategies

5. Using KPIs for Decision-Making and Adaptive Management

KPIs are not merely reporting tools; they are instruments of strategic governance. By tracking inputs and outputs systematically, municipalities can:

- Optimize resource allocation and operational processes
- Adjust incentives, subsidies, and financial mechanisms

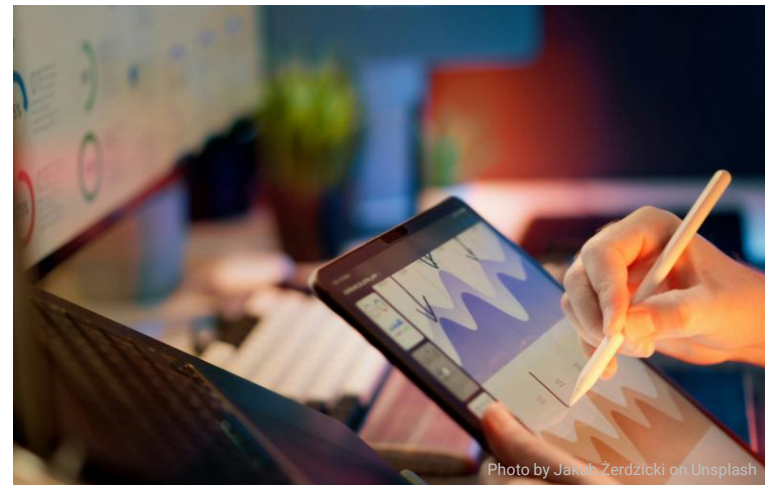




Performance Indicators for I-US

- Refine regulatory frameworks and permitting processes
- Support evidence-based decisions for scaling EcoSites across regions

Longitudinal monitoring is particularly important in early-stage EcoSites. Pilot operations may initially show mixed results, but tracking KPIs over time reveals **optimization potential**, improved resource efficiency, and reductions in environmental and economic impacts. When embedded in adaptive management cycles, KPIs ensure that I-US hubs evolve into resilient, accountable, and sustainable systems.

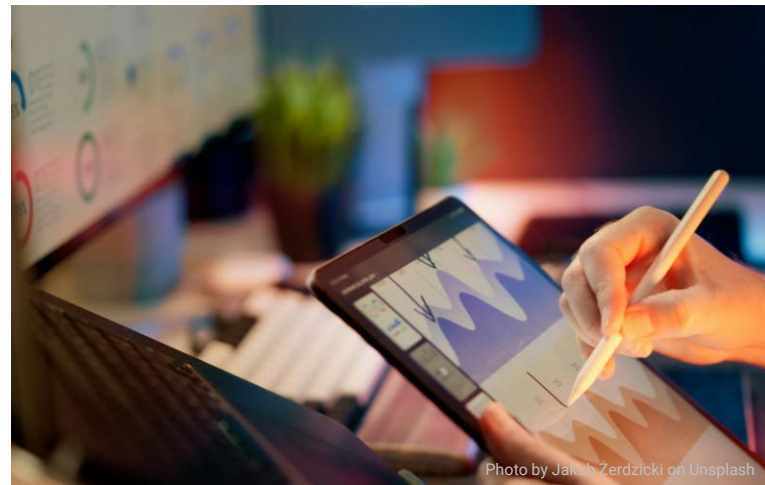




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SYMSITES EcoSites: Monitoring and Performance Evaluation

The SYMSITES project assessed the sustainability performance of four pilot EcoSites located in Austria, Denmark, Greece, and Spain. These EcoSites transform urban and industrial waste streams into high-value resources, including treated water, biogas, hydrogen, digestate, and other by-products. The assessments were structured around three dimensions of sustainability (environmental, economic, and social) using Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (SLCA) methodologies.



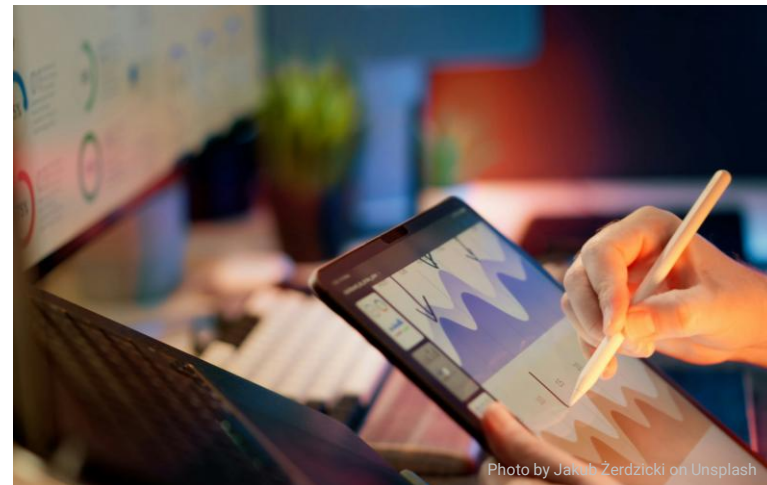


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SYMSITES EcoSites: Monitoring and Performance Evaluation

Benchmarking and Evaluation Approach:

Each EcoSite was compared to a conventional treatment system using the **same functional unit** (e.g., same volume of wastewater treated, same quantity of resources recovered). Because EcoSites are multifunctional, the system expansion method was applied to include all secondary functions, ensuring fair comparisons. Indicators were calculated to show how each EcoSite performed relative to its benchmark. A **single score analysis** aggregated environmental, economic, and social performance for simplified decision-making, while sub-indicator assessments retained transparency regarding trade-offs.





SYMSITES EcoSites: Monitoring and Performance Evaluation

1. Austrian EcoSite

Inputs and Outputs:

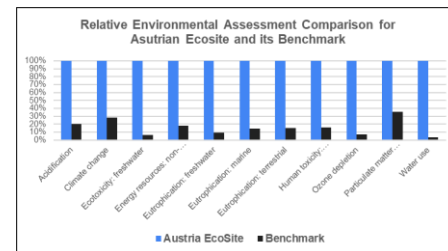
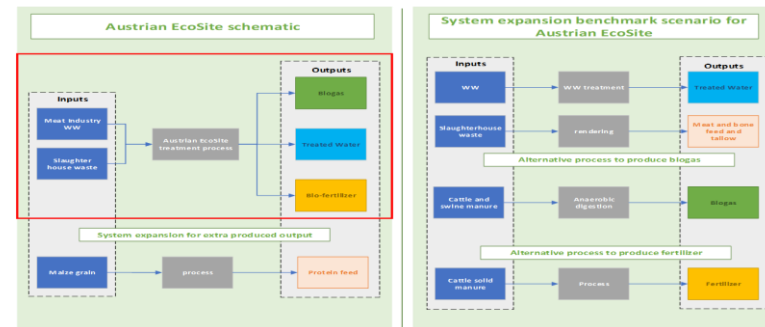
- Treats 4500 L/hr of meat processing wastewater and ~40 L/day slaughterhouse waste
- Additional inputs: 40 kg/week kitchen waste
- Outputs: 750 L/day treated water (65–70% COD reduction), 6 m³/day biogas, 150 L/day digester waste usable as fertilizer

Performance Compared to Benchmark:

Environmental: Impacts were 70–80% higher than the benchmark across most categories, except for **particulate matter formation**, which was lower.

Economic: Slightly better than benchmark; approximately 50% improvement relative to its own economic reference.

Social: High social risk associated with electricity production, particularly **fair salary compliance**; other impacts were lower but still present.





SYMSITES EcoSites: Monitoring and Performance Evaluation

2. Danish EcoSite

Inputs and Outputs:

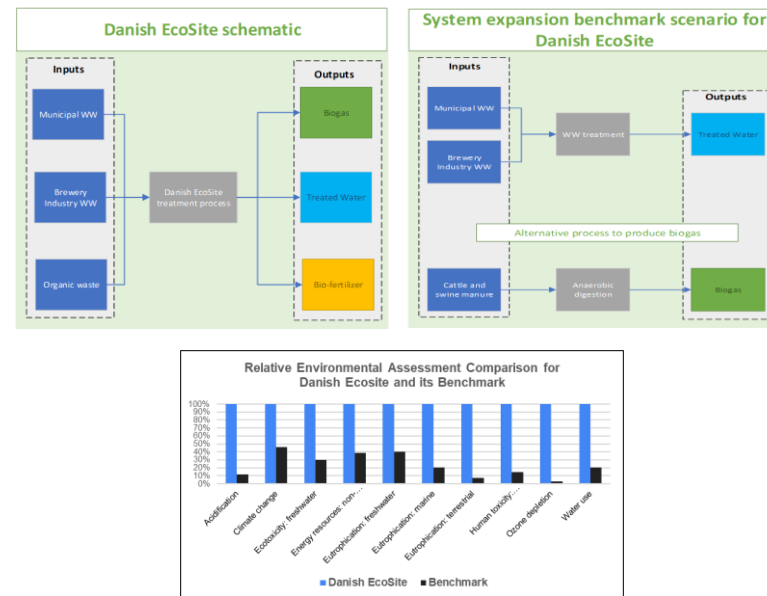
- Treats 250 L/day municipal wastewater and 250 L/day brewery wastewater
- Outputs: 500 L/day treated water (~91% COD reduction), 0.55 Nm³/day biogas

Performance Compared to Benchmark:

Environmental: Overall impacts 70–80% higher than benchmark; however, **climate change impacts** (GHG emissions) were reduced by 50% relative to conventional treatment.

Economic: Approximately 80% improvement compared to its economic benchmark.

Social: Fair salary compliance remains the dominant risk; other social impacts include potential violations of employment laws and regulations.





SYMSITES EcoSites: Monitoring and Performance Evaluation

3. Greek EcoSite

Inputs and Outputs:

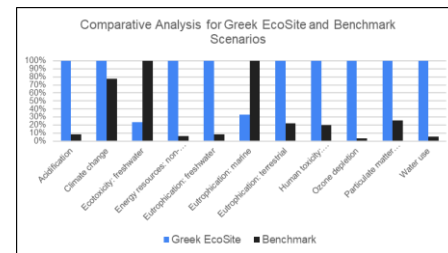
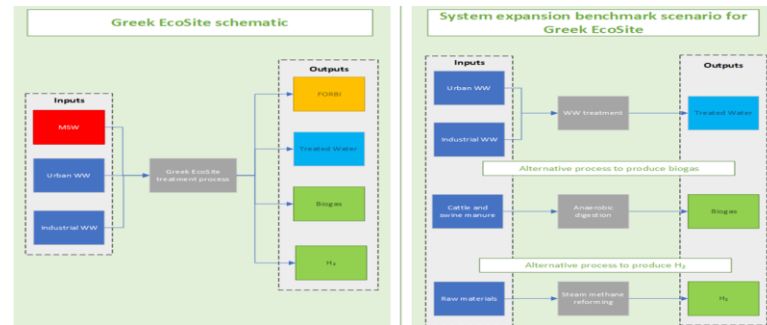
- Treats ~2940 L/day municipal wastewater, olive industry wastewater, and 120 kg/day municipal solid waste
- Outputs: 3000 L/day treated water (<85% COD reduction), 3200 L/day biogas via AnMBR, 100 L/day H_2 , ~20 kg FORBI for char production

Performance Compared to Benchmark:

Environmental: Impacts 70–80% higher than benchmark overall; climate change impacts were only 20–25% higher. **Freshwater ecotoxicity and marine eutrophication** were better due to landfill management of organic waste.

Economic: Approximately 60% improvement compared to benchmark.

Social: Highest risks include fair salary compliance, public sector corruption, and migration/trafficking issues.





SYMSITES EcoSites: Monitoring and Performance Evaluation

4. Spanish EcoSite

Inputs and Outputs:

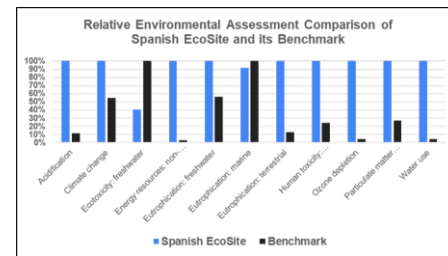
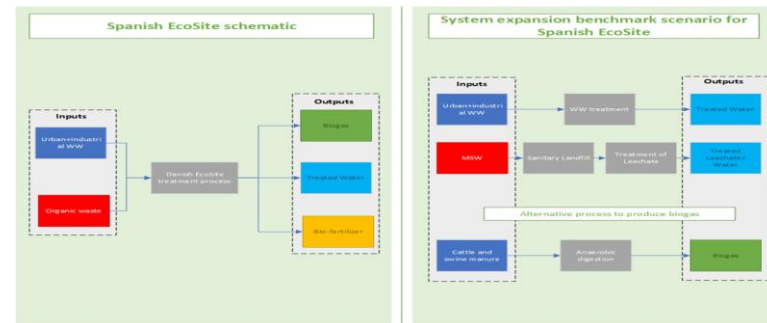
- Treats ~3929 L/day mixed industrial and urban wastewater and 14 kg/day municipal organic waste
- Outputs: 4000 L/day treated water (~100% COD reduction), 0.65 m³/day biogas, 20–30 L/day sludge

Performance Compared to Benchmark:

Environmental: Impacts higher than benchmark; freshwater ecotoxicity and marine eutrophication slightly improved due to landfill practices.

Economic: About 60% improvement relative to economic benchmark.

Social: High social risk linked to electricity consumption and fair salary compliance; other risks include child labour and corruption.





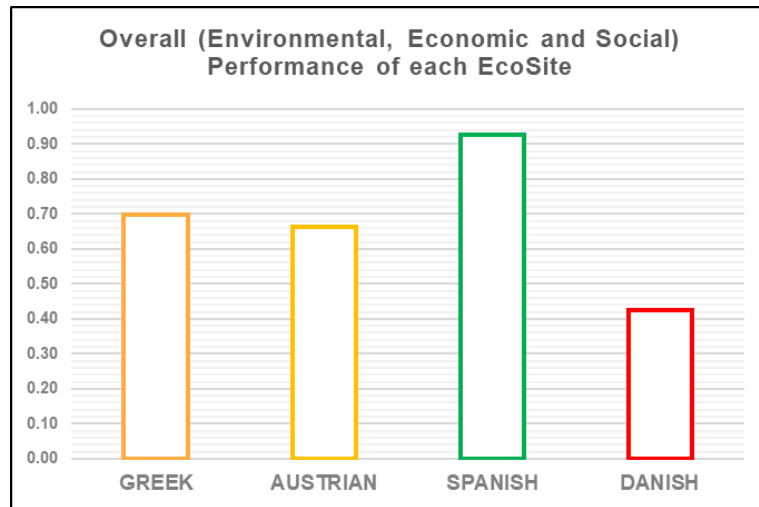
SYMSITES EcoSites: Monitoring and Performance Evaluation

Single Score Analysis and Lessons for Local Authorities

Composite KPI performance: Spanish EcoSite performed strongest overall relative to its benchmark, while Danish EcoSite scored lowest due to lower throughput.

Key observations:

- All EcoSites are **still evolving**, with processes under optimization.
- Not all waste streams are fully treated, affecting benchmark comparability.
- Benchmarks are based on large-scale facilities; local pilots may need context-specific benchmarks.
- **Trends over time:** Over a 24-month monitoring period, climate change impacts decreased by ~50%, showing **substantial improvement potential** with process optimization.



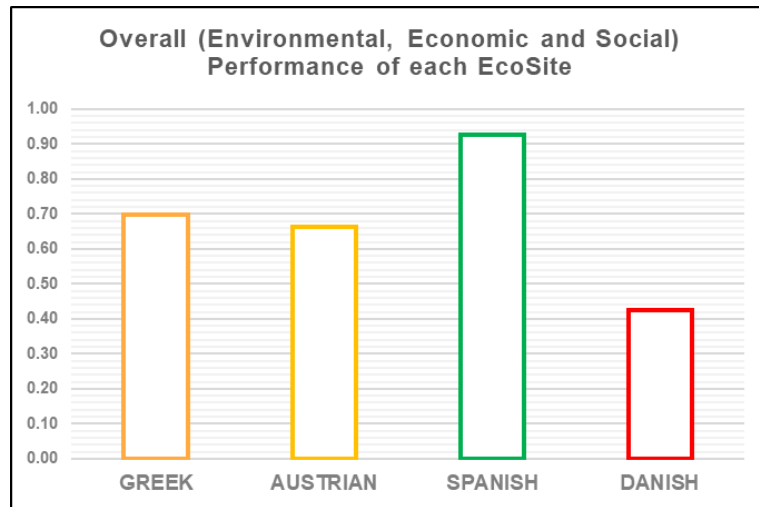


SYMSITES EcoSites: Monitoring and Performance Evaluation

Guidance for Monitoring and Evaluation in a Replicated Pilot

Local authorities planning to replicate a SYMSITES pilot should adopt the following approach:

- **Define functional units** to compare outputs (e.g., volume of wastewater treated, energy produced, nutrients recovered).
- **Select KPIs** across environmental, economic, and social dimensions, adapted to the local context. Environmental: GHG emissions, resource use, waste diversion, ecotoxicity; Economic: life cycle costs, revenues from by-products, avoided disposal costs; Social: labour conditions, fair salary, occupational health and safety, governance indicators
- **Collect input and output data**: track material, energy, water, and human resources used, as well as outputs produced.

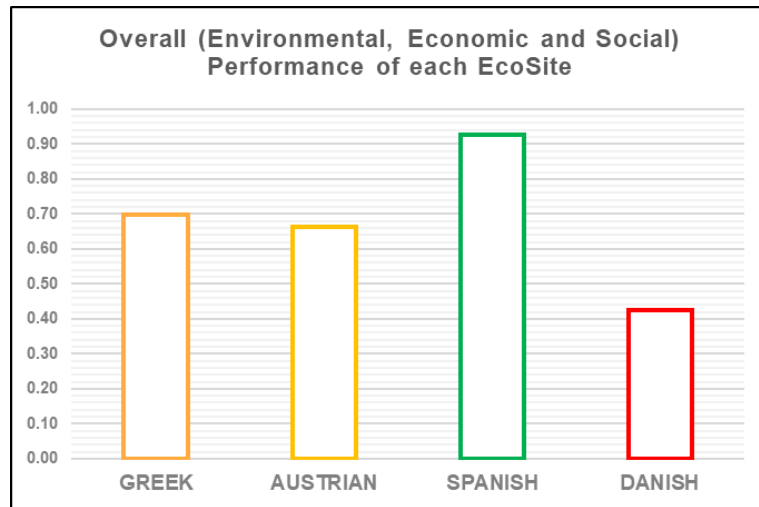




SYMSITES EcoSites: Monitoring and Performance Evaluation

- **Benchmarking:** compare pilot results with conventional treatment systems using system expansion to account for multiple outputs.
- **Single score analysis:** aggregate KPIs to track overall performance but maintain sub-indicator transparency.
- **Longitudinal monitoring:** repeat assessments periodically to capture improvements as processes are optimized.
- **Stakeholder engagement:** involve technical operators, regulators, and local communities to validate results and inform adaptive governance.

By applying this methodology, municipalities can **quantify, monitor, and communicate the sustainability benefits** of I-US pilots, supporting evidence-based decision-making, policy adaptation, and scaling of successful models.





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Chapter 7.2: Policy Feedback and Continuous Improvement

The final chapter discusses policy feedback and continuous improvement, emphasizing the importance of data-driven policy adjustments. By incorporating real-world insights, local governments can refine regulations, optimize incentive structures, and scale successful I-US models across multiple municipalities. It will present how to create adaptive policy frameworks to ensure that I-US remains a viable and evolving solution for sustainable urban-industrial collaboration.

- Target audience: Local Authorities and Municipalities
- Estimated time: 10 minutes
- Includes: Explanations





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Policy Feedback Loops: Function and Importance

Effective implementation of I-US goes beyond establishing technical infrastructure; it requires **adaptive governance systems** capable of responding to real-world performance data. Once KPIs are being consistently used to measure environmental, economic, and social impacts, local and regional authorities can use these insights to iteratively refine policies, regulations, incentives, and institutional frameworks. Adaptive policy feedback ensures that I-US hubs not only deliver measurable benefits but remain resilient, scalable, and integrated into regional development strategies.

Policy feedback transforms traditional static regulatory approaches into dynamic governance systems. In I-US, the performance of resource exchanges (such as energy recovery, wastewater reuse, and by-product valorisation) must be continuously evaluated, and policy mechanisms should respond accordingly.



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Policy Feedback Loops: Function and Importance

Unlike conventional environmental regulation, which may be reviewed only every five to ten years, I-US governance requires **frequent, multi-level feedback loops** encompassing operational, institutional, and systemic levels. This allows authorities to detect deviations, address regulatory bottlenecks, and optimize incentives in near real-time.

1. Policy Feedback Loops: Function and Importance

In SYMSITES, the development of an **IT Regional Management Platform (ITRMP)** and supporting decision-support tools illustrates a best-practice approach to policy feedback. These systems provide authorities with:

- Near-real-time monitoring of **resource flows** (water, energy, materials)
- Performance metrics based on KPIs, aligned with LCA, LCC, and SLCA assessments
- Social outcomes, such as labour compliance and stakeholder engagement metrics



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Policy Feedback Loops: Function and Importance

Feedback mechanisms allow authorities to:

- Detect **performance deviations** in water or energy reuse
- Identify **unintended regulatory barriers** or bottlenecks
- Trigger revisions to permits, standards, or financial incentives
- Support **evidence-based scaling** of successful EcoSites across multiple municipalities

By grounding policy decisions in measured outcomes rather than assumptions, local authorities can ensure I-US initiatives deliver **consistent value** and evolve in alignment with local conditions.

2. Adaptive Regulatory Design and Incentive Mechanisms

Regulations and incentives must be **iterative and performance-based**. Traditional regulatory systems treat rules as static, often inhibiting flexible reuse of resources or novel industrial symbiosis models.



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Policy Feedback Loops: Function and Importance

To overcome these limitations:

- **Iterative Regulatory Design:** Rules include built-in review clauses and thresholds that trigger re-evaluation when performance benchmarks are met or exceeded. For example, if wastewater quality consistently surpasses reuse standards, permitting frameworks can be simplified to expand eligible reuse applications.
- **Incentive Optimization:** Financial incentives—such as subsidies, tax schemes, or performance-based payments—should be recalibrated according to observed outputs and outcomes:
- **High-performing hubs:** incentives may be adjusted to stimulate secondary markets or wider replication.
- **Underperforming hubs:** funds are redirected to areas with greater sustainability impact.



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Policy Feedback Loops: Function and Importance

3. Institutionalizing Adaptive Governance

Adaptive governance bridges the gap between operational performance and strategic oversight. I-US spans multiple sectors—urban planning, environmental management, utility regulation, and economic development—requiring **cross-departmental coordination**. Key institutional mechanisms include:

- **Dedicated I-US coordination units** to centralize monitoring, policy analysis, and technical support
- **Annual performance review workshops** to assess KPI results and identify optimization opportunities
- **Inter-jurisdictional working groups** for regional policy harmonization and knowledge sharing



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Policy Feedback Loops: Function and Importance

Structured governance ensures that feedback informs both **technical operations and strategic decision-making**, preventing siloed decision-making and enhancing the hub's overall resilience.

Stakeholder engagement is another critical component. SYMSITES implemented forums, advisory boards, and consultation cycles to surface non-technical barriers, co-develop solutions, and ensure legitimacy. For local authorities, formal engagement processes help:

- Identify hidden operational or regulatory constraints
- Gather input from private sector participants, public agencies, and civil society
- Strengthen transparency and accountability in policy adjustment





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Policy Feedback Loops: Function and Importance

4. Scaling and Replicating I-US Models

Feedback systems are essential not only for optimization but also for **scaling successful models** across multiple municipalities. Authorities should focus on:

Documentation and Standardization:

- Technical blueprints of processes and infrastructure
- Regulatory adaptations and lessons learned
- Performance outcomes from KPIs
- Stakeholder engagement approaches

Regional Policy Integration:

- Align zoning and permitting standards across jurisdictions
- Harmonize incentive frameworks for shared resources
- Create unified standards for waste quality, energy, and water reuse



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Policy Feedback Loops: Function and Importance

5. Risk Management and Resilience

Adaptive feedback systems also enhance **systemic resilience**. I-US hubs operate in dynamic contexts with potential disruptions in markets, technology, or supply chains. SYMSITES integrated scenario modeling to **stress-test policy and operational options**, helping authorities anticipate emerging risks. Key risk management strategies include:

- Contingency protocols for rapid regulatory adjustments in case of performance shortfalls
- Dynamic reallocation of incentives based on evolving outputs
- Continuous assessment of environmental and social risks to ensure regulatory compliance





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Policy Feedback Loops: Function and Importance

6. Common Pitfalls and Recommendations

Authorities often face challenges when implementing feedback-driven governance:

- **Data silos** impede comprehensive evaluation of EcoSite performance
- **Infrequent policy reviews** prevent timely course correction
- **Weak stakeholder integration** reduces legitimacy and limits insight
- **Under-resourced monitoring systems** compromise KPI accuracy

7. Strategic Outlook

Robust feedback loops transform I-US hubs from isolated pilots into **enduring elements of sustainable regional development**. Authorities equipped with adaptive policy frameworks and performance-based governance can:

- Enhance circular economy outcomes by optimizing resource flows



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Policy Feedback Loops: Function and Importance

- Promote local economic competitiveness through recovered materials and energy
- Strengthen urban-industrial resilience against environmental and market changes
- Enable the scaling and replication of high-performing EcoSites

By embedding continuous policy feedback into the lifecycle of I-US initiatives, municipalities can ensure that I-US evolves dynamically with local conditions, generating measurable environmental, economic, and social benefits over time.



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Sources

H4C ECoP (2022) D1.3 Key Performance Indicators for H4C. Available: <https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e50afeff36&appId=PPGMS>

Kantor, I., Bütün, H. E., Robineau, J. L., Maqbool, S., Norbert, R., Zwaenepoel, B., ... & Maréchal, F. (2019). Long-and short-lists of key performance indicators in industry and for industrial symbiosis

Katana, K., Glaa, B., & Mirata, M. (2024). Facilitator roles for knowledge sharing in industrial symbiosis networks during emergence. *Business Strategy and the Environment*, 33(8), 8540-8558.

Kosmol, L. (2019, July). Sharing is caring-information and knowledge in industrial symbiosis: a systematic review. In 2019 IEEE 21st conference on business informatics (CBI) (Vol. 1, pp. 21-30). IEEE.

Lütje, A., & Wohlgemuth, V. (2020). Tracking sustainability targets with quantitative indicator systems for performance measurement of industrial symbiosis in industrial parks. *Administrative sciences*, 10(1), 3.

Valenzuela-Venegas et al. 2018. A resilience indicator for Eco-Industrial Parks. *Journal of Cleaner Production* 174: 807–20.

Zhang, X., & Chai, L. (2019). Structural features and evolutionary mechanisms of industrial symbiosis networks: Comparable analyses of two different cases. *Journal of Cleaner Production*, 213, 528–539.



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CONSORTIUM MAP

