

Module 1: What is I-US?

This project has received funding from the European Union's Horizon Europe program under GA Project 101058426.





SYMSITES

Module Overview

In this module, learners gain a clear understanding of Industrial-Urban Symbiosis (I-US) and its role in the circular economy. They will explore how collaboration between industries and cities can optimize resource use, reduce waste, and create shared environmental, economic, and social benefits.

- [Chapter 1.1: Introduction to the Circular Economy](#)
- [Chapter 1.2: Introduction to IS and I-US](#)
- [Chapter 1.3: I-US examples – generic introduction](#)
- [Chapter 1.4: Environmental, Economic and Social co-benefits for different stakeholders](#)





SYMSITES

Chapter 1.1: Introduction to the Circular Economy

This chapter provides a foundational understanding of the circular economy, explaining its principles and how it contrasts with the traditional linear economy as well as its sustainable concept. It covers key strategies such as resource efficiency, waste reduction, and closed-loop systems that contribute to sustainability. The chapter also introduces the role of industries and municipalities in achieving a circular economy.

- Target audience: General Audience (no prior knowledge required)
- Estimated time: 15 minutes
- Includes: Explanations Exercises



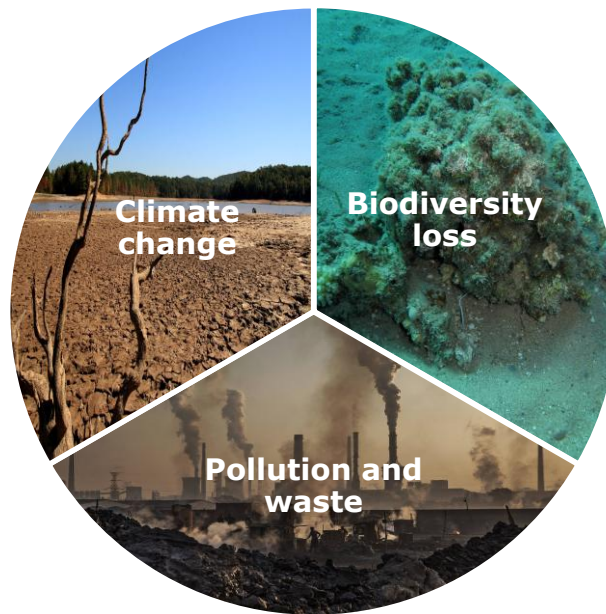


Why do we need a Circular Economy?

Triple planetary crisis

The Triple Planetary Crisis refers to the United Nations adopted framework describing the three intersecting and mutually reinforcing global environmental crises of 1) climate change, 2) biodiversity loss and 3) Pollution and waste.

These crises are driven largely by human activity and the unsustainable use of natural resources. Climate change is caused by the accumulation of greenhouse gases in the atmosphere, leading to rising temperatures, extreme weather events, and sea level rise. Biodiversity loss results from habitat destruction, overexploitation, pollution, and climate change itself, threatening the stability of ecosystems and the services they provide. Meanwhile, pollution—of air, water, and soil—damages human health, degrades ecosystems, and further accelerates climate and biodiversity issues.





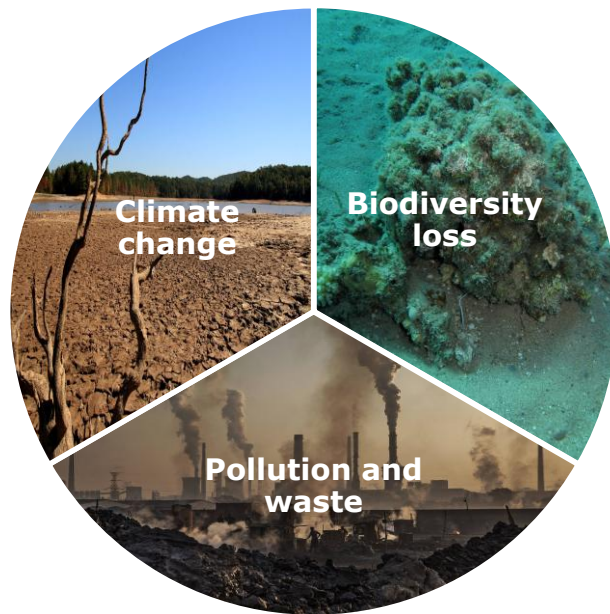
Why do we need a Circular Economy?

Triple planetary crisis

Together, these three crises form a feedback loop that intensifies global environmental and socio-economic challenges. For example, climate change can worsen biodiversity loss, while pollution can exacerbate climate impacts and harm fragile ecosystems. Addressing them requires integrated, systemic solutions that promote sustainability, equity, and resilience, such as transitioning to a circular economy, conserving ecosystems, and reducing emissions and waste. Solving the triple planetary crisis is essential to safeguarding the planet's health and ensuring a liveable future for all.

Want to learn more?

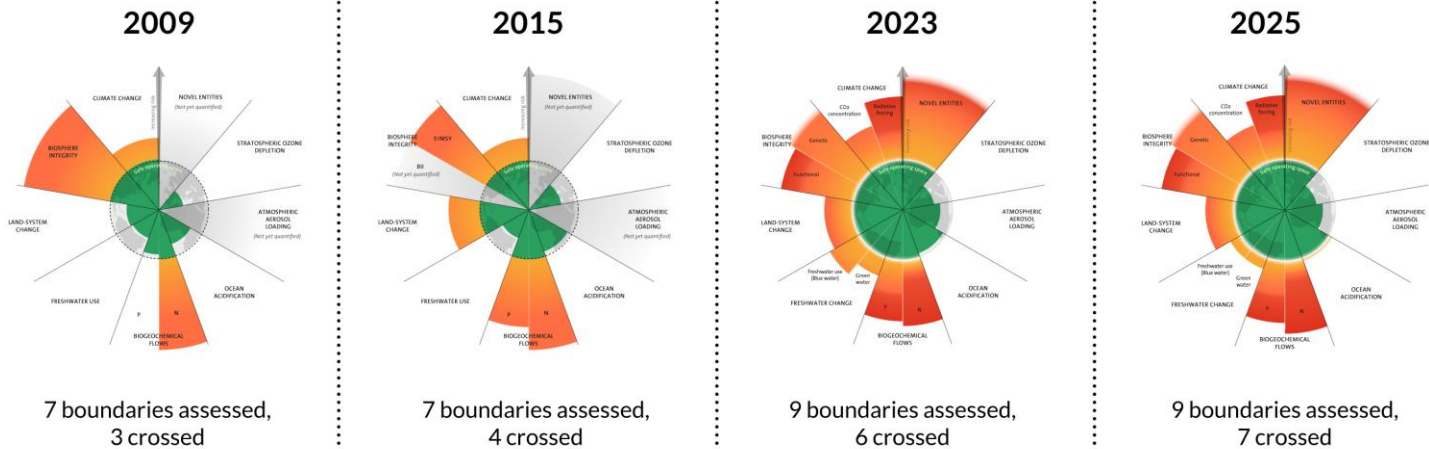
- Read this: [UNCC - The triple planetary crisis of pollution, climate change and biodiversity loss](#)
- Watch this: [UNFCCC - What is the Triple Planetary Crisis?](#)





Why do we need a Circular Economy?

Breaching Planetary Boundaries



Source: Azote for Stockholm Resilience Centre, Stockholm University. Based on Sakschewski and Caesar et al. 2025, Richardson et al. 2023, Steffen et al. 2015, and Rockström et al. 2009

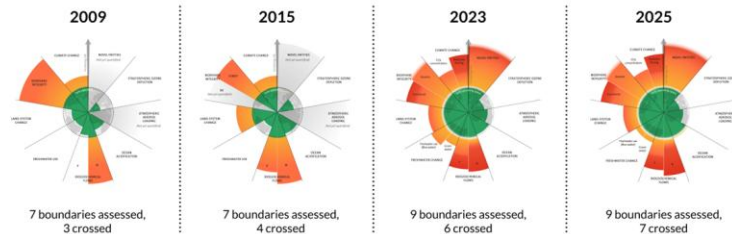




Why do we need a Circular Economy?

Breaching Planetary Boundaries

It refers to humanity's overstepping of critical ecological limits that keep Earth's systems stable and hospitable for life. Scientists have identified nine such boundaries (covering areas like climate change, biodiversity loss, freshwater use, land-system change, and chemical pollution) that act like guardrails for the planet's resilience. When these thresholds are crossed, the Earth system can undergo abrupt, potentially irreversible changes that undermine the conditions that have allowed human societies to flourish. For example, exceeding the climate boundary through excessive greenhouse gas emissions leads to global warming, while biodiversity loss weakens ecosystems' ability to support life and recover from stress. Breaching planetary boundaries is therefore a warning that human activities are destabilizing the very systems that sustain civilization.



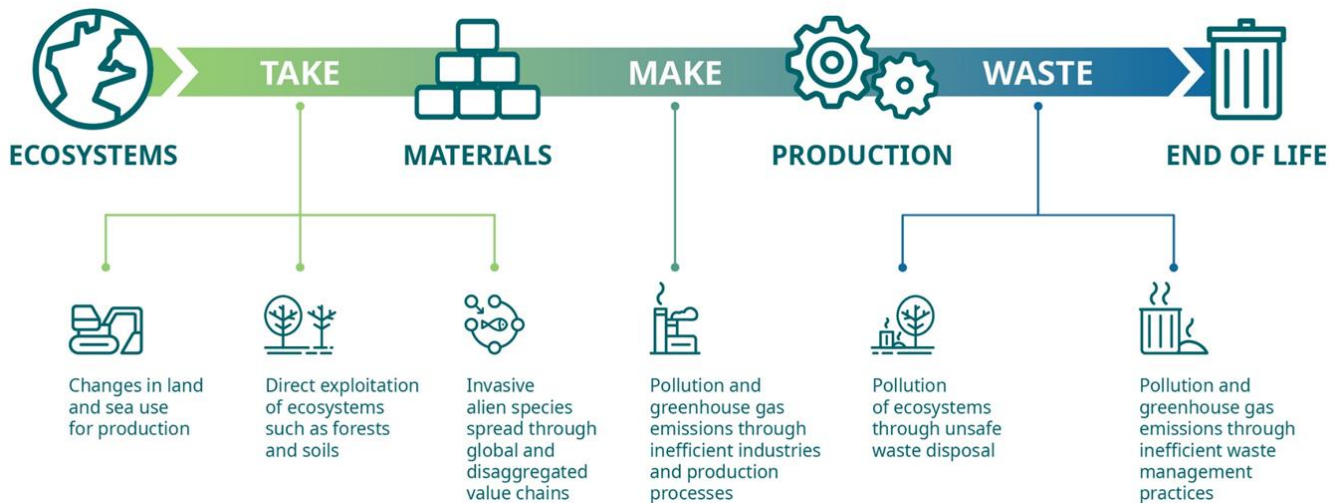
Source: Azte for Stockholm Resilience Centre, Stockholm University. Based on Sakachewski and Caesar et al. 2023, Richardson et al. 2023, Steffen et al. 2015, and Rockström et al. 2009





Why do we need a Circular Economy?

Linear Economy



Source: ICLEI Circular City Actions Framework



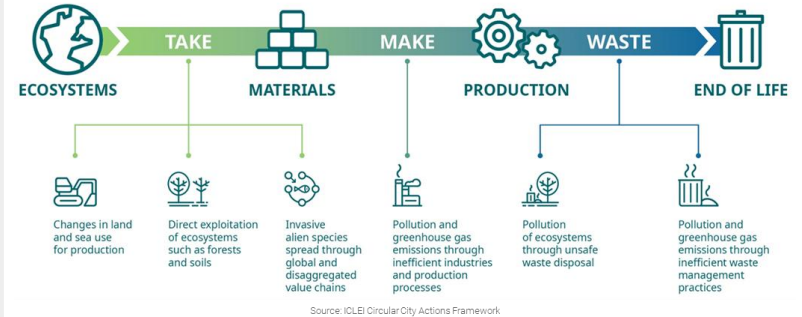


Why do we need a Circular Economy?

Linear Economy

The linear economy, as has been introduced previously, is based on the concept of "*take, make and dispose*." This has been the model used traditionally and is present in most economies worldwide.

In this system, raw materials are extracted, transformed into products, used by consumers, and then discarded as waste, often without being reused or recycled. It assumes that natural resources are abundant and that ecosystems can absorb large amounts of waste. While this model has fuelled industrial growth and mass production, it is highly resource-intensive and unsustainable in the long run. By continuously depleting finite resources and generating waste and pollution, a linear economy contributes to environmental degradation, climate change, and the breaching of planetary boundaries.





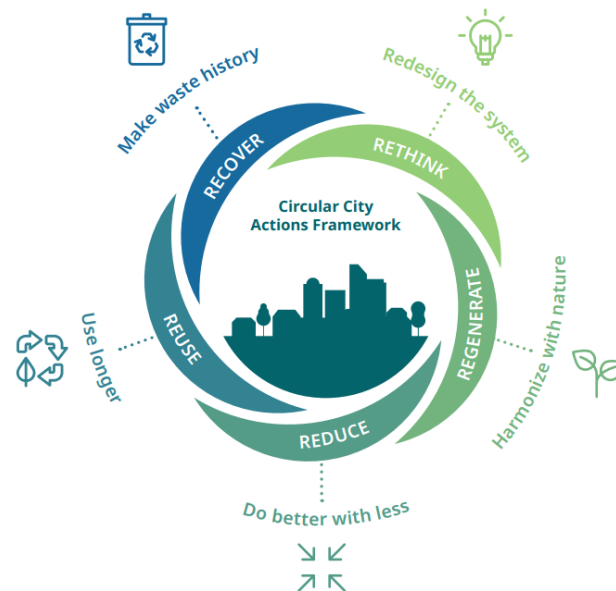
What is a Circular Economy?

Circular Economy: the Concept

As a response to the challenges posed by a linear economic model, the circular economy is a systemic solution framework designed to tackle the global challenges of climate change, biodiversity loss, waste, and pollution. It is a production and consumption model that fundamentally aims to maintain the value of products, materials, and resources in the economy for as long as possible while minimizing waste generation. This approach represents a systemic shift to a regenerative economic model that is intrinsically good for business, people, and the environment.

At its core, the circular economy is driven by design and is based on three fundamental principles:

- Eliminate waste and pollution.
- Circulate products and materials at their highest value.
- Regenerate nature.





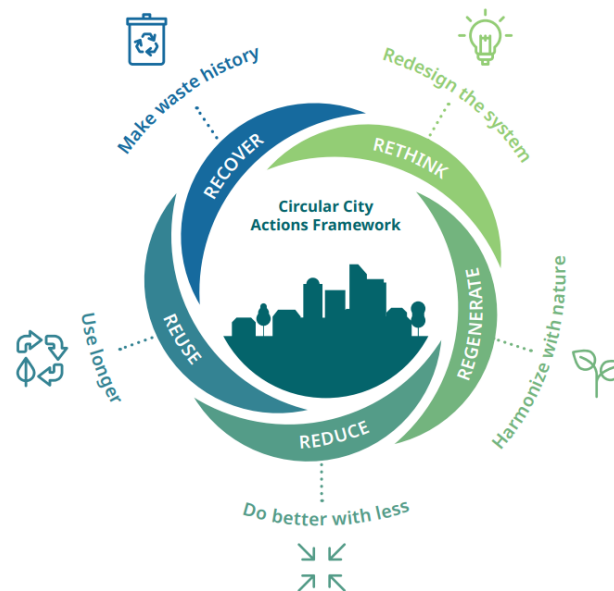
What is a Circular Economy?

Circular Economy: the Concept

This economic model seeks to decouple economic growth from resource use and environmental harm, positioning it at the centre of efforts to transform societies into fair and prosperous ones and achieve climate neutrality within planetary boundaries. It offers the tools to grow prosperity, jobs, and resilience while simultaneously cutting greenhouse gas (GHG) emissions, waste, and pollution.

Want to learn more?

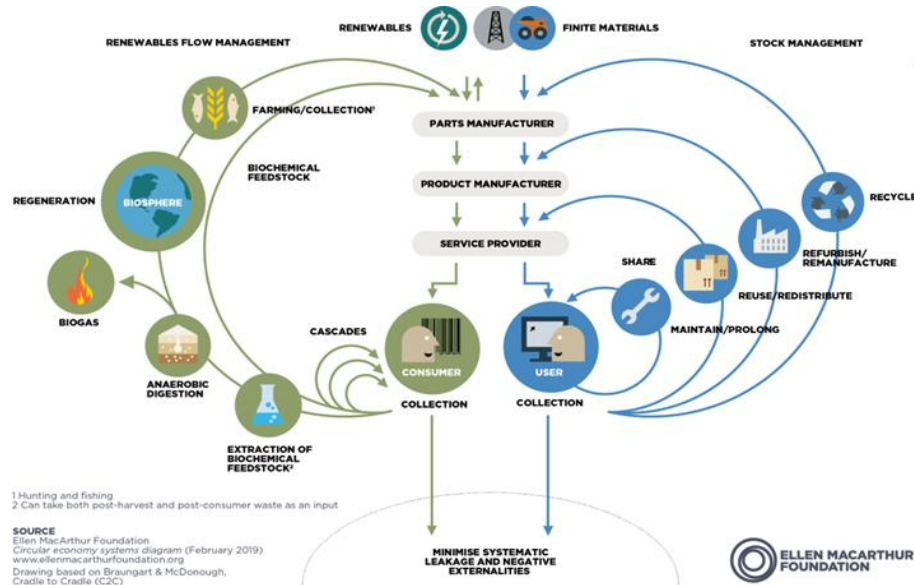
- Watch this: [Explaining the Circular Economy and How Society Can Re-think Progress | Animated Video Essay](#)





What is a Circular Economy?

Circular Economy: the Ellen MacArthur Butterfly Diagram



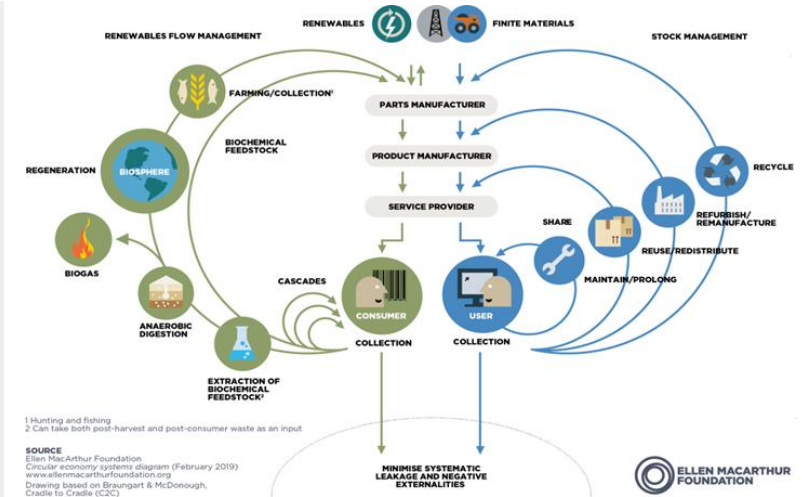


What is a Circular Economy?

Circular Economy: the Ellen MacArthur Butterfly Diagram

To transition towards a circular economy, it's crucial to have a clear understanding of how materials flow within such a system. The Ellen MacArthur Foundation's Butterfly Diagram is a widely recognized and powerful visual tool that illustrates the continuous flow of materials in a circular economy. This diagram serves as a systems solution framework that helps to address global challenges such as climate change, biodiversity loss, waste, and pollution. It represents a system where materials are intended to never become waste and nature is regenerated.

While the R-strategies described earlier focus on what actions to take, the Butterfly Diagram focuses on where those actions fit within a systemic material flow.





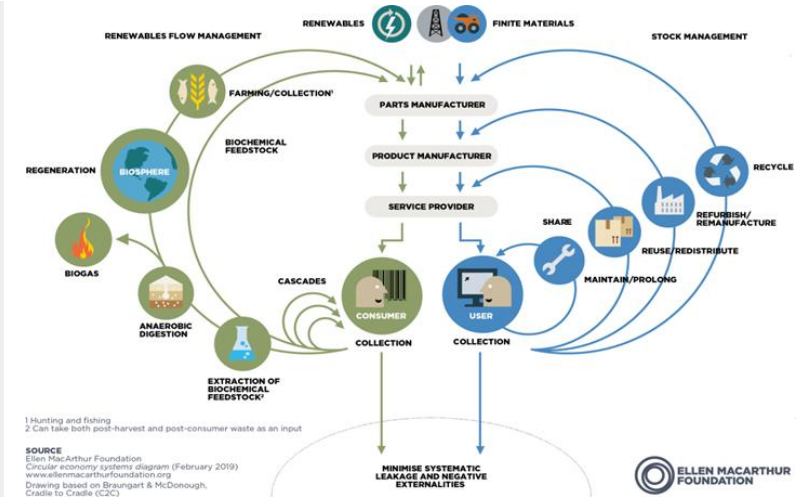
What is a Circular Economy?

Circular Economy: the Ellen MacArthur Butterfly Diagram

The Butterfly Diagram is fundamentally driven by design and is based on three core principles:

- Eliminate waste and pollution
- Circulate products and materials at their highest value
- Regenerate nature

The diagram is divided into two main cycles, reflecting the different types of materials and their respective pathways for circulation: the technical cycle and the biological cycle.



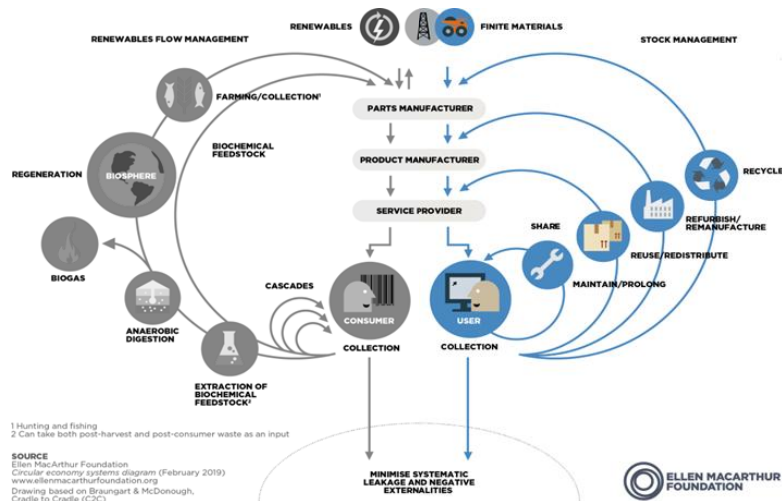


Circular Economy: the Ellen McArthur Butterfly Diagram

1) The Technical Cycle: Keeping Products and Materials in Use

The technical cycle is designed for products and materials that are not consumed during use, such as metals, plastics, and wood. The primary goal of this cycle is to keep these materials in circulation at their highest possible value for as long as possible. This is achieved through the “R-strategies” explained earlier that focus on extending product lifespan and material utility:

- **Reuse:** This involves the repeated use of a product or component for its intended purpose without significant modification.
- **Repair:** This is the operation by which a faulty or broken product or component is returned to a usable state to fulfill its intended use.





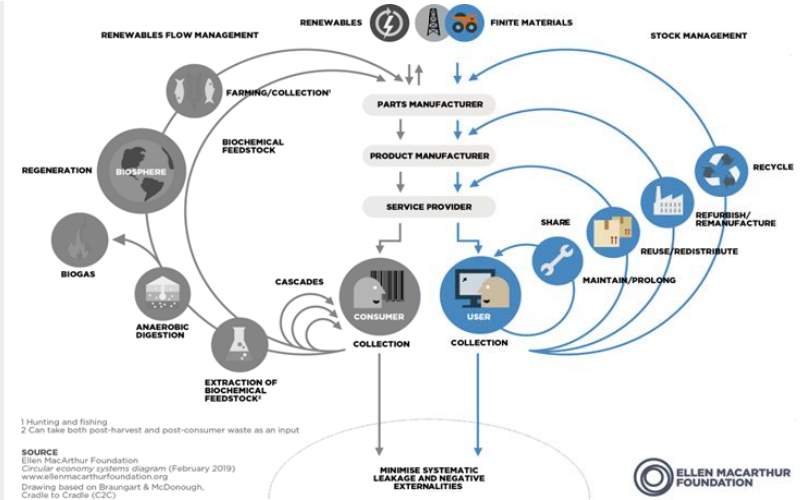
What is a Circular Economy?

Circular Economy: the Ellen MacArthur Butterfly Diagram

1) The Technical Cycle: Keeping Products and Materials in Use

- **Refurbish:** This strategy involves restoring products and infrastructure to an updated or improved condition.
- **Remanufacture:** This process re-engineers products and components to an "as-new" condition, often with the same or improved level of performance as a newly manufactured one.
- **Recycle:** When products or components can no longer be reused, repaired, refurbished, or remanufactured, their materials are processed to produce new resources. This is typically the last resort within the technical cycle to maintain material value.

These processes aim to slow down and close material loops within the economy, reducing the need for virgin resource extraction and minimizing waste.





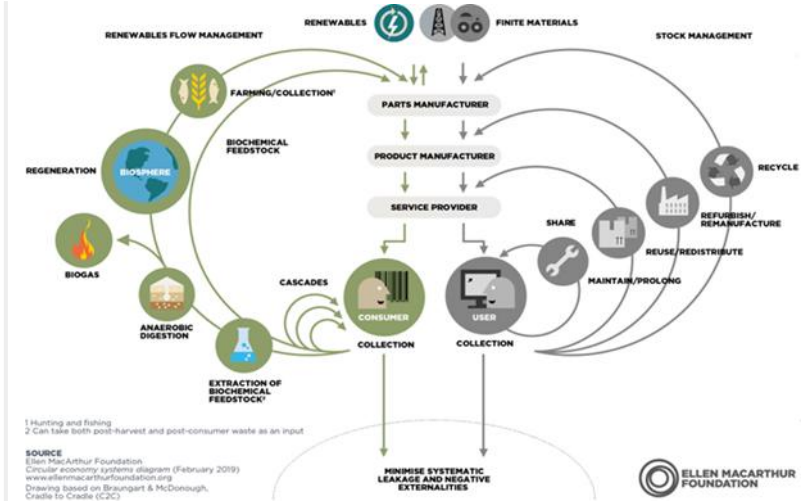
What is a Circular Economy?

Circular Economy: the Ellen McArthur Butterfly Diagram

2) The Biological Cycle: Regenerating Natural Systems

The biological cycle focuses on biodegradable materials that can be safely returned to the biosphere. The objective here is to regenerate natural capital by returning nutrients to the Earth. Key processes in this cycle include:

- **Composting:** This is a process where organic materials decompose under controlled conditions to produce nutrient-rich soil amendments.
- **Anaerobic Digestion:** This process breaks down organic matter in the absence of oxygen to produce biogas and digestate, both of which can be valuable resources.





What is a Circular Economy?

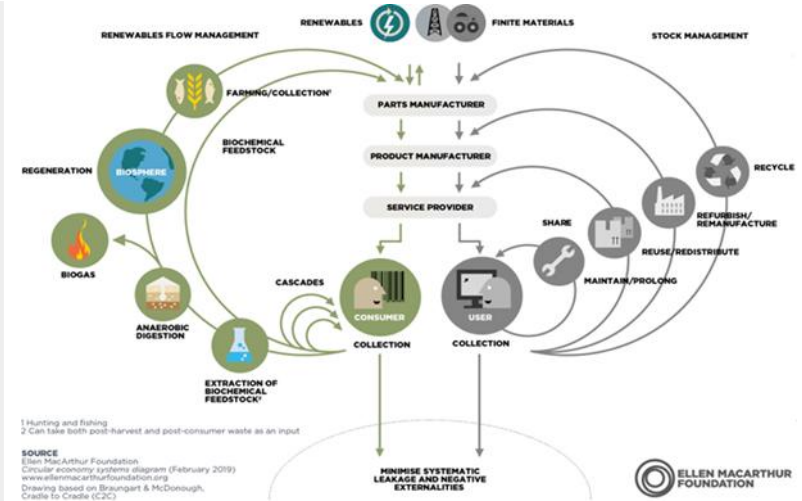
Circular Economy: the Ellen MacArthur Butterfly Diagram

2) The Biological Cycle: Regenerating Natural Systems

These biological processes help regenerate nature, contributing to healthy ecosystems and productive land, which is a core principle of the circular economy. The overall system is underpinned by a transition to renewable energy and materials, creating a resilient economy that benefits business, people, and the environment. By embracing the principles illustrated in the Butterfly Diagram, cities and regions can work towards a future where economic activity is decoupled from the consumption of finite resources and environmental harm.

Want to learn more?

- Read this: [The biological cycle of the butterfly diagram](#); [The technical cycle of the butterfly diagram](#);
- Watch this: [Ellen MacArthur Foundation - Butterfly diagram animation](#)



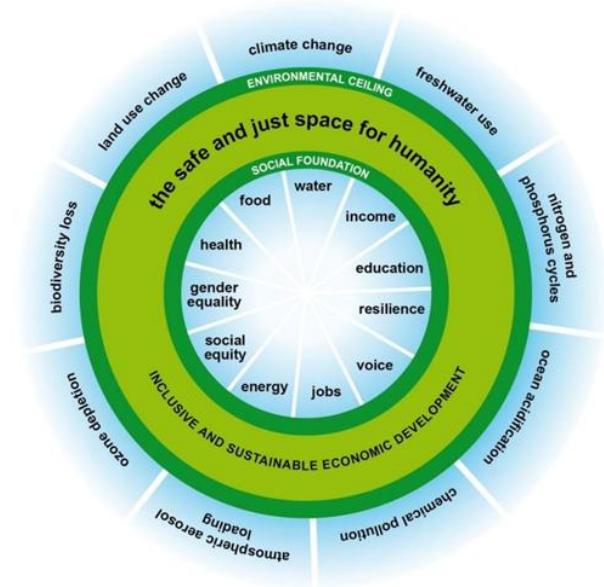


What is a Circular Economy?

Circular Economy: Doughnut Economy

While the Ellen MacArthur Foundation's Butterfly Diagram provides a visual representation of how materials continuously flow in a circular economy, another crucial framework for understanding sustainable urban development is Doughnut Economics. Created by Oxford Economist Kate Raworth, Doughnut Economics offers a new perspective on balancing the needs of people with the limitations of our planet, aiming to create a regenerative economy that is beneficial and realistic.

The Doughnut model visually represents the "safe and just space for humanity", where human well-being is achieved within planetary boundaries.



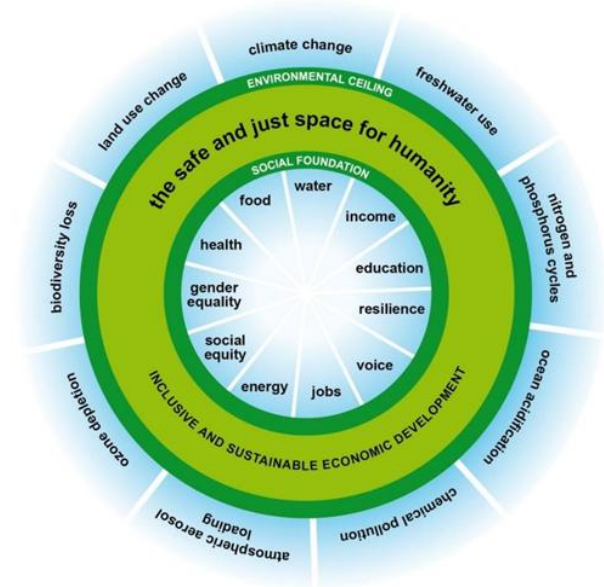


What is a Circular Economy?

Circular Economy: Doughnut Economy

Social Foundation (Inner Ring): This inner ring represents the basic human needs that everyone requires. If people fall below this inner ring, they are in a space of deprivation and shortfall, lacking essentials for a dignified life. These include e.g. water, food, health, education, housing, and peace and justice.

Ecological Ceiling (Outer Ring): This outer ring signifies the planetary boundaries which humanity must not exceed to remain sustainable. Going beyond this "outer crust" means entering a space of ecological overshoot, where human activity puts more pressure on the planet than it can take, causing environmental damage. These boundaries include e.g. Climate change, Chemical pollution, Biodiversity loss, Freshwater withdrawals, and Land conservation.





What is a Circular Economy?

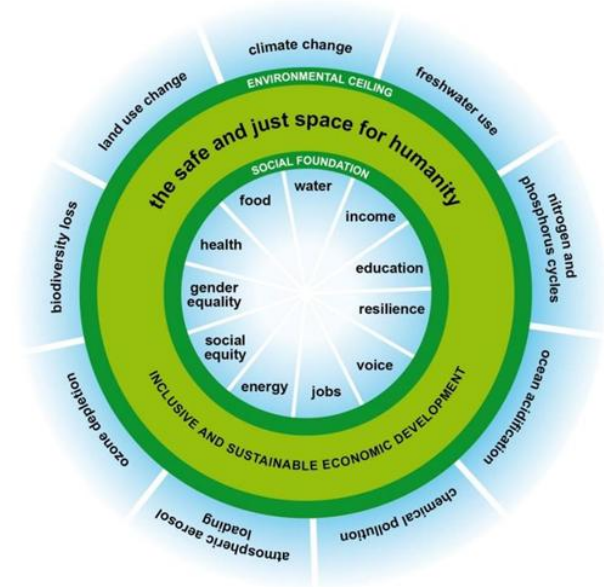
Circular Economy: Doughnut Economy

The Safe and Just Space for Humanity: The circular doughnut shape itself represents the need to find balance between the social foundation and the ecological ceiling. This is the desired space where well-being is developed for both people and the planet, avoiding both deprivation and environmental destruction.

The ultimate goal is to get everybody out of poverty (the inner hole) while simultaneously coming back within the ecological limits (the outer crust), achieving a dynamic balance within the Doughnut's safe and just space.

Want to learn more?

- Read this: [Doughnut Economics Action Lab - About Doughnut Economics](#)
- Watch this: [What is Doughnut Economics? - with Kate Raworth](#)



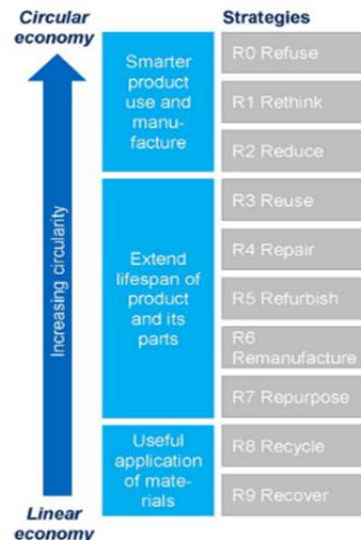


What is a Circular Economy?

Circular Economy: the 9R Framework

One of the operational conceptualizations of the Circular Economy is the 9R framework which prioritises circular actions to be applied across a product's entire life cycle following a hierarchical order. This is:

- **Refuse:** Eliminating the use or demand for harmful or unnecessary materials or products. For example, prohibiting single-use plastics in public services or digitalizing services to replace physical products.
- **Rethink:** Reformulating consumption and use models to intensify resource utilization, such as promoting compact city designs, multi-use community spaces, or shared mobility platforms.
- **Reduce:** Minimizing raw material and energy inputs. This includes business models like user-oriented product-service systems (e.g., leasing, pay-per-use, subscriptions) that provide access without ownership, reducing material footprint consumption.



Source: The 9R Framework on the Circular Economy, theorized by Kirchherr et al. (2017), Potting et al. (2017)

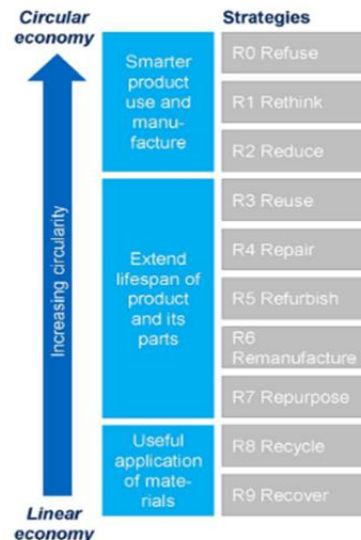




What is a Circular Economy?

Circular Economy: the 9R Framework

- Reuse: Using products and materials for their original purpose, either by the same user or a new one, through initiatives like community exchange centres or second-hand markets.
- Repair: Preventing the disposal of products by offering repair workshops or prioritizing repair of goods in public services.
- Refurbish: Restoring products and infrastructure to an updated or improved condition, such as renovating public buildings instead of demolishing them.
- Remanufacture: Transforming discarded products or components into new items with the same quality and functionality as the original, incentivizing local industries to adopt such practices.



Source: The 9R Framework on the Circular Economy, theorized by Kirchherr et al. (2017), Potting et al. (2017)

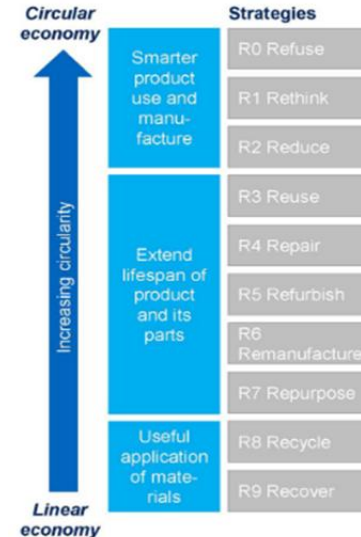




What is a Circular Economy?

Circular Economy: the 9R Framework

- **Repurpose:** Adapting discarded items for new uses, like transforming old railways into bike paths or underused public buildings into community centres.
- **Recycle:** Processing discarded materials to produce new resources, for example, prioritizing recycled materials in construction or building city-wide recycling systems.
- **Recover:** Extracting value from non-recyclable materials, often through waste-to-energy technologies, to produce energy or valuable by-products and reduce reliance on virgin resources.



Source: The 9R Framework on the Circular Economy, theorized by Kirchherr et al. (2017), Potting et al. (2017)





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Exercise – Quiz:

Understanding Circular Economy Actions *(4 questions, solution at the end)*

Question 1: A city replaces single-use plastic cutlery at public events with reusable tableware that is washed and used again. Which circular economy strategy does this best represent?

A: Recycle

B: Reuse

C: Recover

D: Remanufacture

Question 2: Which of the following actions is the most circular option?

A: Buying a new product made from recycled materials

B: Recovering energy from waste through incineration

C: Recycling a product at the end of its life

D: Repairing a broken product to extend its life





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Exercise – Quiz:

Understanding Circular Economy Actions

Question 3: A company shifts from selling office printers to offering “printing as a service,” maintaining ownership of the machines and taking them back for refurbishment. Which circular economy principle is most clearly applied?

A: Eliminate waste and pollution

B: Circulate products & materials at their highest value

C: Regenerate nature

D: Recover energy from waste

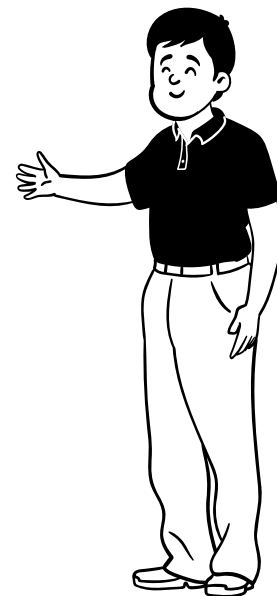
Question 4: Food waste from households is collected separately and processed in an anaerobic digestion plant to produce biogas and fertilizer. Which part of the circular economy system does this example belong to?

A: Technical cycle

B: Biological cycle

C: Linear economy

D: Resource extraction





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Exercise – Quiz: Solution

Understanding Circular Economy Actions

Question 1: A city replaces single-use plastic cutlery at public events with reusable tableware that is washed and used again. Which circular economy strategy does this best represent?

A: Recycle

☒ **B: Reuse**

C: Recover

D: Remanufacture

Why?

This example keeps products in use for the same purpose multiple times, avoiding waste altogether. Reuse is higher in the circular hierarchy than recycling because it preserves the product's value and avoids additional processing.





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Exercise – Quiz: Solution

Understanding Circular Economy Actions

Question 2: Which of the following actions is the most circular option?

- A: Buying a new product made from recycled materials
- B: Recovering energy from waste through incineration
- C: Recycling a product at the end of its life

☒ **D: Repairing a broken product to extend its life**

Why?

Repair keeps an existing product in use with minimal additional resource input. In the circular hierarchy, extending product life through repair is more circular than recycling or energy recovery, which occur later in the value chain.





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Exercise – Quiz: Solution

Understanding Circular Economy Actions

Question 3: A company shifts from selling office printers to offering “printing as a service,” maintaining ownership of the machines and taking them back for refurbishment. Which circular economy principle is most clearly applied?

- value**
- A: Eliminate waste and pollution ☒ **B: Circulate products & materials at their highest**
- C: Regenerate nature D: Recover energy from waste

Why?

By retaining ownership, the company is incentivized to design durable, repairable, and upgradable products. This model maximizes product lifespan and value, a core principle of the circular economy.





SYMSITES

Exercise – Quiz: Solution

Understanding Circular Economy Actions

Question 4: Food waste from households is collected separately and processed in an anaerobic digestion plant to produce biogas and fertilizer. Which part of the circular economy system does this example belong to?

A: Technical cycle

☒ **B: Biological cycle**

C: Linear economy

D: Resource extraction

Why?

Organic waste is safely returned to natural systems through biological processes, producing renewable energy and nutrients. This is a clear example of regenerating natural systems within the biological cycle.





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Chapter 1.2: Introduction to IS and I-US

This chapter explores the concepts of Industrial Symbiosis (IS) and Industrial-Urban Symbiosis (I-US), highlighting their significance in sustainable development. It outlines how industries and urban areas can exchange resources (such as energy, water, materials, and by-products) to create mutual benefits. The historical development of these concepts and their integration within the circular economy are also discussed.

- Target audience: General Audience (no prior knowledge required)
- Estimated time: 15 minutes
- Includes: Explanations Exercises



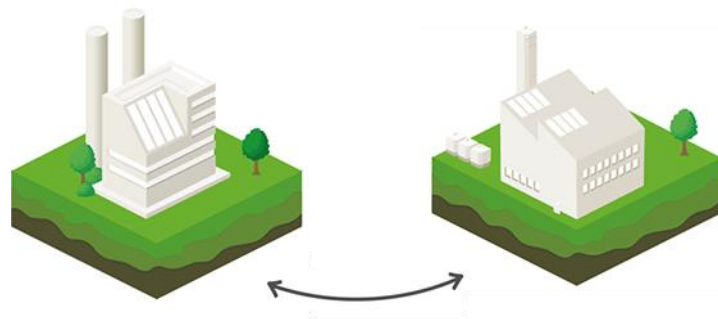


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What is Industrial Symbiosis (IS)?

Most people have heard the saying: “One man’s trash is another man’s treasure.” → In industrial symbiosis (IS), this idea becomes a business model.

Industrial symbiosis describes the exchange of including waste, by-products, residues, energy, water, logistics, capacity, expertise, equipment and materials between companies and value chains and sectors. Instead of using virgin materials, a company can use secondary materials – surplus or waste streams – from another. In doing so, both sides can benefit: *one reduces waste and disposal costs, the other saves on input materials*. Together, they achieve greater environmental and economic efficiency than they could on their own. It presents a systems approach to a more sustainable and integrated industrial economy that identifies business opportunities to improve resource utilisation and productivity. IS has its roots in industrial ecology and is integral to the circular economy agenda due to its potential for closing resource loops.





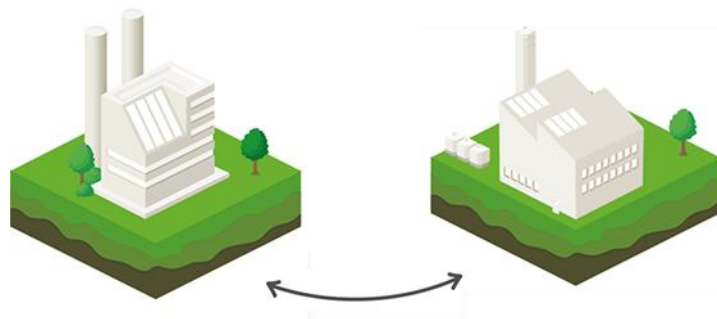
SYMSITES

What is Industrial Symbiosis (IS)?

IS, when successfully implemented, can be understood through several lenses:

- Operational: optimizing production processes, reducing waste streams, improving logistics.
- Financial: cutting costs, creating new revenue streams, sharing infrastructure.
- Environmental: reducing emissions, conserving resources, and lowering the overall ecological footprint.

Behind these tangible benefits lie intrinsic motivations - the logic of making better use of what already exists, and the growing awareness that resource efficiency is smart business. Historically, industrial symbiosis was market-driven, emerging where businesses saw clear mutual advantage.





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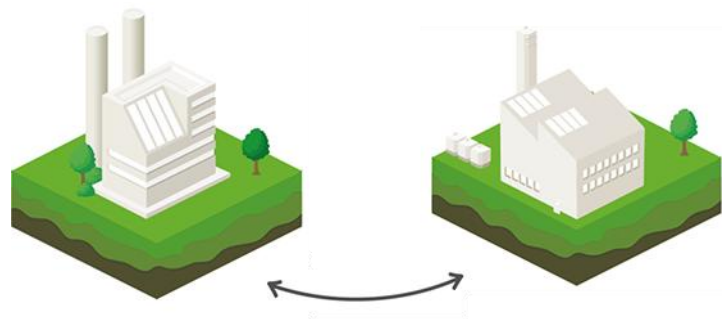
What is Industrial Symbiosis (IS)?

Today, new drivers reinforce it:

- EU and national policy frameworks promoting circular economy and waste valorisation,
- Technological innovation that allows better matching, tracking, and treating of secondary materials,
- And growing corporate sustainability commitments that reward collaboration over isolation.

Want to learn more?

- Read this: [Neves, A., Godina, R., Azevedo, S. G., & Matias, J. C. \(2020\). A comprehensive review of industrial symbiosis. Journal of cleaner production, 247, 119113.](#)
- Watch this: [SCALER Project - Introduction to industrial symbiosis](#)



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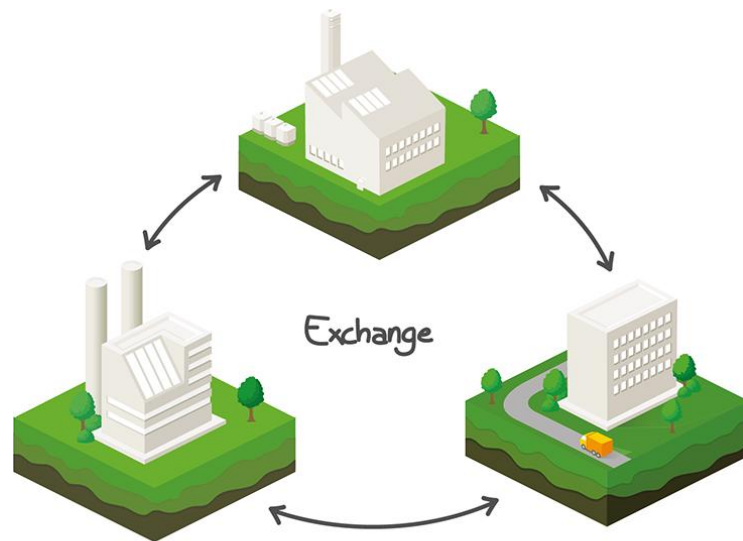


What is Industrial-Urban Symbiosis (I-US)?

If Industrial Symbiosis focuses on collaboration between companies, Industrial-Urban Symbiosis (I-US) expands the lens - connecting industry with the urban systems that surround it.

Where IS typically looks at exchanges within an industrial park, cluster or directly between companies, I-US includes cities, municipalities, and local utilities as active players in circular cooperation.

Urban areas generate, manage and consume enormous material, water, and energy flows. While these flows take place everywhere, specifics can depend on culture, geography, history, local economies and other factors and path dependencies. Nevertheless, there is room for shaping and using these flows ranging from waste collection and wastewater treatment to district heating and food systems. When these flows relate to nearby industries, new synergies emerge.

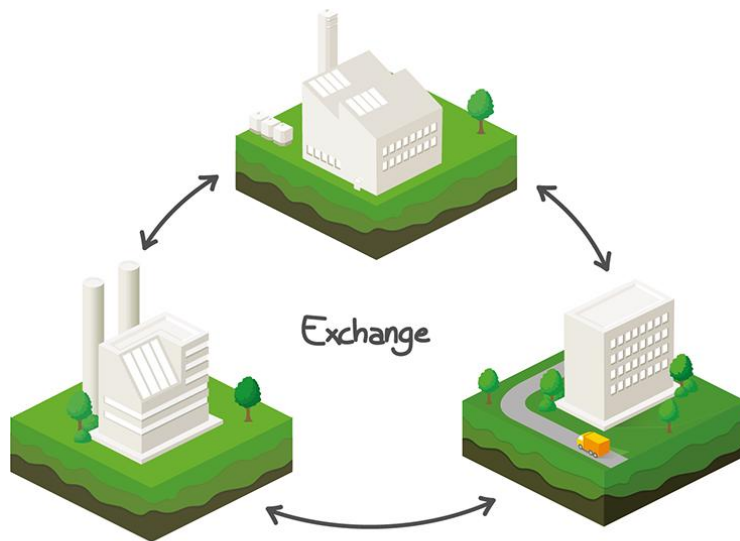




What is Industrial-Urban Symbiosis (I-US)?

While the resource flows are the core goal that I-US aims for, it's also about governance and building relationships. Municipalities, local utilities, and regional planners become key facilitators, helping to identify synergies, mediate interests, and align regulations. This represents a shift from firm-to-firm collaboration to a multi-actor, system-level approach, where:

- Municipalities coordinate and plan infrastructure that supports symbiotic connections.
- Utilities (water, waste, energy) act as connectors, linking industrial and urban metabolisms.
- Industries and SMEs explore innovative ways to valorise by-products and collaborate locally.
- Research and innovation actors help design and optimise the systems behind these exchanges.



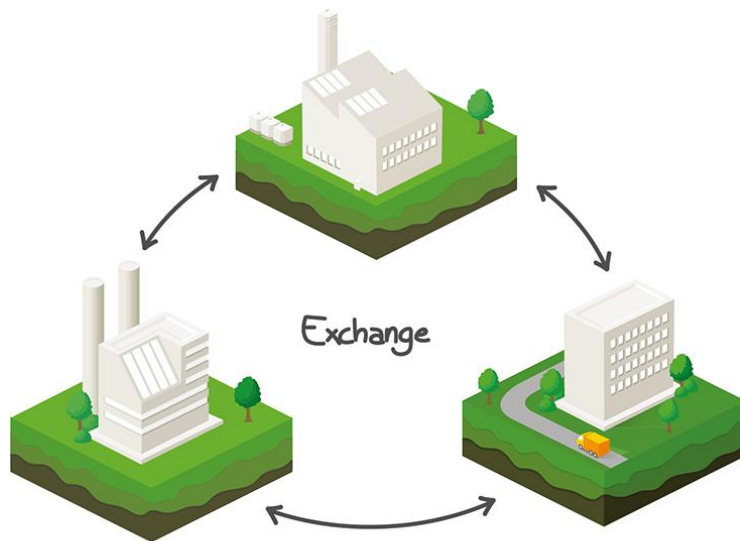


What is Industrial-Urban Symbiosis (I-US)?

I-US therefore demands not only technical alignment, but also policy coherence, stakeholder trust, and long-term planning - areas where cities and regions play a leading role. While these points are also relevant for IS, I-US expands the scope towards the public sector and thus adds another layer of complexity.

By including the urban dimension, I-US looks beyond isolated facilities to the whole territorial metabolism. This broader perspective allows:

- Potential better resource matching, since urban and industrial sectors generate complementary waste and by-products.
- Higher environmental impact, as exchanges can address local energy, waste, and emission goals simultaneously.
- Stronger local value creation, keeping materials and investments within the region.





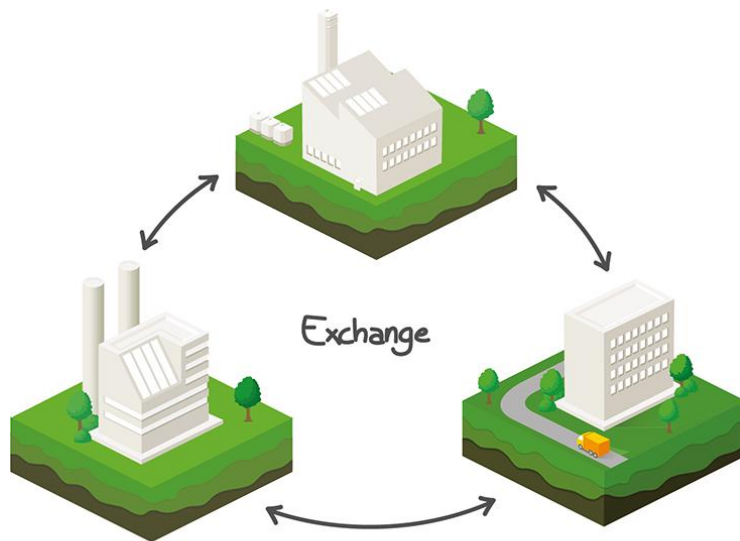
What is Industrial-Urban Symbiosis (I-US)?

Industrial-Urban Symbiosis turns the logic of “one company’s waste is another’s resource” into a **whole-system collaboration**, one that includes factories, municipalities, utilities, and citizens.

It is not only a technical model for exchanging materials, but also a governance model for co-creating sustainable, resilient, and competitive local economies.

Want to learn more?

- Read this: [Chertow, M.R., 2000. Industrial symbiosis: Literature and taxonomy. Annu. Rev. Energy Environ 25, 313–337](#)
- Watch this: [SYMSITES: Have you ever heard about “Industrial-Urban Symbiosis”?](#)

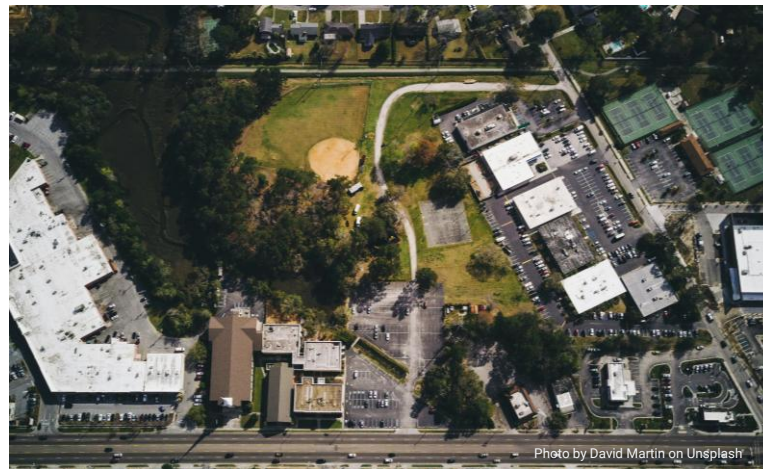




What is an I-US Hub?

The question about how IS or I-US comes to fruition is a key and can be answered in many ways. One common proactive approach is the creation of strong local networks for companies, usually called a “*hub*”, willing to work together and to explore collaboration.

To be functional, these hubs need an entity playing the facilitator role to drive the work and to play the mediator role between companies. As a collaborative process, it can take time to set up a hub and to build trust within its members. However, this is a worthwhile journey, as the benefits are multiple. [[Click here to jump to Chapter 1.4 Environmental, Economic and Social co-benefits for different stakeholders](#)]



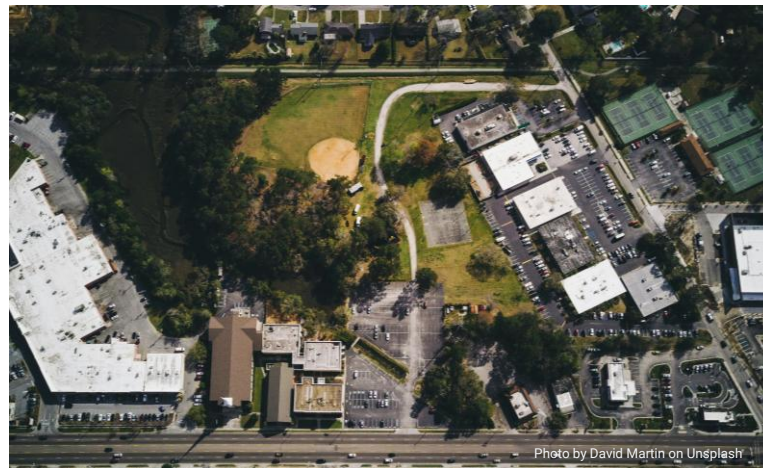


What is an I-US Hub?

Diversity and Synergies of Circular Hubs

Because I-US is complex and strongly influenced by local conditions, circular hubs can develop in many different forms depending on their geographic context, industrial structure, and sectoral priorities. One widely recognized example is the **eco-industrial park (EIP)**. An eco-industrial park consists of a group of businesses located within the same area that collaborate to improve resource efficiency by sharing and exchanging materials, energy, water, waste, or by-products.

Given this diversity, creating a strict classification of circular hubs is difficult. However, it is possible to identify several common **types of synergies** that typically emerge among the actors participating in these hubs.





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What is an I-US Hub?

- **Mutuality synergies:** These involve the shared use of services, infrastructure, or facilities among companies within the hub. Examples include shared energy systems, common logistics services, or joint waste management infrastructure, such as in the *Manresa Ilumina* initiative.
- **Substitution synergies:** These occur when the residual outputs of one company—such as by-products, excess heat, or wastewater—are used as inputs by another company. This type of exchange allows resources that would otherwise be discarded to be reused productively, as seen in the *Port of Amsterdam*.
- **Genesis synergies:** These arise when entirely new activities or enterprises are established specifically to recover, reuse, or valorize underutilized resource streams. In such cases, new value chains can develop around resources that were previously considered waste.





What is an I-US Hub?

In addition to the different forms of collaboration, the **types of resources exchanged within circular hubs can vary widely**. These may include tangible resources such as raw materials, by-products, energy, and water. Exchanges may also involve **intangible resources**, including shared utilities, transport capacity, technical expertise, or knowledge.

This broad range of potential interactions makes circular hubs a highly adaptable concept, capable of responding to different local conditions and supporting a wide variety of industrial and urban collaboration models.





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Exercise – Reflection:

Instructions:

Can you think of examples in your city, where one sector's waste can become another's resource? Describe it!

You can answer the following guiding questions:

- What type of waste, by-product, or surplus is being produced (e.g., heat, water, materials, organic waste)?
- Which sector or company generates this waste?
- Who could potentially use or benefit from it as a resource?
- How could the exchange or reuse process work in practice?





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Chapter 1.3: I-US examples – generic introduction

This chapter presents various examples of Industrial-Urban Symbiosis from different regions and sectors. It covers generic case studies and the ones specific to the SYMSITES project (hereby called '*EcoSites*') demonstrating how industries and urban entities collaborate to optimize resource flows, reduce waste, and improve efficiency. These examples showcase different models of I-US and highlight key success factors.

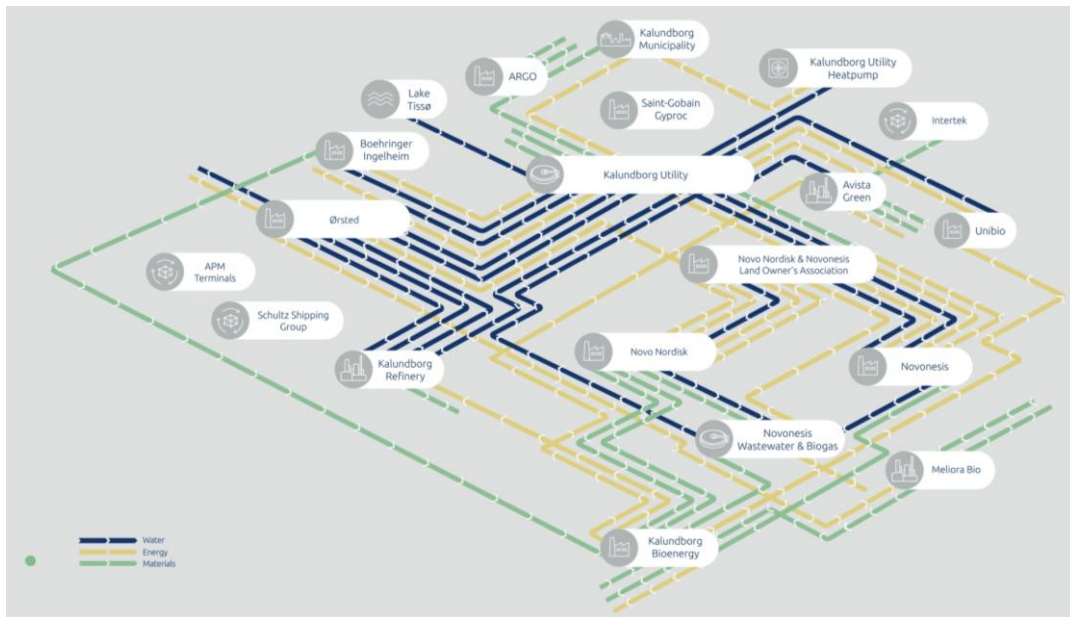
- Target audience: General Audience (no prior knowledge required)
- Estimated time: 20 minutes
- Includes: [Case Studies](#)





Industrial-Urban Symbiosis examples in Europe

Kalundborg Symbiosis (Denmark)





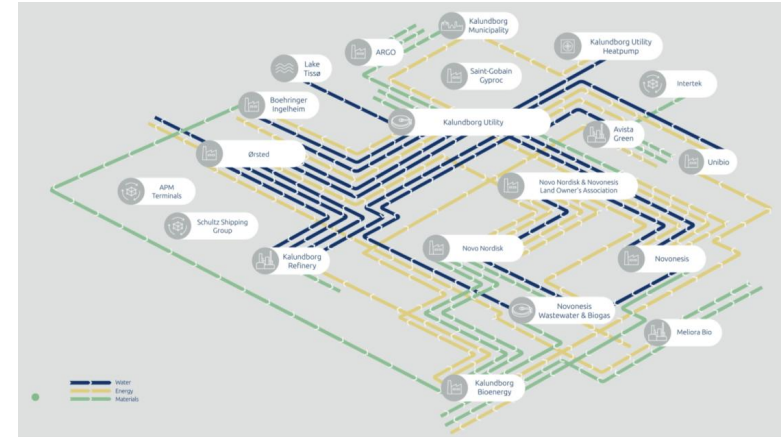
Industrial-Urban Symbiosis examples in Europe

Kalundborg Symbiosis (Denmark)

One of the most prominent examples of Industrial Symbiosis in the world is the Kalundborg Symbiosis in the Kalundborg municipality, Denmark.

Kalundborg Symbiosis is a partnership between 9 public and private companies in Kalundborg, Denmark. Since 1972, they have developed the world's first industrial symbiosis with a circular approach to production.

In Kalundborg Symbiosis, the city's biggest industrial companies work together across sectors to share excess energy, water, and materials, so less goes to waste. As public and private companies are physically connected, one company's surplus of resources adds value to another. Today, more than 20 different streams of excess resources flow between the companies, creating a symbiosis of resource exchange, adding more resilience and profit to the partners.





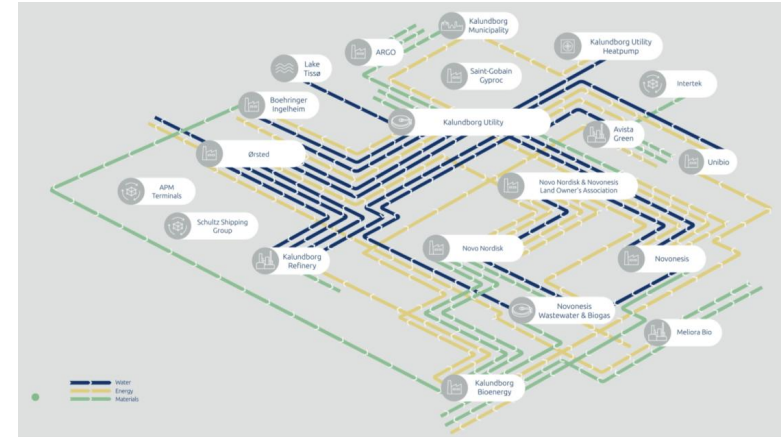
Industrial-Urban Symbiosis examples in Europe

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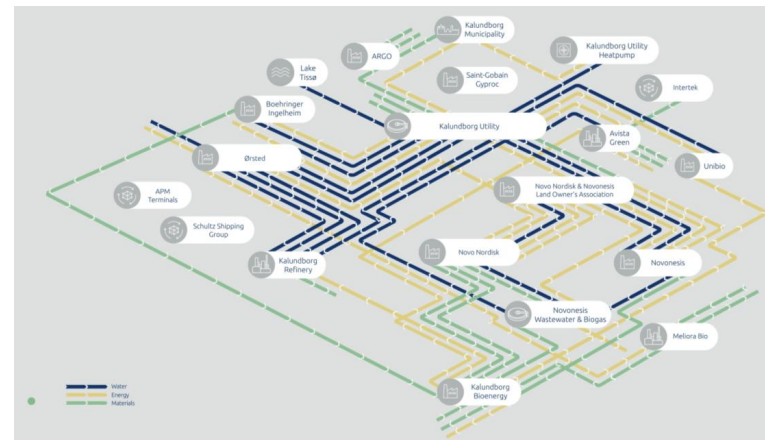


Industrial-Urban Symbiosis examples in Europe

Kalundborg Symbiosis (Denmark)

Major Industrial Participants

The Kalundborg network is a cooperative industrial community that brings together five key companies, each contributing unique capabilities to a shared resource-exchange system. The Asnæs Power Station anchors the network by producing electricity while converting excess heat into steam used by neighboring facilities. Novo Nordisk and Novozymes (leaders in pharmaceuticals and biotechnology) both rely on shared energy and utilities, with Novozymes further enhancing sustainability by supporting advanced wastewater treatment, including the reuse of organic by-products such as biogas in other operations.





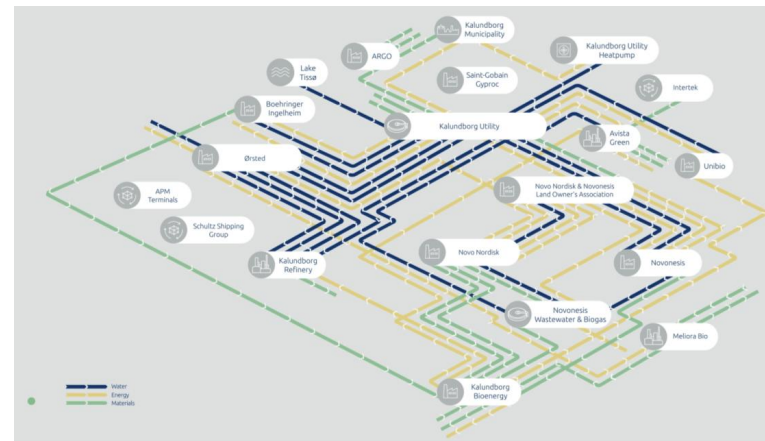
Industrial-Urban Symbiosis examples in Europe

Kalundborg Symbiosis (Denmark)

Equinor advances circular energy use by integrating biogas generated from local biotech and organic waste streams into its oil refining processes. Kalundborg Utility manages the city's water and wastewater infrastructure, prioritizing efficient reuse across all industrial sites. Collaboration across the network is guided by the Kalundborg Industrial Symbiosis Association, founded in 1972, which streamlines resource-sharing practices and fosters ongoing cooperation.

Want to learn more?

- Read this: [Transition ApS - Guide for Industrial Symbiosis Facilitators](#)
- Watch this: [Symbiosis Center Denmark - Kalundborg Symbiosis 2022](#)

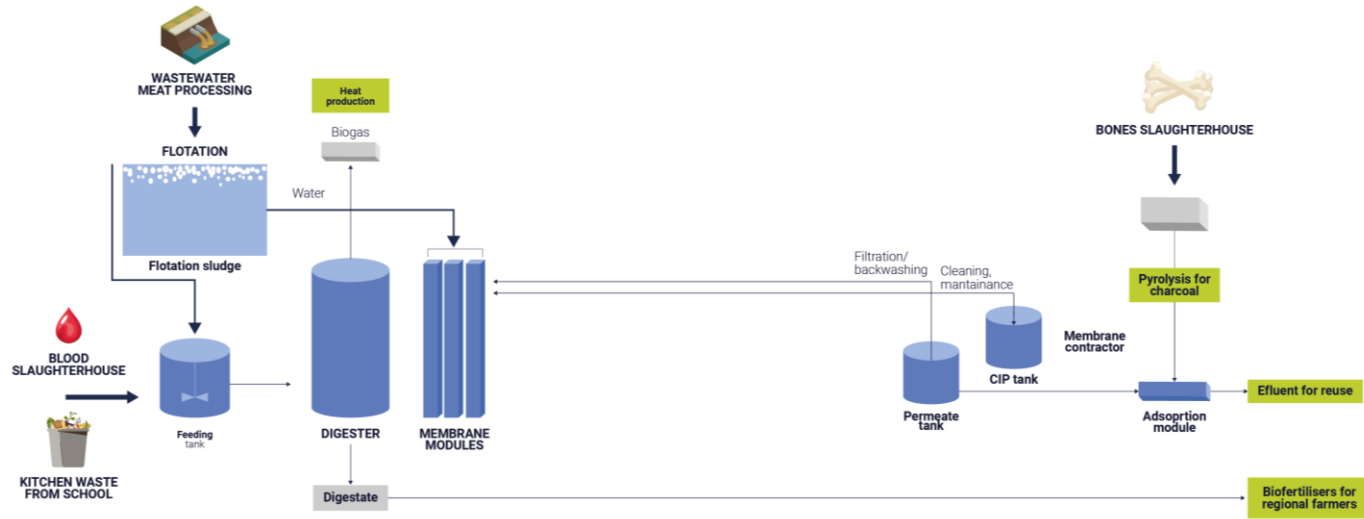




SYMSITES

The SYMSITES EcoSites

The Austrian EcoSite





The SYMSITES EcoSites

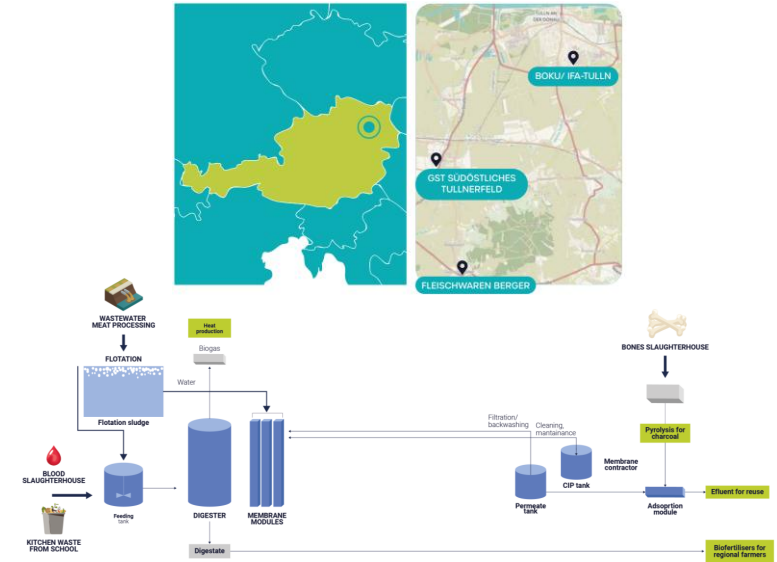
The Austrian EcoSite

The Austrian EcoSite is located at the production facilities of Fleischwaren Berger GesmbH in the town of Sieghartskirchen, within the south-eastern Tullnerfeld area. The local wastewater treatment plant (GST) is located in Tullnerfeld, covering the wastewater (WW) of an area of 131km² including the municipalities of Sieghartskirchen, Michelhausen, Judenau-Baumgarten and Lagenrohr.

The partners

The Austrian EcoSite was developed under the scientific direction of IFA Tulln in cooperation with the following partners:

- Manager of the EcoSite: IFA TULLN, BOKU UNIVERSITY (BOKU)
- Meat processing industry: FLEISCHWAREN BERGER GESMBH (BER)





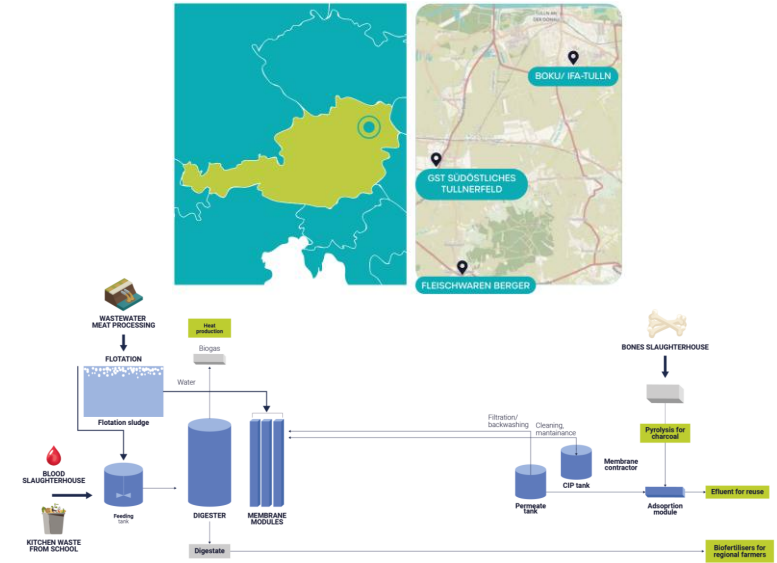
The SYMSITES EcoSites

The Austrian EcoSite

- Wastewater treatment: GEMEINDEABWASSERVERBAND SÜDÖSTLICHES TULLNERFELD (GST)
- Membrane technology: SPITZER GESMBH
- Biogas pilot plant installation: AAT ABWASSER AND ABFALLTECHNIK GMBH

Local challenges

In the area many residential development projects are realised and the wastewater treatment plant capacities will not be sufficient in the near future. The wastewater volume from Berger can reach up to 630 m³/day and represents a significant share of the treatment plant's volume.





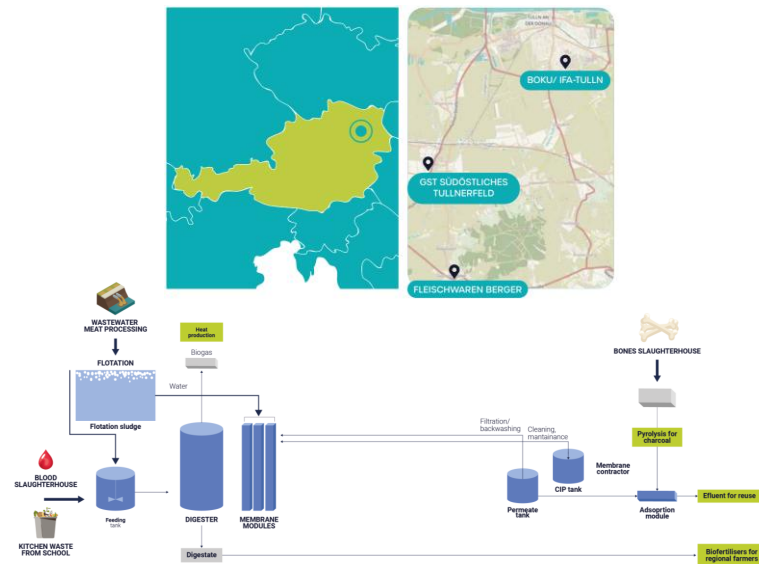
The SYMSITES EcoSites

The Austrian EcoSite

Local challenges:

From this follows that a reduction of the input to the WWTP by the meat industry is of high importance, to free capacities for the treatment of municipal wastewater from the surrounding communities/ households. In addition, the meat industry consumes large volumes of water that could be reused with appropriate technologies. Especially in view of the fact that there is a lot of agriculture in the area and with the increase in drought risk due to global warming the importance of water security is increasing.

The meat processing industry is the only large operation in the area and provides many job opportunities as well as tax income for the municipality. The company is essential for the regional development despite its high water consumption and wastewater volume.





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The SYMSITES EcoSites

The Austrian EcoSite

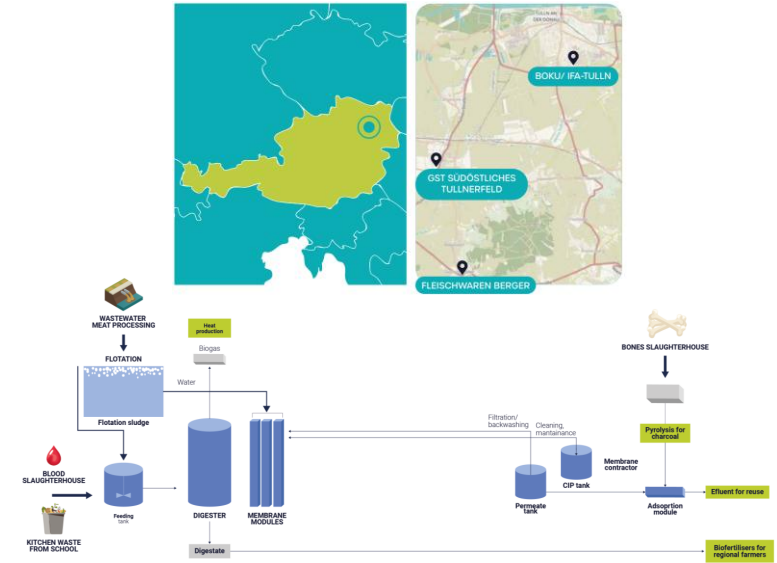
Local challenges:

The wastewater contains many organics, mostly fats, but also high amounts of detergents from cleaning and salts from the production.

Another factor is the treatment of other residues from the meat processing and slaughter house, which are difficult and costly in their disposal, like blood.

The EcoSite Solution

The Austrian EcoSite focuses on the treatment of the wastewater from the meat processing industry and blood waste from the slaughterhouse as well as food waste from the school and kindergarten supplied by the companies catering.





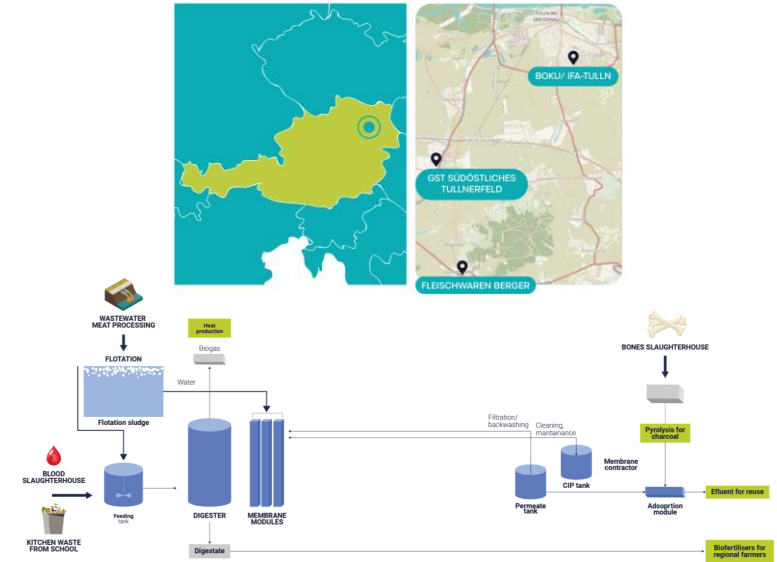
The SYMSITES EcoSites

The Austrian EcoSite

The EcoSite Solution

The industry WW contains a higher organic load than municipal wastewater and is used for biogas production. After a flotation process that reduces the volume of the primary stream, the flotation sludge is fed into the biogas reactor. The treated water is further cleaned with ultrafiltration and nanofiltration membranes to produce purified water for reuse as process water at the company or potentially as irrigation water in the future.

As a co-substrate, waste from the associated slaughterhouse is used, resulting in high levels of ammonium and hydrogen sulphide from protein degradation. The ammonium in the outflow can be recovered by extraction with sulfuric acid, which is produced by desulfurization bacteria in a desulfurization column from the hydrogen sulphide contained in the biogas. This process forms the valuable fertilizer ammonium sulphate.





SYMSITES Training Materials on Industrial-Urban Symbiosis

← Module 1: What is I-US?

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The SYMSITES EcoSites

The Austrian EcoSite

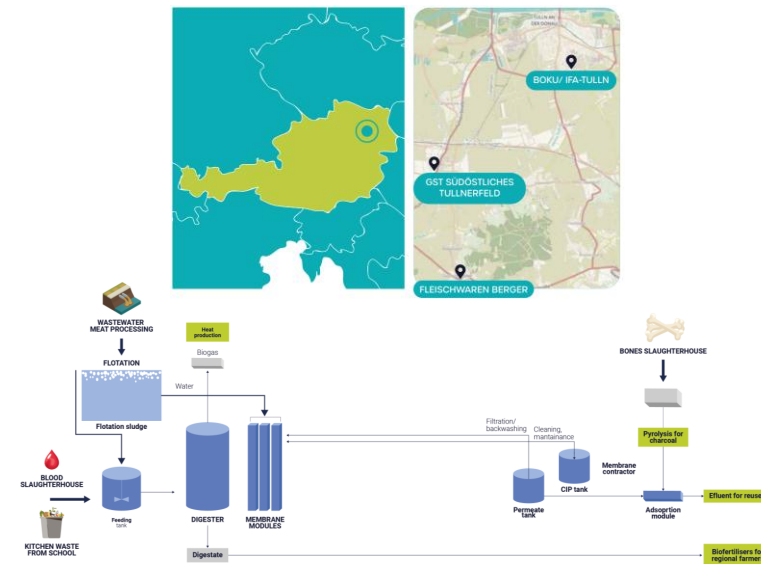
The EcoSite Solution

The fertilizer can be used in regional agriculture, thereby keeping the nutrients in a loop.

The sources of waste in the Austrian EcoSite are:

- Meat processing wastewater
- Slaughterhouse waste: blood, bones, intestines
- Food waste from school canteens

The aim of the Austrian EcoSite is to treat 4 m³ of wastewater per day and 50 kg of biowaste per week, resulting in a daily maximum biogas yield of 6 m³ and additional streams of new added-value products:



Funded by
the European Union



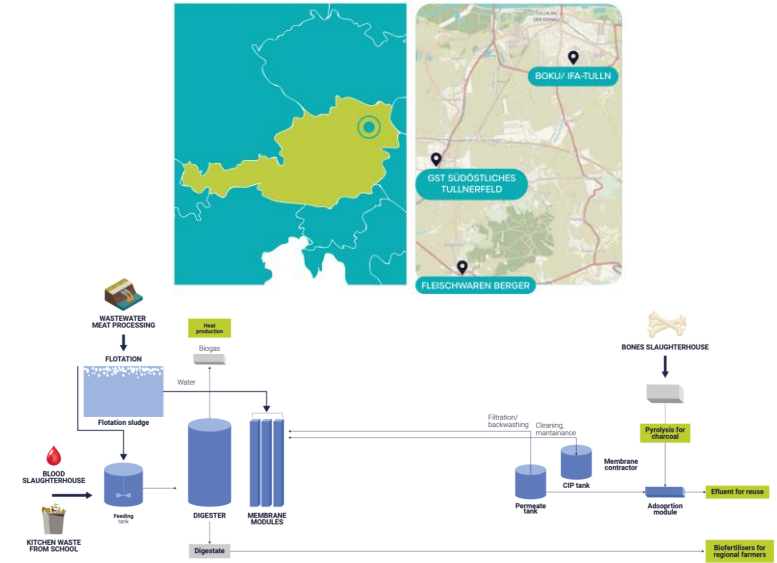
The SYMSITES EcoSites

The Austrian EcoSite

The EcoSite Solution

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- Cleaned water for cooling or irrigation, instead of using ground water
- Biogas for energetic use
- Fertilizer for the surrounding farmers



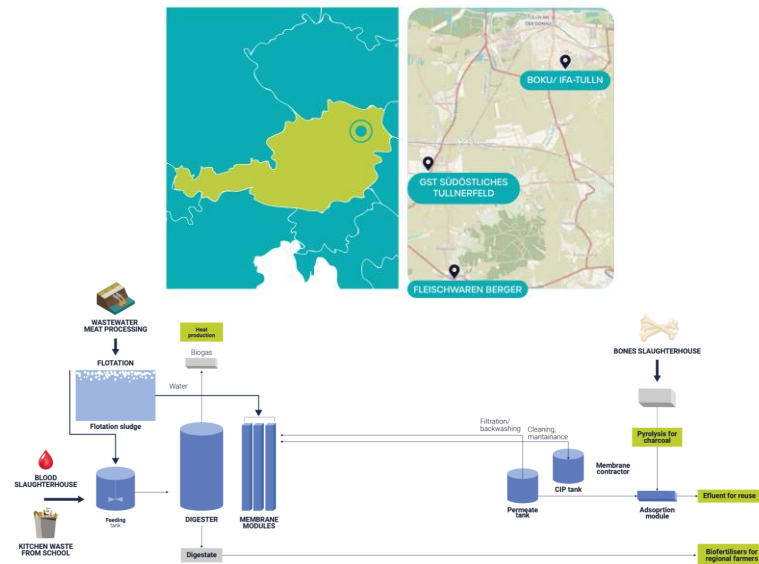


The SYMSITES EcoSites

The Austrian EcoSite

Benefits of the Symbiosis

- *Use of Slaughterhouse Waste:* Organic waste from slaughterhouses can be used as a valuable resource rather than a hazardous waste. This reduces the environmental impact and effort for transport and treatment. Additionally, the company can save disposal costs.
- *Energy Production:* The wastewater can be used to generate energy instead of energy-intensive treatment processes. The additional treated organic waste can increase the biogas production. The produced biogas can be used as a renewable energy source for the generation of electricity and heat. The continuous supply of wastewater and organic waste ensures a steady production of biogas.



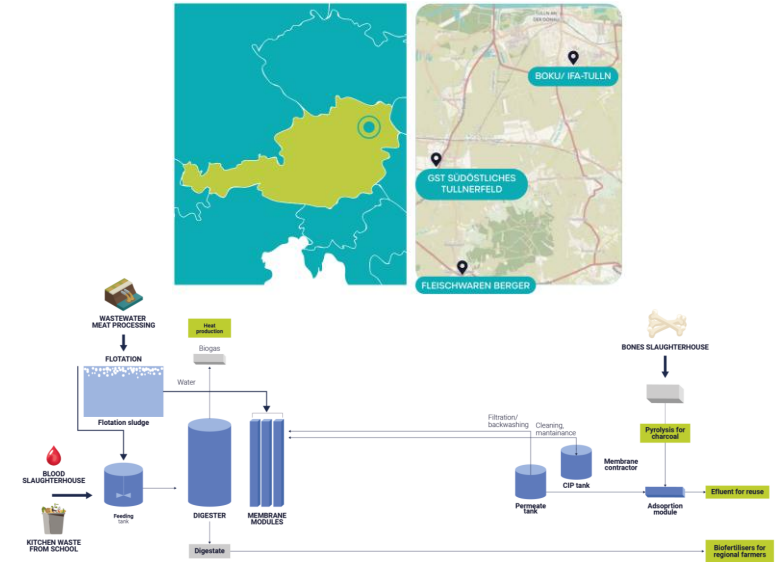


The SYMSITES EcoSites

The Austrian EcoSite

Benefits of the Symbiosis

- *Environmental Benefits:* The treatment of wastewater and biowaste in a close proximity decreases the environmental impact of infrastructure and traffic. The treatment of the wastewater combining a flotation and anaerobic digestion requires less space and can thereby reduce the land consumption. By combining desulfurization with a membrane contactor, a valuable fertilizer can be produced and distributed locally keeping the nutrients in a regional loop and counteracting dependency on international fertilizer suppliers.
- *Sustainable Development:* The integration of the wastewater treatment with biowaste for energy production allows the company to grow sustainable with less negative effects for the municipality and the community.

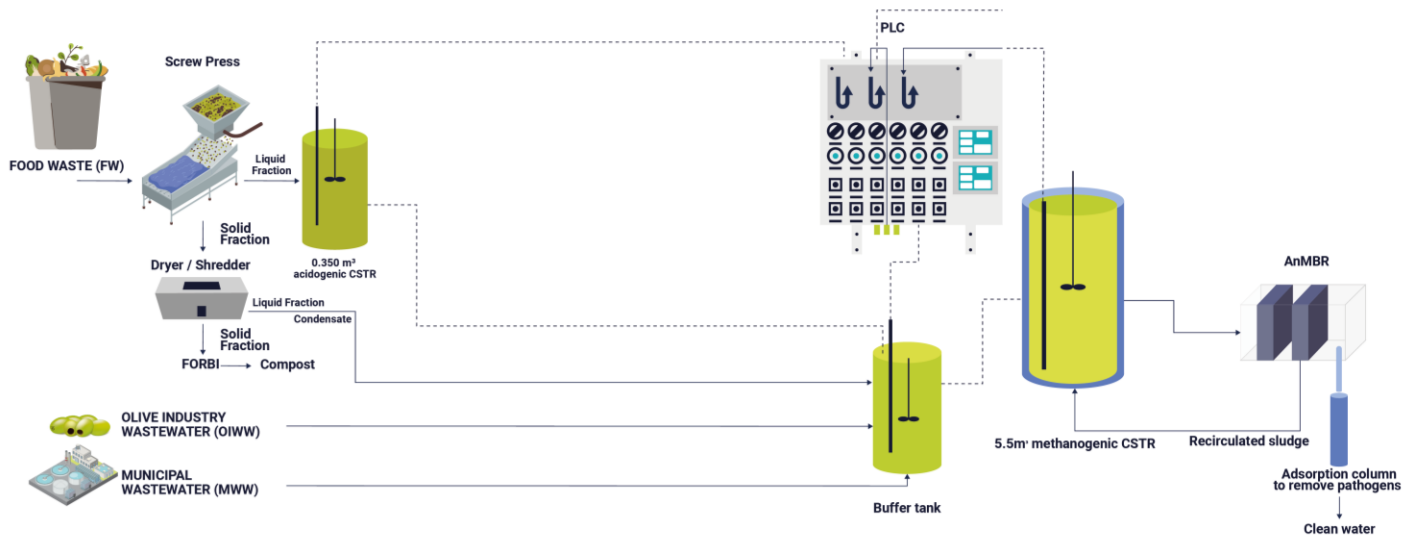




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The SYMSITES EcoSites

The Greek EcoSite





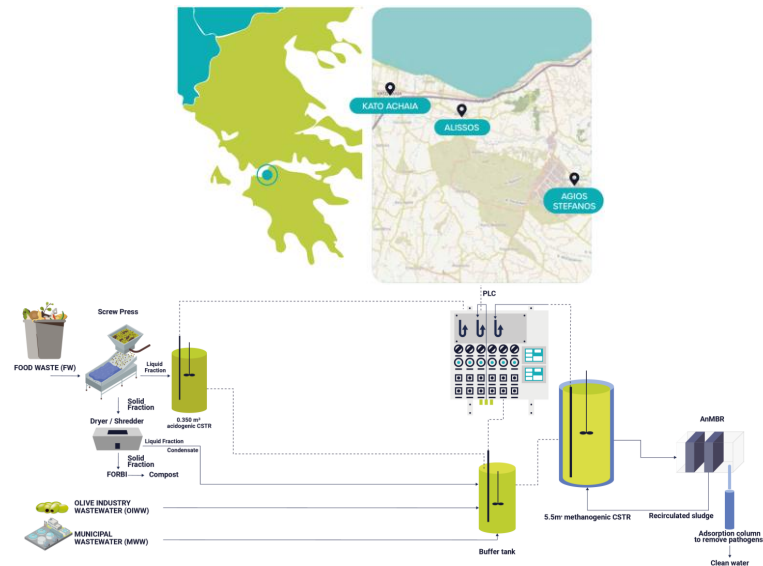
The SYMSITES EcoSites

The Greek EcoSite

The Greek Ecosite is located at the wastewater treatment plant (WWTP) in the municipality of Western Achaia. This urban-industrial symbiosis extends over a larger area of approximately 13.5 km², encompassing Ano Alissos, the industrial zone, and the WWTP. The Ecosite focuses on waste from olive oil production and is designed to treat industrial and urban wastewater (WW) as well as food waste (FW).

The partners

- Manager of the EcoSite: NATIONAL TECHNICAL UNIVERSITY OF ATHENS (NTUA)
- Developer of the Ecosite: SIRMET S.A. (SIRMET)
- Operator of the WWTP: MUNICIPALITY OF WESTERN ACHAIA (MWA)





The SYMSITES EcoSites

The Greek EcoSite

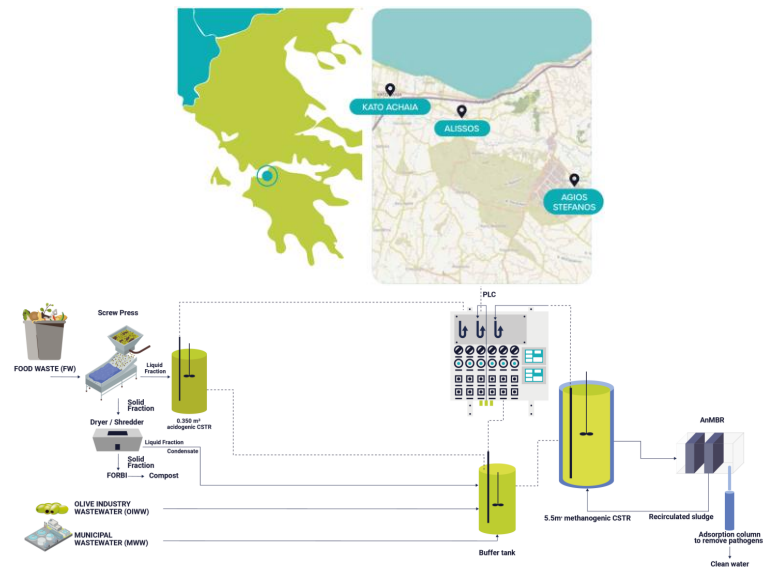
- Partner from the olive oil industry: ELAIOURGIKES EPIHEIRISEIS PATRON S.A. (EEP)

Local challenges

The region faces significant challenges due to the diverse sources and types of waste generated, necessitating a comprehensive and integrated solution.

In particular, the olive oil industry produces substantial amounts of wastewater and solid waste. Key challenges include:

- High Organic Load: Olive oil wastewater contains high concentrations of organic matter, complicating treatment with conventional methods.





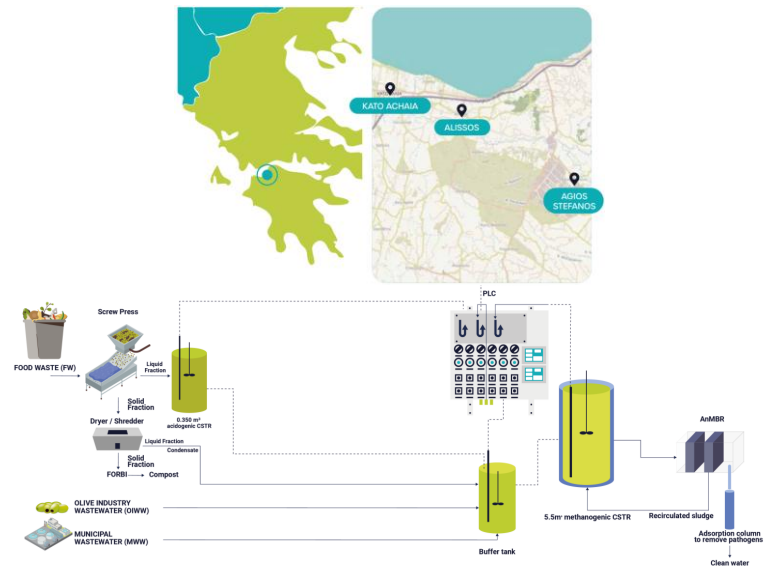
The SYMSITES EcoSites

The Greek EcoSite

Local challenges

- **Seasonal Production:** The seasonal nature of olive oil production causes fluctuations in waste volume, challenging capacity planning for waste management facilities.
- **Solid Waste Disposal:** Olive pomace, the primary solid waste, poses disposal issues due to its volume and environmental impact.

Additionally, there is a critical need to treat urban wastes to prevent environmental degradation and improve public health. The Ecosite leverages sustainable waste treatment processes to address these issues, mitigating environmental impacts and enhancing the overall waste management system in the region.





The SYMSITES EcoSites

The Greek EcoSite

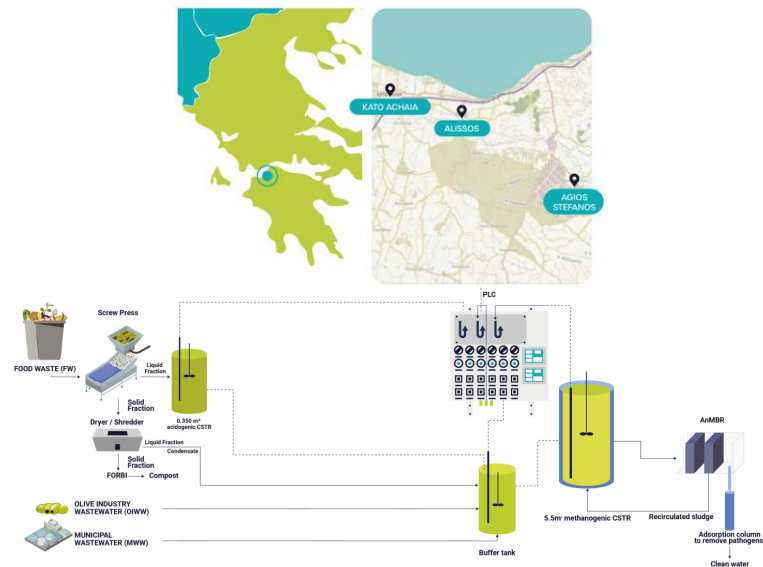
The EcoSite Solution

The main objective of the Greek EcoSite is to treat industrial and urban wastewater (WW) from the municipality of Western Achaia, along with urban organic solid waste from the village of Ano Alissos. This treatment process aims to produce hydrogen, methane in AnMBR, compost, and clean water.

The three sources of waste at the Greek EcoSite are:

- Urban organic solid waste from the village of Ano Alissos
- Urban WW from the area of Kato Achaia (WWTP)
- Industrial wastewater from Elaiourgikes Epiheiriseis Patron S.A. (EEP)

The Greek EcoSite will treat between 2-4 m³/day of urban and industrial WW, and up to 100-200 kg/day of urban organic solid waste.





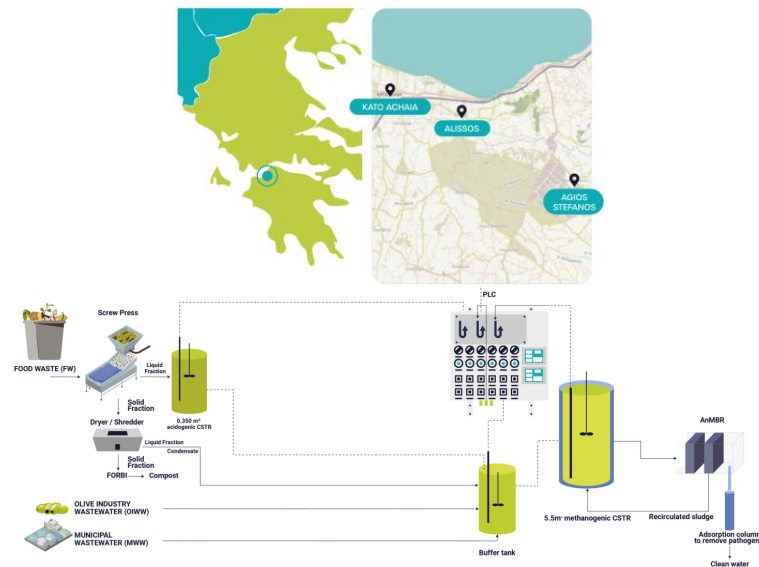
The SYMSITES EcoSites

The Greek EcoSite

The EcoSite Solution

This process will produce gaseous biofuels (hydrogen and methane) and other valuable products. The advanced wastewater treatment pilot facility consists of multiple interrelated processes:

- Pre-treatment of food waste: Using a screw press for hydrogen production and drying shredding for methane production, the biomass (FORBI, Food Residue Biomass) generated from the drying/shredding will be led for composting.
- Bioreactors: A 0.350 m³ acidogenic CSTR for hydrogen production and a 5.5 m³ methanogenic CSTR in tandem with anaerobic membrane system (AnMBR) for methane production.
- Membrane unit: For producing filtered water.





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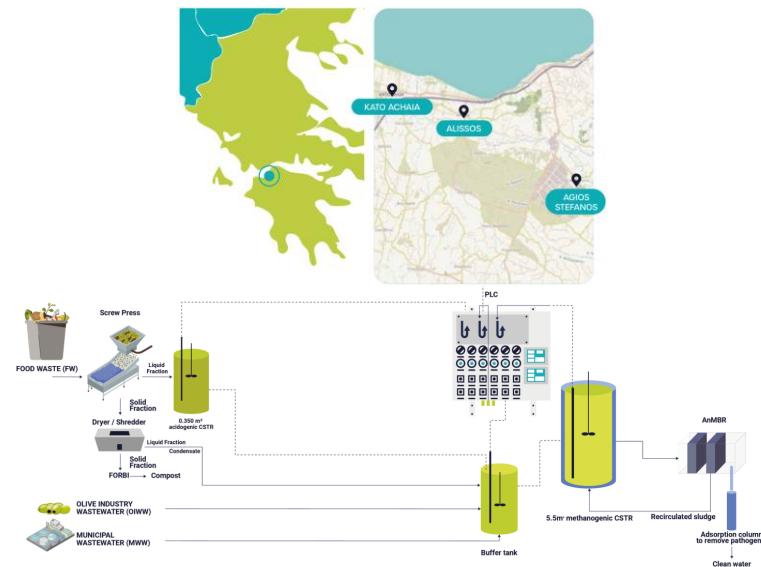
The SYMSITES EcoSites

The Greek EcoSite

The EcoSite Solution

As a result, high-value new resources will be available:

- Biogas rich in methane
- Hydrogen production
- PHAs (lab scale)
- Treated wastewater for irrigation
- Compost from the solid phase after pre-treatment (FORBI) along with the digestate





The SYMSITES EcoSites

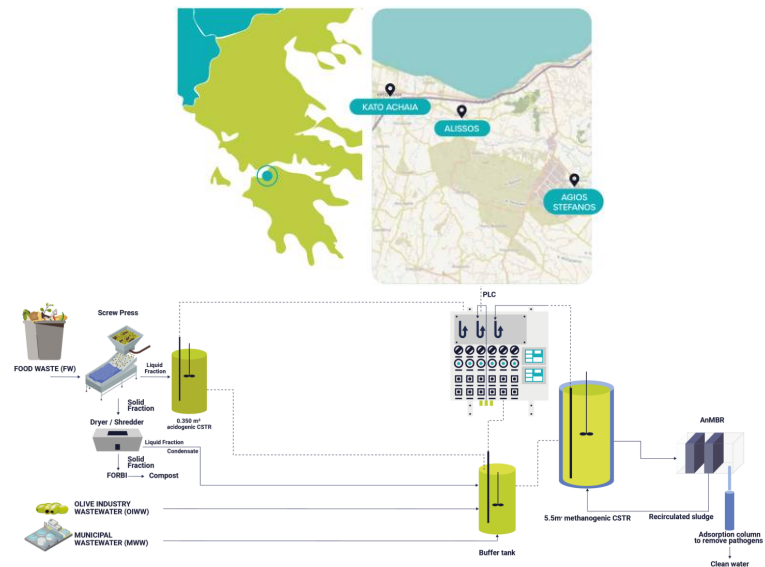
The Greek EcoSite

Benefits of the Symbiosis

The Greek EcoSite, located in Western Achaia, exemplifies the benefits of I-US through its innovative waste treatment processes and integrated approach. By promoting collaboration between industries and urban areas, the EcoSite optimizes resource use and minimizes waste, addressing critical waste management challenges in the region.

In brief the benefits arising from this symbiosis are:

- **RESOURCE RECOVERY AND RECYCLING:** Collaboration between SIRMET S.A., EEP, NTUA, and MWA results in a pilot system for treating industrial wastewater, municipal household waste, and urban wastewater using anaerobic technology and solids drying. This system not only treats waste but also recovers biogas and biohydrogen, addressing green power challenges.



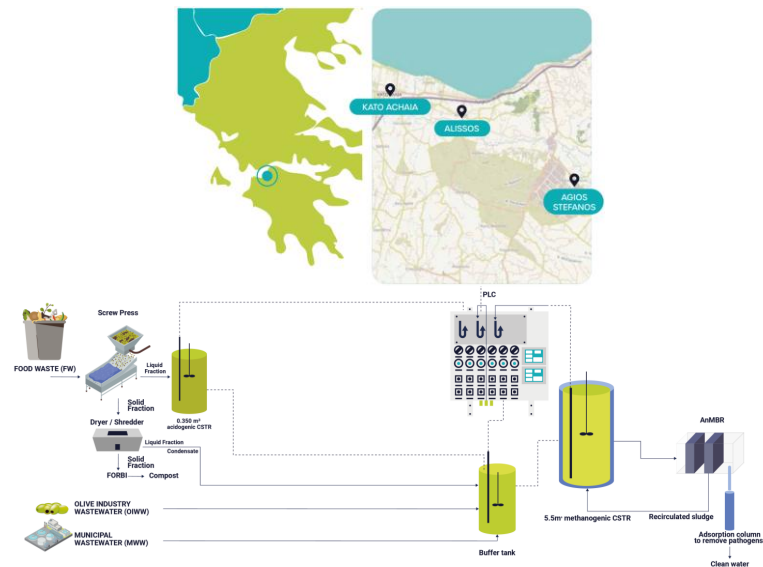


The SYMSITES EcoSites

The Greek EcoSite

Benefits of the Symbiosis

- **UTILIZATION OF BY-PRODUCTS:** EEP provides wastewater and dry olive heartwood, exploring their potential uses. Treated wastewater enhances biogas production, while olive heartwood's antimicrobial properties are investigated for use as filtering media in tertiary wastewater treatment, turning waste into resources.
- **STAKEHOLDER ENGAGEMENT:** Forming stakeholder forums involving local communities, food processing industries, universities, and government organizations ensures the integration of advanced waste exploitation knowledge into local practices and addresses community needs.





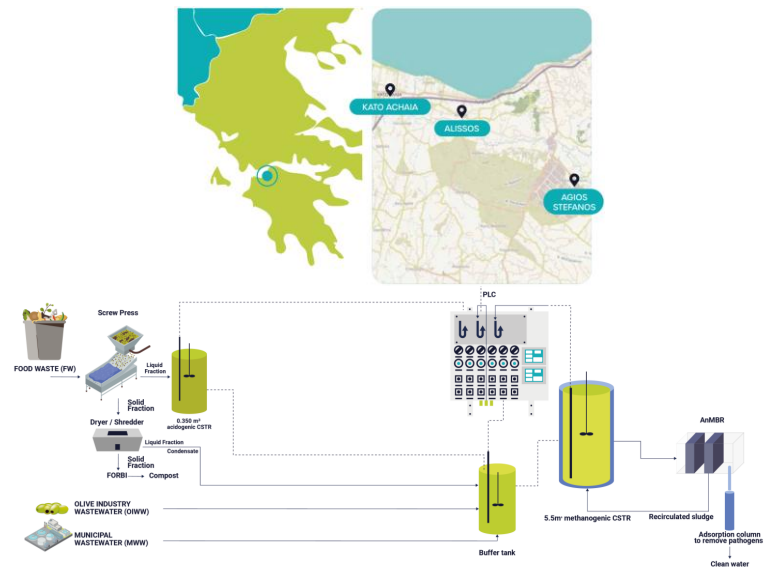
The SYMSITES EcoSites

The Greek EcoSite

Benefits of the Symbiosis

- **TESTING AND OPTIMIZATION:** The Greek EcoSite pilot tests various wastewaters, optimizing waste treatment processes. By addressing challenges such as high organic load, industrial waste inhibitors, energy production through anaerobic technology, and stakeholder involvement, the project becomes a model for innovative waste management.

Through industrial-urban symbiosis, the Greek EcoSite not only addresses waste management challenges but also promotes sustainability, resource efficiency, and environmental stewardship in Western Achaia, setting a precedent for similar initiatives globally.

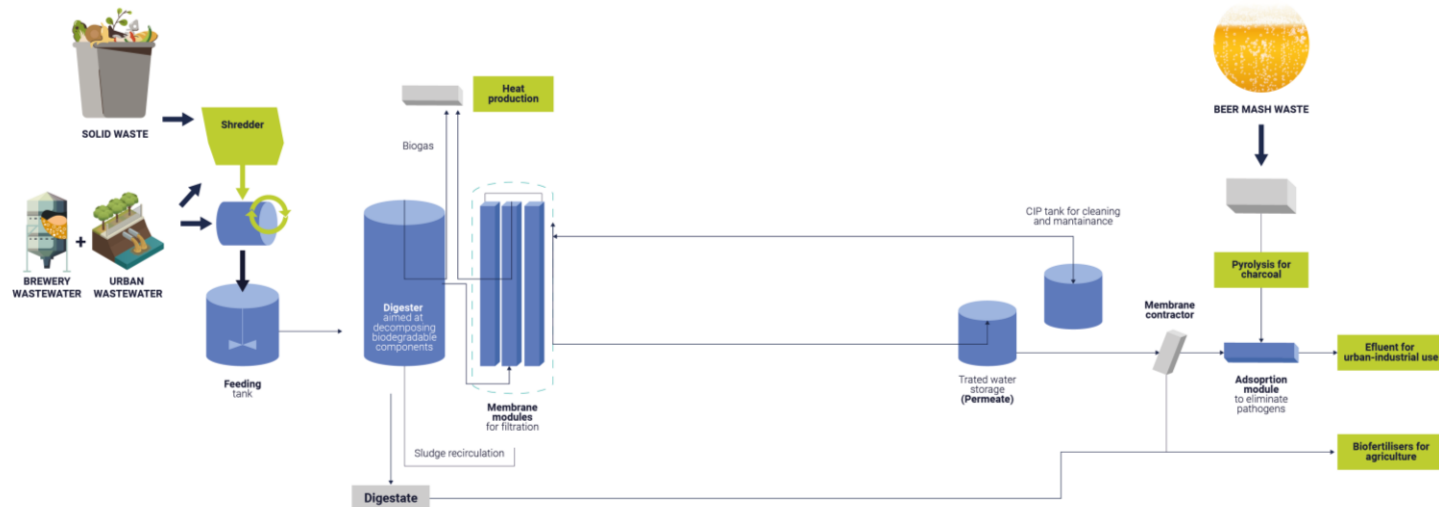




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The SYMSITES EcoSites

The Danish EcoSite





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The SYMSITES EcoSites

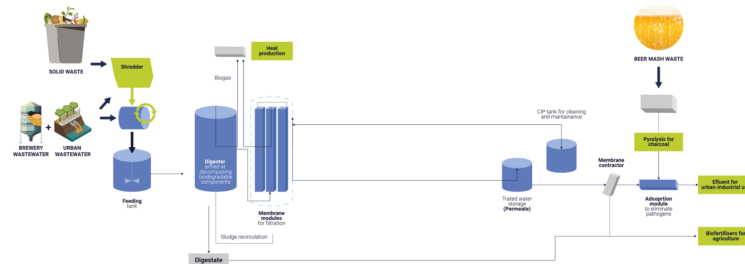
The Danish EcoSite

The Danish EcoSite is located on the island of Bornholm in the Baltic Sea, in and around the small town of Svaneke. The town has a population of 1,100 people and covers an area of about 6 km². The island of Bornholm is a unique test platform with a solid foundation of data in a secluded energy system, with a large production of renewable energy, up to 1% of all of Denmark.

The partners

The EcoSite treats municipal wastewater and organic waste with waste from the brewing industry, and involves the following public and private actors:

- The island's multi-utility company operating the wastewater treatment plant: BEOF





The SYMSITES EcoSites

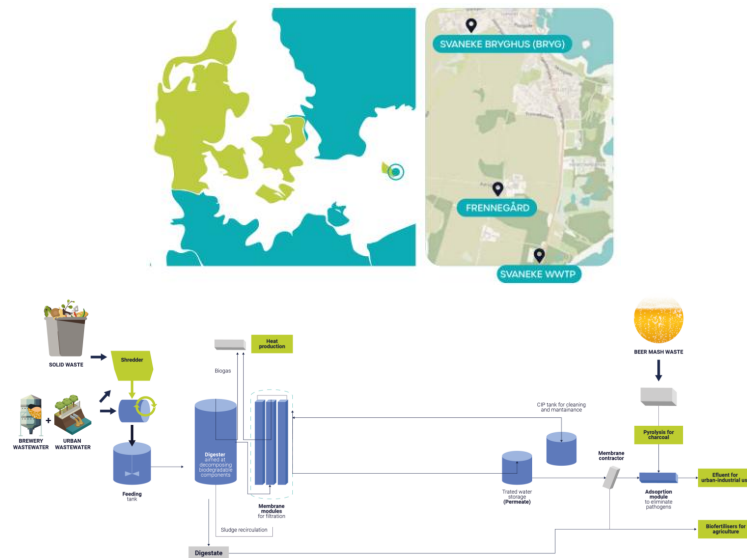
The Danish EcoSite

- A local brewery: SVANEKE BRYGHUS (BRYG)
- A local farmer from Frennegård: FINN HARILD (GARD)
- The municipal waste handling company: BOFA

For the past 16 years, Bornholms Energi & Forsyning has been a pioneer when it comes to analysis, tests, demonstrations and data within future energy and utility technology. The multi-utility company is located in Bornholm and has participated in international innovation projects with a total budget of approximately 161 million EUR.

Local challenges

Svaneke is a small village in the municipality of Bornholm, mainly known for agriculture and its brewing industry.





The SYMSITES EcoSites

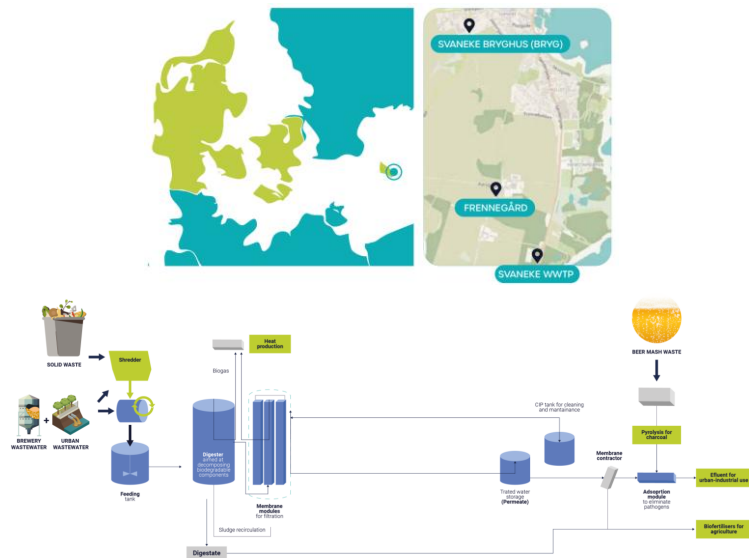
The Danish EcoSite

While the brewing industry produces large volumes of wastewater and solid waste, the large presence of agriculture requires high volumes of water to meet the demand for irrigation.

The EcoSite Solution

The pilot facility (demo plant) was put in operation in May 2024 and its objective is to investigate the prospects of biogas production for industrial use and filtered wastewater for agricultural irrigation, in particular:

- Up to 4 m³ of wastewater daily from the Wastewater Treatment Plant run by BEOF and from the brewery BRYG are treated by the Anaerobic Membrane BioReactor (AnMBR).
- Up to 50 kg of municipal solid biowaste is provided by BOFA every week.





The SYMSITES EcoSites

The Danish EcoSite

The wastewater comes from Svaneke Brewery and the nearby town of Svaneke. The ground food waste, collected by BOFA, is added to increase the volume of biogas. Quality checks of the produced biogas determine potential industrial applications, including a future source to process heat at Svaneke Bryghus. Due to extremely small amounts, the biogas is finally discharged.

The filtered wastewater is analysed to determine its applicability to agricultural irrigation at Frennegård, in accordance with the EU regulation on minimum requirements for wastewater reuse. Sludge from the test facility is used as fertiliser at Frennegård if the quality is suitable according to the Sludge Order.





The SYMSITES EcoSites

The Danish EcoSite

The advanced wastewater treatment pilot facility consists of multiple interrelated processes:

- Pre-treatment: grinder, agitators, dosing pumps, and drum filter.
- Bioreactor to produce biogas and sludge.
- Membrane unit to produce filtered water.

As a result, High-Value New Resources are available:

- Treated wastewater for irrigation
- Digested sludge for fertiliser
- Biogas rich in methane
- Char from the Beer mash



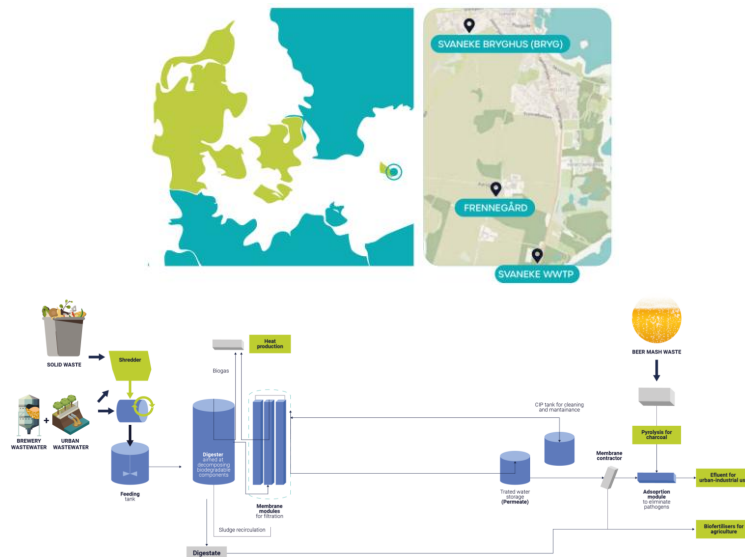


The SYMSITES EcoSites

The Danish EcoSite

Benefits of the Symbiosis

- *Circular Value Chains Between Industry, Cities, and Citizens:* waste streams are processed and upgraded into new products using technology. Thus, waste and residual products from one area can be turned into a useful resource in another area.
- *Production of Biogas and Wastewater:* while biogas converts into energy and heat, purified wastewater can be used for agricultural irrigation as well as irrigation of gardens, trees or parks.
- *Social Cohesion:* cooperation between industry, cities, and citizens.

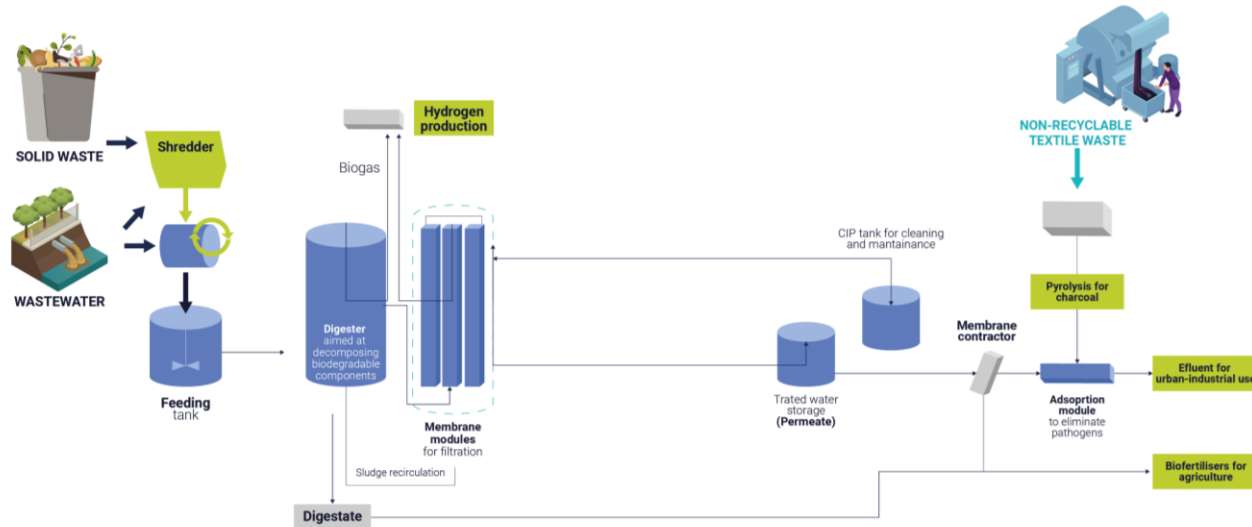




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The SYMSITES EcoSites

The Spanish EcoSite





The SYMSITES EcoSites

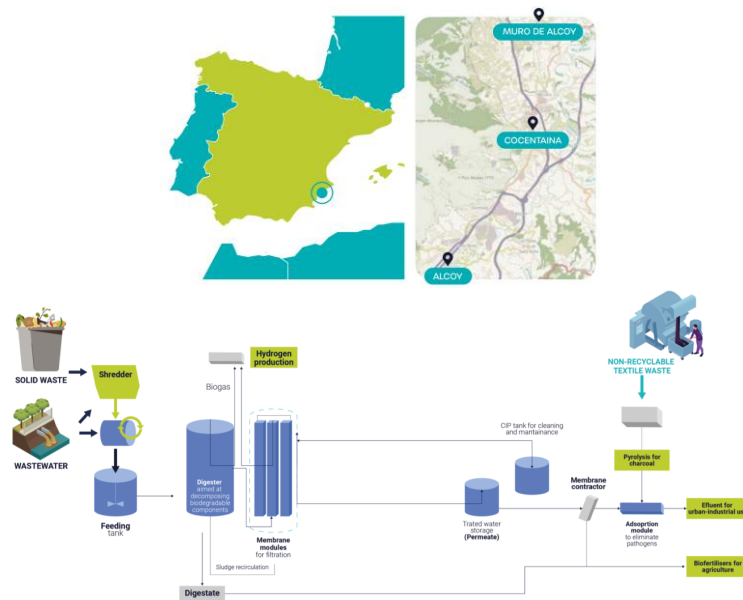
The Spanish EcoSite

The Spanish EcoSite is located at the wastewater treatment plant (WWTP) in Alcoy, within the Valencian Community. However, the urban-industrial symbiosis covers a bigger area of approximately 8 km², spanning the municipalities of Muro de Alcoy, Alcoy and Cocentaina in the province of Alicante.

The partners:

At the pilot-scale plant, urban and industrial wastewater is treated along with organic waste from urban areas and waste from sectors such as textiles, with the participation of the following partners:

- Manager of the EcoSite: SOCIEDAD DE FOMENTO AGRICOLA CASTELLONENSE, S.A. (FACSA)





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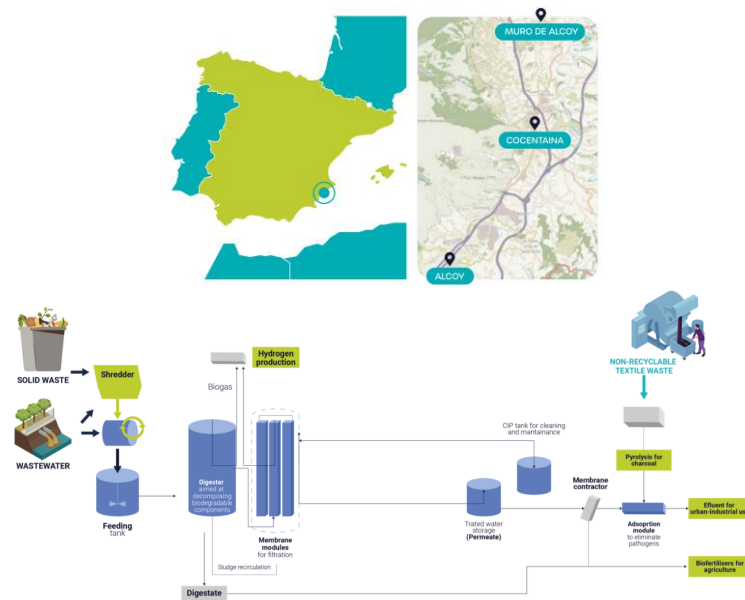
The SYMSITES EcoSites

The Spanish EcoSite

- Waste collection company: FOMENTO VALENCIA MEDIOAMBIENTE SL (FOVASA)
- Manager of the project: ASOCIACIÓN DE INVESTIGACIÓN DE LA INDUSTRIA TEXTIL Y COSMÉTICA (AITEK)
- Textile industry: FRANCISCO JOVER SA (JOV)
- Cosmetics industry: GERMAINE DE CAPUCCINI SAU (GERM)
- MMV system builder: KATHOLIEKE UNIVERSITEIT LEUVEN (KUL)

Local challenges

The Valencian Community faces significant *water scarcity* due to a combination of factors, including its climate, irregular rainfall patterns, and increasing demands from agriculture, tourism, and economic development.





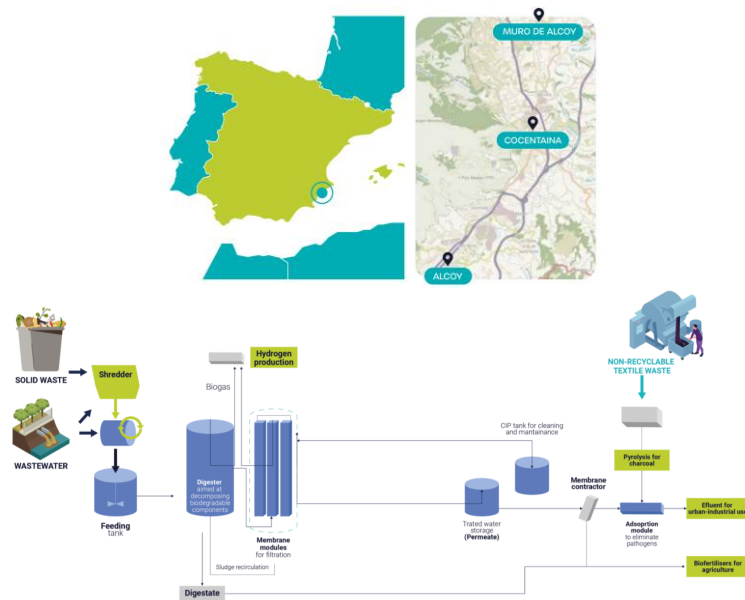
The SYMSITES EcoSites

The Spanish EcoSite

Local challenges

Additionally, climate change is expected to intensify these challenges, making sustainable water management crucial for the region's future.

The predominant industries in the Alcoy area are *textile and cosmetics*, both requiring a reliable water supply for their industrial processes. Currently, both industries produce waste that is difficult to treat in a sustainable way. The cosmetics industry discharges reactor cleaning streams with a high organic load and low biodegradability (30%). Meanwhile, the textile industry generates non-recyclable textile waste that ends up in landfills, as well as transfers paper waste from the printing process, which is highly difficult to manage due to the traces of silicone and printing paste in the cellulose-based material.





The SYMSITES EcoSites

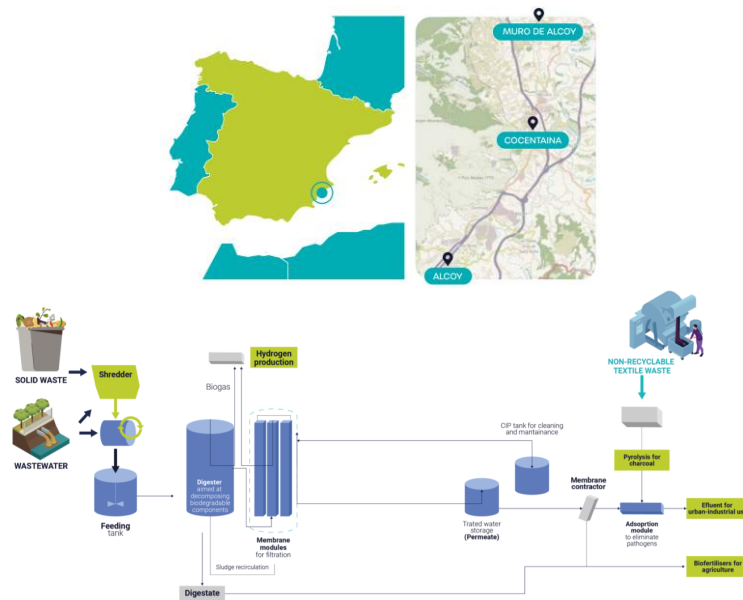
The Spanish EcoSite

The EcoSite Solution

The main objective of the Spanish EcoSite is to treat industrial and urban wastewater (WW) from the municipality of Alcoy together with urban organic solid waste from the town of Muro de Alcoy to produce green hydrogen, high-quality reclaimed water and added-value products, through an anaerobic membrane bioreactor (AnMBR) with a magnetic membrane vibration system (MMV) innovation and tertiary treatment.

The three sources of waste in the Spanish EcoSite are:

- Urban organic solid waste generated and collected in the municipality of Muro de Alcoy;
- Urban and industrial WW from the municipal Alcoy WWTP;
- Non-recyclable solid waste produced in the textile industry.





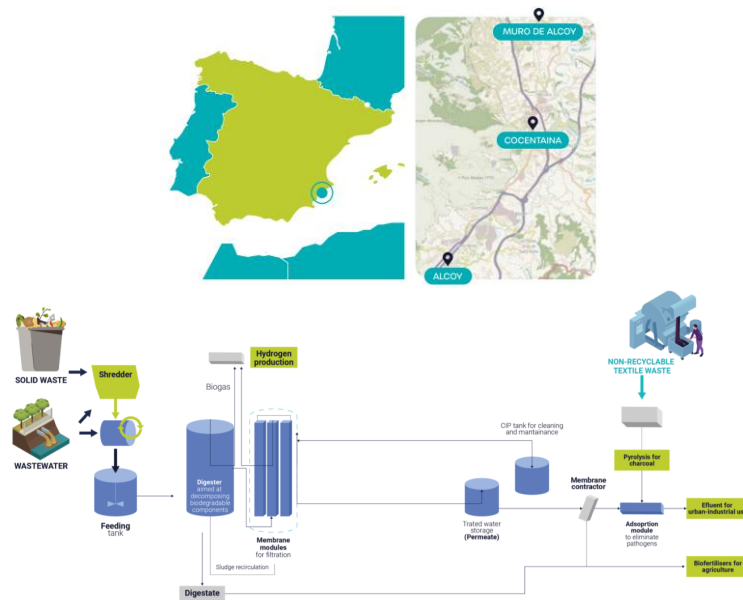
The SYMSITES EcoSites

The Spanish EcoSite

The EcoSite Solution:

The Spanish EcoSite is treating between 2-4 m³ /day of WW, and up to 50 - 100 kg/week of urban organic solid waste, allowing five streams of new added-value products to be obtained as output:

- *Platform molecules*: Benzoic or acetic acid will be produced from the liquid fraction of the pyrolysis treatment and will be used in industry.
- *Charcoal*: from pyrolysis of textile waste and transfer paper from the printing process stamps. Adsorption capacity tests will be carried out after and before activation to assess its removal capacity.
- *Digested sludge*: 9.9 kg biomass/m³ of treated water will be produced and tested for application as fertiliser.



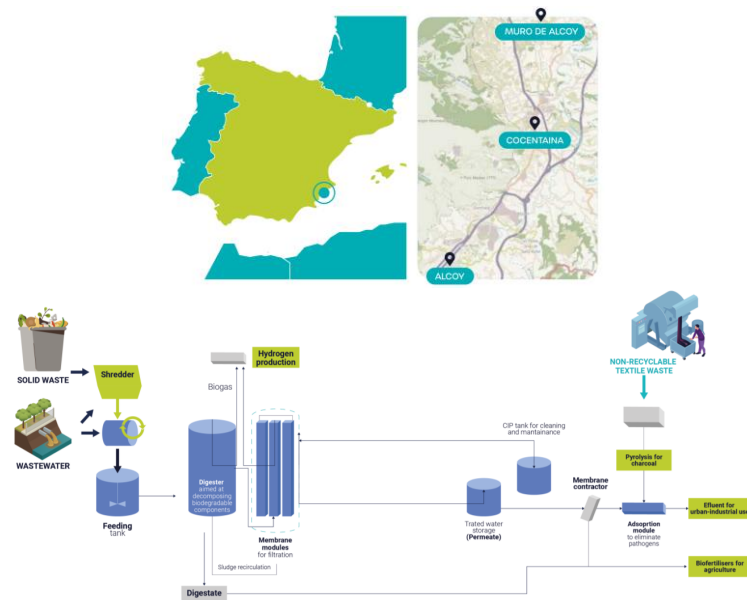


The SYMSITES EcoSites

The Spanish EcoSite

The EcoSite Solution

- *Green hydrogen*: CH₄ from AnMBR will be reformed into H₂ for use by urban and industrial users.
- *Treated water*: The treated water produced will be tested in industrial processes to replace all or part of the water employed conventionally.



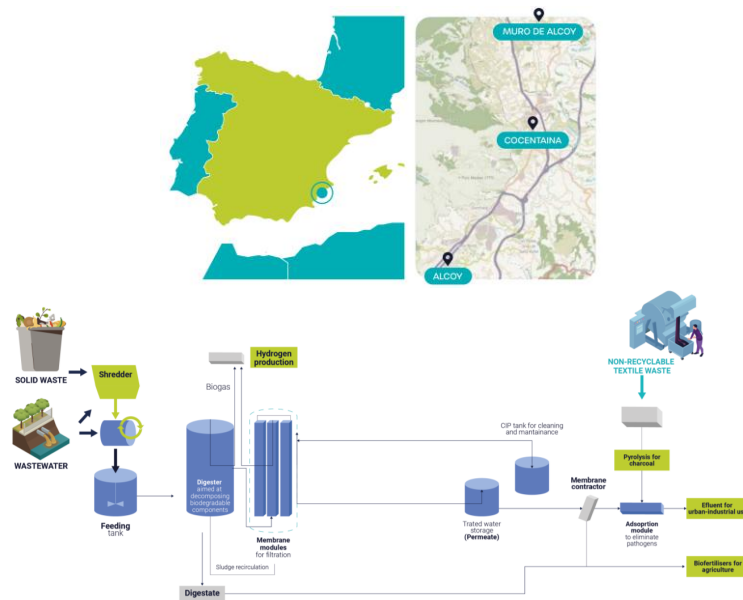


The SYMSITES EcoSites

The Spanish EcoSite

Benefits of the Symbiosis

- **Efficient Waste Management.** Organic waste from urban areas can be seen as a valuable resource rather than being disposed of in landfills. This reduces the environmental impact and extends the lifespan of existing landfill sites. Additionally, by diverting organic waste from traditional waste streams to bioenergy production facilities, municipalities and industries can save on disposal costs.
- **Energy Production.** Organic waste can be processed in the AnMBR to produce biogas, a renewable energy source. This biogas can be used to generate electricity, heat, or be upgraded to other biofuels such as biohydrogen. The continuous supply of organic waste ensures a steady production of biogas, contributing to a reliable and sustainable energy source.



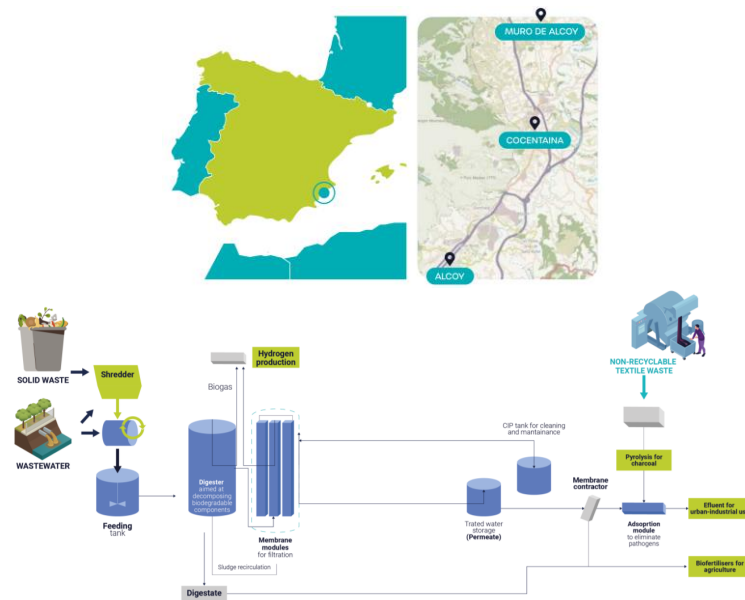


The SYMSITES EcoSites

The Spanish EcoSite

Benefits of the Symbiosis

- *Environmental Benefits:* Anaerobic digestion of organic waste reduces methane emissions from landfills and decreases reliance on fossil fuels, thus lowering greenhouse gas emissions. Additionally, the digestate, a by-product of anaerobic digestion, can be used as a biofertilizer, returning valuable nutrients to the soil and reducing the need for chemical fertilizers.
- *Sustainable Development:* Integrating waste treatment and bioenergy production into urban planning fosters resilient infrastructure capable of adapting to population growth and industrialisation. This fact encourages the circular economy where waste is minimised, water is reused and citizens are aware of the main environmental goals, contributing to the sustainability of the area.





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

This chapter explores the multiple co-benefits that I-US can generate across environmental, economic, and social dimensions. It explains how collaboration between industries, municipalities, and communities can improve resource efficiency, reduce environmental impacts, create economic value, and enhance urban well-being, and outlines the value that I-US can bring to different stakeholder groups. Finally, it introduces key approaches and methodologies used to measure and assess the environmental, economic, and social impacts of I-US initiatives.

- Target audience: General Audience (no prior knowledge required)
- Estimated time: 15 minutes
- Includes: Explanations Tools

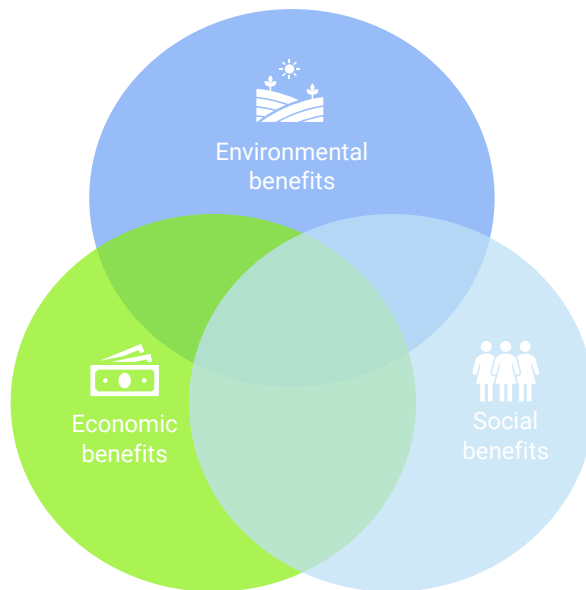




I-US Co-benefits

I-US creates opportunities for industries, cities, and communities to collaborate in ways that improve how resources are used across urban-industrial systems. These collaborative approaches generate co-benefits: many positive outcomes emerge simultaneously and interact with each other.

In the context of I-US, co-benefits are the environmental, economic, and social advantages that arise together from the same set of symbiotic activities or resource exchanges. A key feature of these co-benefits is that they are mutually reinforcing. Improvements in one dimension often stimulate positive effects in another, creating feedback loops that strengthen the overall value of symbiosis initiatives. This interconnected nature distinguishes I-US from traditional environmental management approaches, where actions aimed at environmental protection are sometimes perceived as separate from economic or social goals.



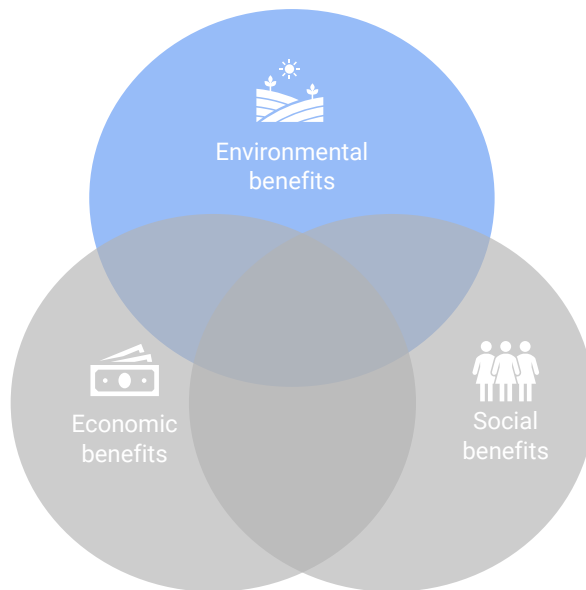


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Environmental benefits

Environmental improvements are often the primary motivation for developing I-US initiatives. By optimizing resource flows and enabling the reuse of materials, energy, and water, I-US contributes to more sustainable production and consumption patterns. In many cases, symbiotic exchanges help reduce the environmental footprint of both industrial activities and urban services.

- **Waste reduction:** Industrial processes frequently generate by-products such as heat, gases, sludge, wastewater, or residual materials that may traditionally be disposed of as waste. Through symbiotic collaboration, these outputs can be redirected to other users who can utilize them productively. This approach prevents valuable resources from being lost, thus also reducing the need for landfill space and other waste management infrastructure.

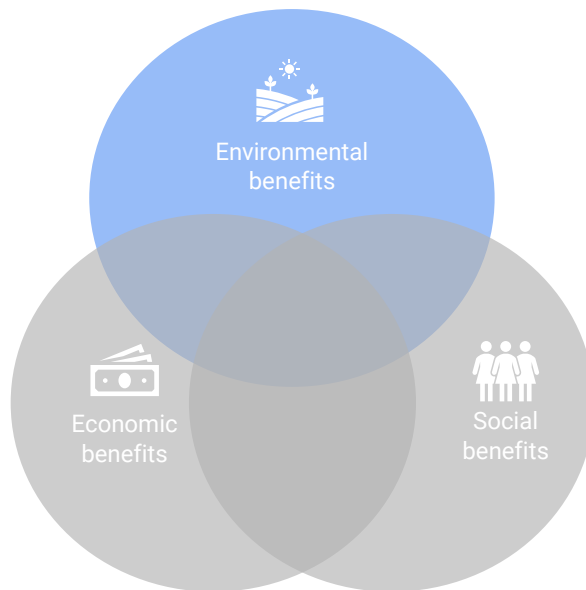




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Environmental benefits

- **Reduction of greenhouse gas emissions:** When secondary resources replace primary raw materials or fossil fuels, the overall energy demand of production systems decreases. For example, industrial waste heat can be captured and used to supply nearby district heating networks or municipal buildings. This reduces the need for additional energy generation and contributes to climate mitigation efforts.
- **Resource efficiency:** Water, energy, and materials are used more intensively and circulated within local systems rather than being used once and discarded. For instance, treated industrial wastewater may be reused in cooling systems, irrigation, or other industrial processes, reducing the extraction of freshwater resources.

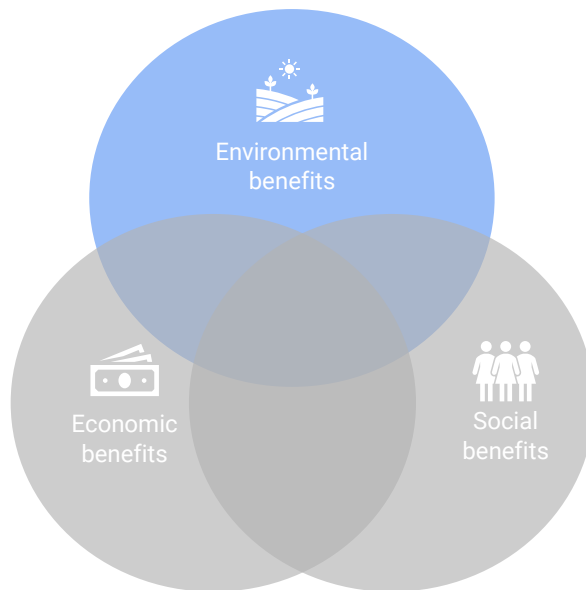




SYMSITES

Environmental benefits

- **Reduced extraction of virgin resources:** When industrial by-products or secondary materials are reused by other actors, they can replace primary resources that would otherwise need to be extracted from natural ecosystems. Reducing the extraction of minerals, fossil resources, and biomass helps limit environmental pressures associated with mining, logging, and other resource-intensive activities. These activities often lead to habitat disruption, landscape degradation, and significant energy use.
- **Improved water management and water security:** I-US can also play an important role in sustainable water management, particularly in regions where freshwater resources are limited or under increasing pressure. Many industrial processes generate wastewater that, after appropriate treatment, can be reused for other industrial processes, urban services, or irrigation. This type of cascading water use helps reduce freshwater withdrawals from rivers, lakes, and aquifers.

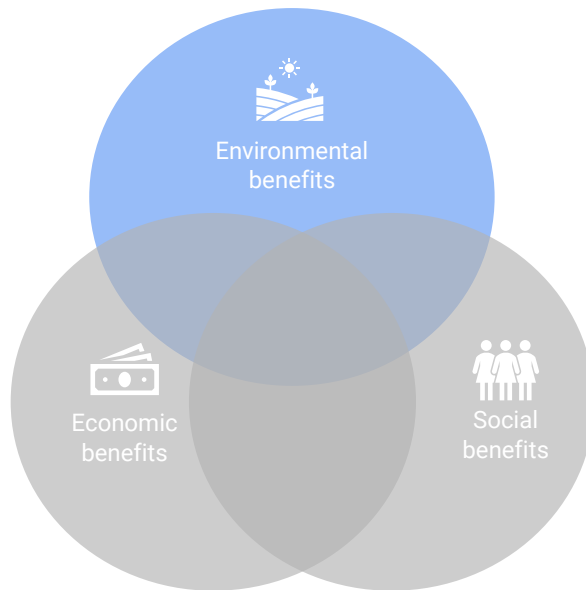




SYMSITES

Environmental benefits

- It can also alleviate pressure on municipal wastewater treatment infrastructure by promoting local reuse. As water scarcity becomes a growing global concern, such approaches can contribute to improved water security and resilience in urban-industrial systems.
- **Pollution prevention:** Better management of industrial outputs helps minimize emissions to air, water, and soil. When materials are recovered and reused instead of disposed of, the environmental impacts associated with waste treatment and raw material extraction are also reduced. Although biodiversity protection may not always be the primary objective of symbiosis initiatives, the reduction of environmental impacts across supply chains can generate positive effects for ecosystems at regional and global scales.

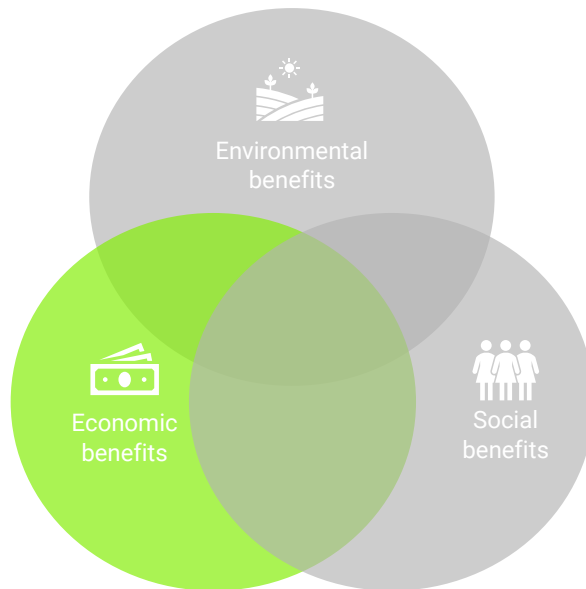




Economic benefits

Many symbiotic exchanges are driven by the potential to reduce costs, improve efficiency, and create new business opportunities. By transforming waste streams into valuable resources, companies and municipalities can unlock economic value that would otherwise remain untapped.

- **Cost reduction:** Companies can lower expenses related to raw materials, energy, water consumption, and waste disposal. For example, if a company can use a nearby industry's by-product instead of purchasing virgin materials, production costs may decrease while resource efficiency improves. Similarly, the recovery of waste heat, water, or materials can reduce operational expenses while improving overall process efficiency.

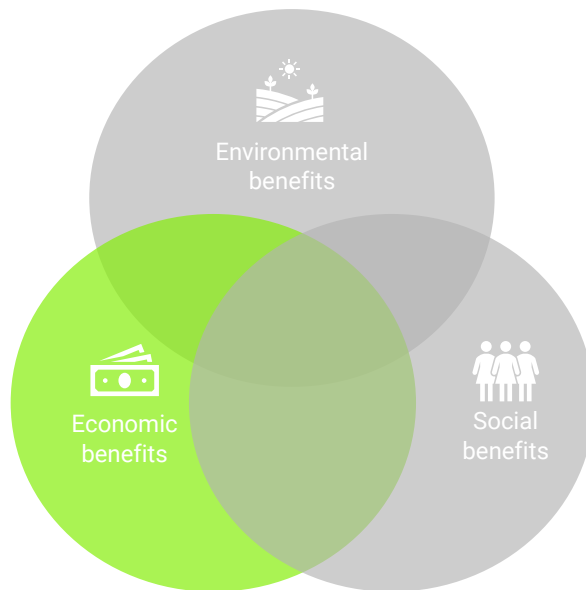




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Economic benefits

- **New revenue streams:** Materials that were previously treated as waste may become marketable products or inputs for other processes. For instance, construction materials, chemical by-products, or recovered metals can be sold or exchanged within local industrial networks. This transforms waste management from a cost center into a potential source of income. In some cases, entirely new markets can emerge around secondary materials, recycling services, or resource recovery technologies.
- **Improved operational efficiency and resilience:** Access to alternative resource streams can reduce dependence on volatile global supply chains or scarce raw materials. This diversification of resource sources can help companies better cope with fluctuations in material prices, supply disruptions, or geopolitical risks affecting resource availability. In this way, symbiotic relationships can increase the stability of industrial operations and strengthen regional supply networks.

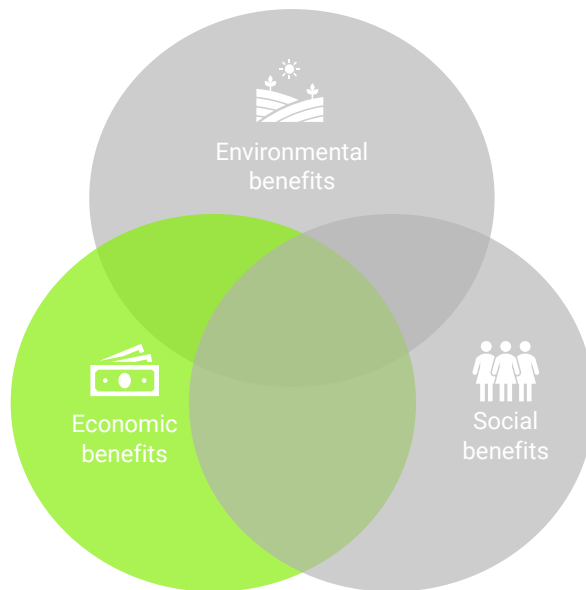




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Economic benefits

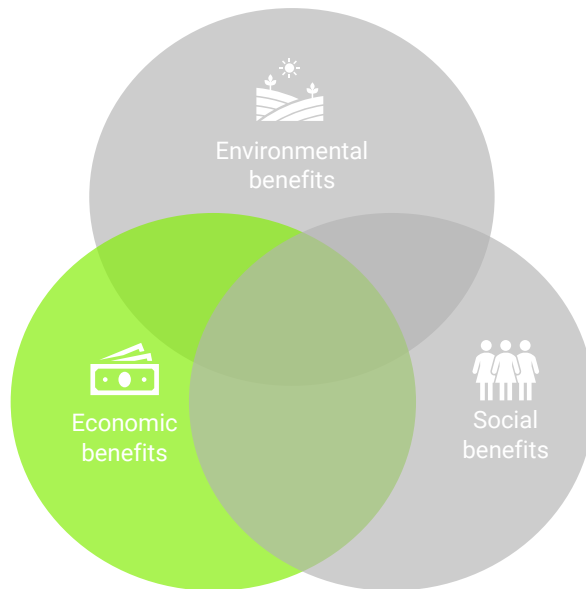
- **Development of new business models and services:** Companies may specialize in collecting, processing, or distributing secondary resources within symbiotic networks. For example, specialized firms may emerge to manage waste heat distribution, material recovery, or resource exchange platforms. These services create additional economic activity and contribute to the growth of circular economy sectors.
- **More efficient infrastructure management** (for cities and regions): Waste treatment facilities, energy systems, and water infrastructure can operate more effectively when industrial and urban flows are coordinated. For example, industrial waste heat can be integrated into district heating systems, while treated industrial wastewater may be reused for municipal purposes. These arrangements can reduce public expenditure on waste management, energy production, and water supply while improving service efficiency.





Economic benefits

- **Stimulate regional economic development and innovation:** Collaboration between industries, research institutions, technology providers, and local governments often leads to the development of new technologies and solutions related to resource recovery, recycling, and energy efficiency. Over time, these innovations can strengthen local industrial ecosystems, attract investment, and enhance the competitiveness of regions that actively support circular economy initiatives.
- **Corporate reputation and regulatory compliance:** Demonstrating commitment to sustainability can enhance relationships with regulators, investors, and customers while reducing the risks associated with future environmental regulations.

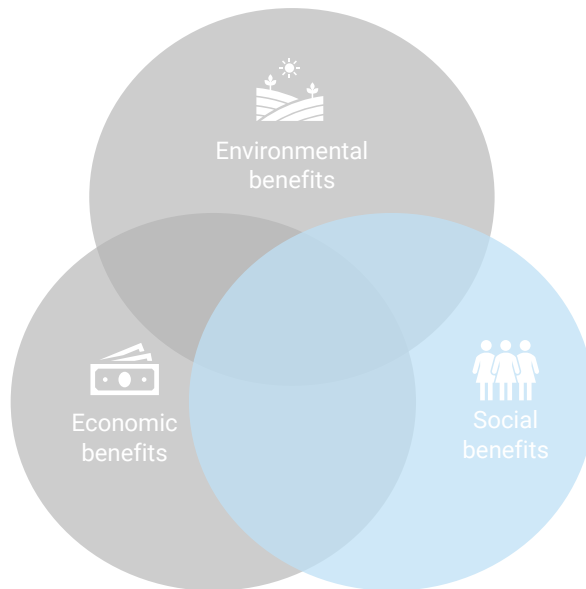




Social Benefits

While environmental and economic benefits are often emphasized, the social dimension of I-US is equally important. By improving the integration of industrial activities within urban environments, I-US can contribute to healthier, more resilient, and more inclusive communities.

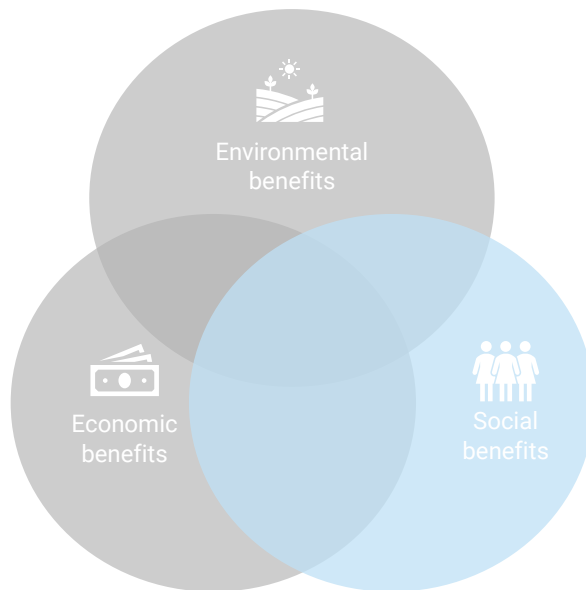
- **Job creation:** Symbiotic initiatives often require new activities such as resource recovery, recycling, materials processing, logistics coordination, and environmental management. These activities can generate employment opportunities across a range of skill levels, including technical, operational, and research roles. In addition, new jobs may emerge in areas such as environmental consulting, circular economy innovation, and infrastructure management.





Social Benefits

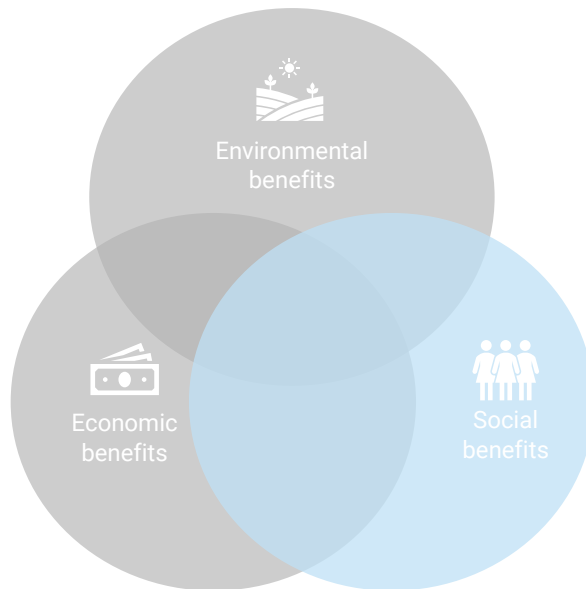
- **Skills development and knowledge creation:** As companies adopt new technologies and practices related to resource efficiency and circularity, there is increasing demand for specialized expertise. Universities, research institutions, and vocational training programs may develop new courses and training opportunities focused on circular economy practices, further strengthening the local knowledge base.
- **Urban liveability:** When industrial emissions, waste, and resource consumption are reduced, the environmental quality of surrounding areas improves. Cleaner air, better water management, and reduced waste contribute to healthier living conditions for residents. In some cases, symbiotic energy systems (such as district heating supplied by industrial waste heat) can provide more affordable and reliable energy services to local communities, reducing energy costs for households and public buildings.





Social Benefits

- **Strengthening of collaboration and trust between stakeholders:**
Industrial-urban partnerships often require cooperation among businesses, local authorities, universities, civil society organizations, and residents. These interactions encourage knowledge sharing, transparency, and dialogue between different groups. Over time, such cooperation can help build stronger local networks and foster a shared commitment to sustainable development.
- **Improved relationship between industry and local communities:**
Industrial activities are sometimes perceived negatively due to concerns about pollution, environmental risks, or resource consumption. By actively participating in symbiotic initiatives that reduce environmental impacts and support community goals, industries can demonstrate their role as responsible partners in sustainable urban development.



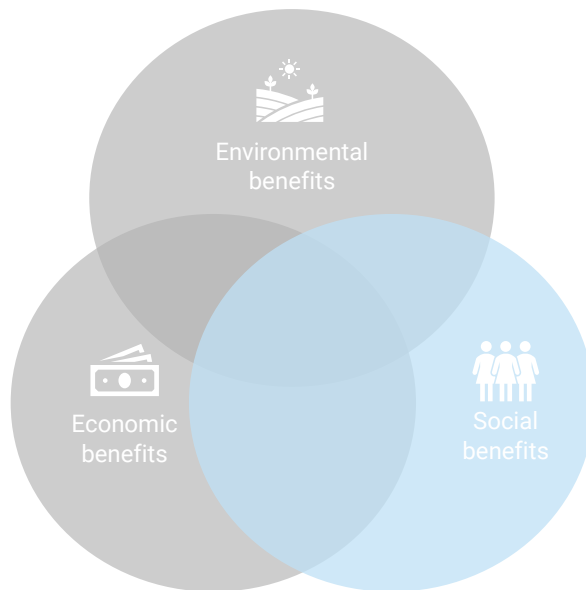


Social Benefits

- **Promotion of public awareness and engagement with circular economy practices:** When citizens see practical examples of resource reuse, energy recovery, and sustainable infrastructure in their cities, it can increase understanding of how circular systems work. Demonstration projects, educational programs, and community engagement initiatives linked to symbiosis projects can encourage more sustainable behaviors and strengthen public support for environmental policies.

Want to learn more?

- Read this: Nugroho, Y. A., Asih, A. M. S., & Sopha, B. M. (2025). Development of urban-industrial symbiosis to support sustainability: Bibliometric analysis and systematic literature review. *Discover Sustainability*, 6(1), 196. Accessible here: <https://link.springer.com/article/10.1007/s43621-025-01030-1>





Measuring the benefits

Measuring the benefits of I-US is crucial for demonstrating value, guiding decision-making, and improving system design. Impacts can be measured across environmental, economic, and social dimensions, with methods ranging from quantitative modelling to stakeholder surveys.

Monitoring provides the empirical basis to assess whether these strategic objectives are being met, while evaluation enables adaptive management and course correction. Without a structured monitoring system, the benefits of industrial symbiosis risk remaining anecdotal, limiting both learning and replicability, as well as hindering future investments and funding opportunities.

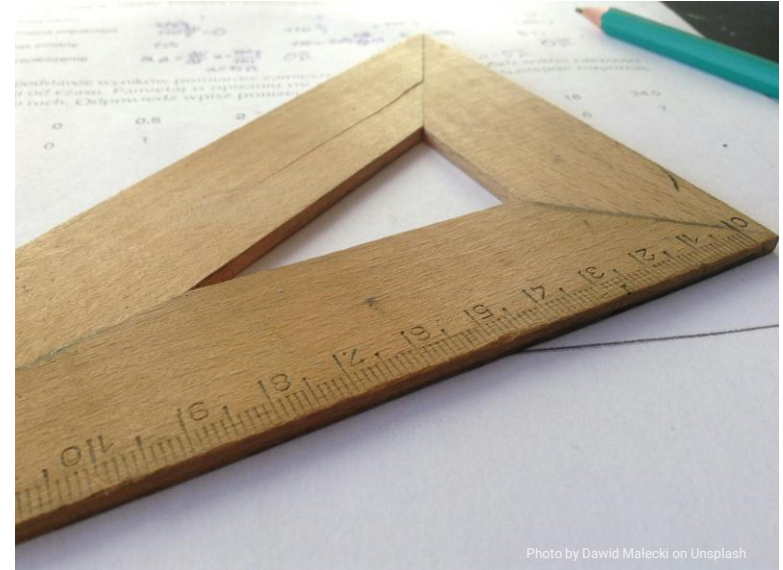


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Environmental Impact Measurement

Environmental assessment focuses on **resource efficiency, emissions reduction, waste reduction, and pollution prevention**. Common methodologies include:

1. Life Cycle Assessment (LCA)

Description: LCA evaluates the environmental impacts of a product, process, or system across its entire life cycle.

Application to I-US: Assess the benefit of using industrial by-products or waste heat in other processes. For example, LCA can quantify CO₂ emissions saved when waste heat from a steel plant is redirected to heat residential buildings.

Metrics: Global warming potential (CO₂-equivalent), energy use, water footprint, acidification potential, and waste reduction.

Benefits: Provides a comprehensive, science-based estimate of environmental impacts and helps compare alternative strategies.

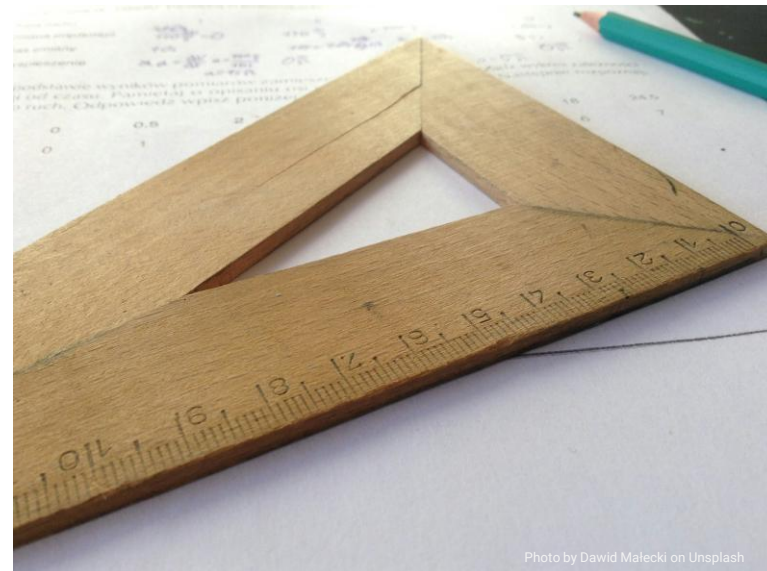


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Environmental Impact Measurement

2. Material Flow Analysis (MFA)

Description: MFA tracks the flow of materials, water, and energy within a defined system (e.g., industrial cluster, urban region) to identify reuse or recycling opportunities.

Application to I-US: Map industrial outputs that can serve as inputs for nearby industries or municipal systems.

Metrics: Tons of materials reused, percentage of materials circulated within the system, water reuse rates, energy recovery rates.

Benefits: Helps visualize resource loops, identify bottlenecks, and support planning for new symbiotic exchanges.

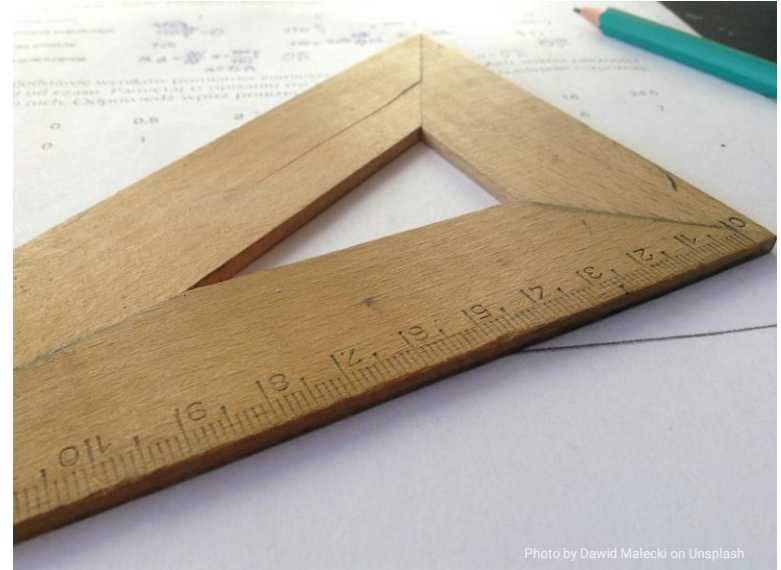


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Environmental Impact Measurement

3. Carbon and Water Footprinting

Description: Measures greenhouse gas emissions (carbon footprint) and water usage (water footprint) associated with a process or product.

Application to I-US: Quantify emissions reductions from substituting waste materials for virgin materials, or water savings from industrial wastewater reuse.

Metrics: kg CO₂-eq per ton of resource reused, cubic meters of water conserved.

Benefits: Provides a clear, communicable measure of environmental impact that stakeholders can monitor over time.

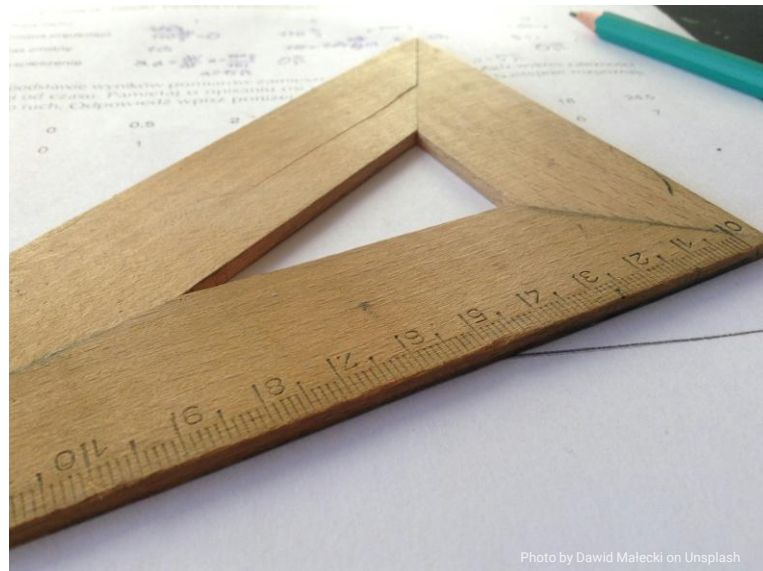


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Environmental Impact Measurement

4. Environmental Key Performance Indicators (KPIs)

Description: Simple, targeted metrics to track specific environmental performance aspects.

Application to I-US: Monitor progress in real-time or across projects.

Metrics: Waste diverted from landfill (tons/year), energy recovered (MWh/year), reduction in hazardous emissions (kg/year), percentage of materials reused.

Benefits: Quick-to-understand measures useful for internal reporting or communication to the public.

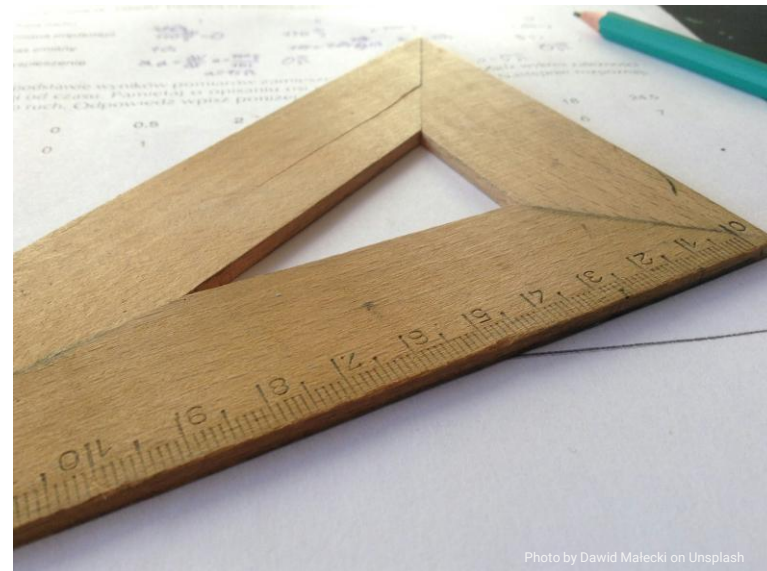


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Environmental Impact Measurement

5. Ecosystem and Biodiversity Indicators

Description: Assess indirect environmental benefits such as reduced pressure on ecosystems or habitats.

Application to I-US: Evaluate reduced resource extraction or pollution impacts on local flora and fauna.

Metrics: Hectares of land spared from extraction, reduced pollutant concentrations in water bodies, species richness or habitat quality indices.

Benefits: Connects industrial symbiosis activities to broader ecological sustainability goals.

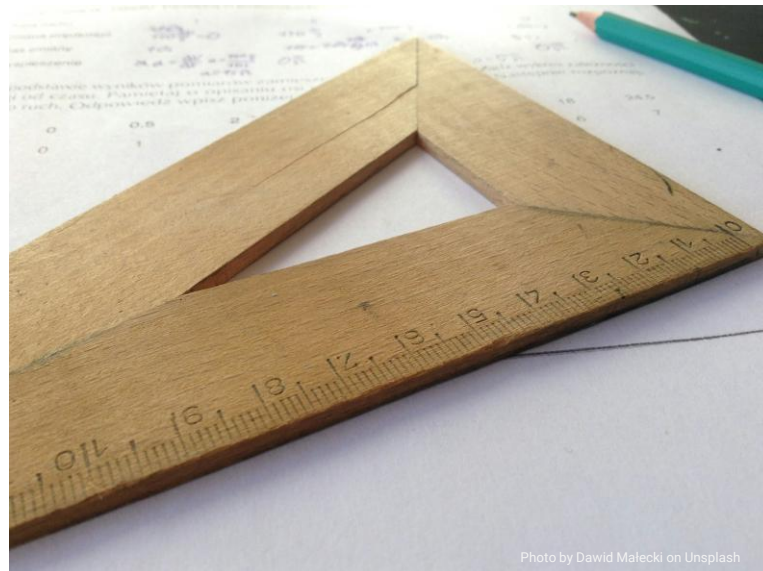


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Economic Impact Measurement

Economic assessment measures **cost savings, new revenues, investments, and regional economic development** arising from I-US.

Common methodologies include:

1. Cost-Benefit Analysis (CBA)

Description: Compares all costs of implementing a symbiosis initiative against its expected benefits over time.

Application to I-US: Include capital investments (infrastructure, technology), operational costs, avoided disposal fees, and revenue from selling by-products.

Metrics: Net benefit, payback period, benefit-cost ratio.

Benefits: Helps stakeholders assess financial feasibility and justify projects to investors or municipal authorities.

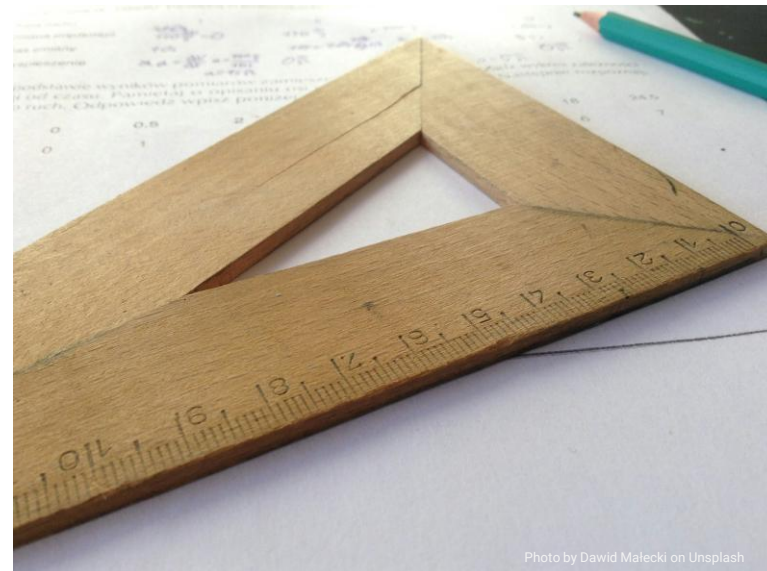


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Economic Impact Measurement

2. Input-Output Analysis (IOA)

Description: Models economic interactions between sectors in a region to estimate indirect and induced economic effects.

Application to I-US: Quantify how resource exchanges generate jobs, increase regional GDP, or stimulate local supply chains.

Metrics: Employment generated, regional value added, multiplier effects on local industries.

Benefits: Captures wider economic impacts beyond direct project benefits.

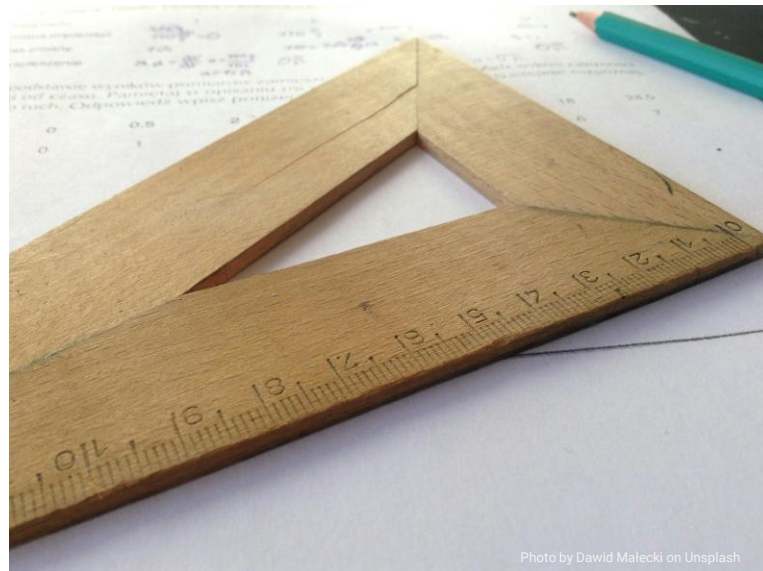


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Economic Impact Measurement

3. Return on Investment (ROI) and Net Present Value (NPV)

Description: Financial metrics evaluating profitability and long-term economic sustainability.

Application to I-US: Calculate monetary benefits of symbiosis initiatives relative to capital and operational investments.

Metrics: ROI (%), NPV (currency units), internal rate of return (IRR).

Benefits: Supports business case development and prioritization of alternative strategies.

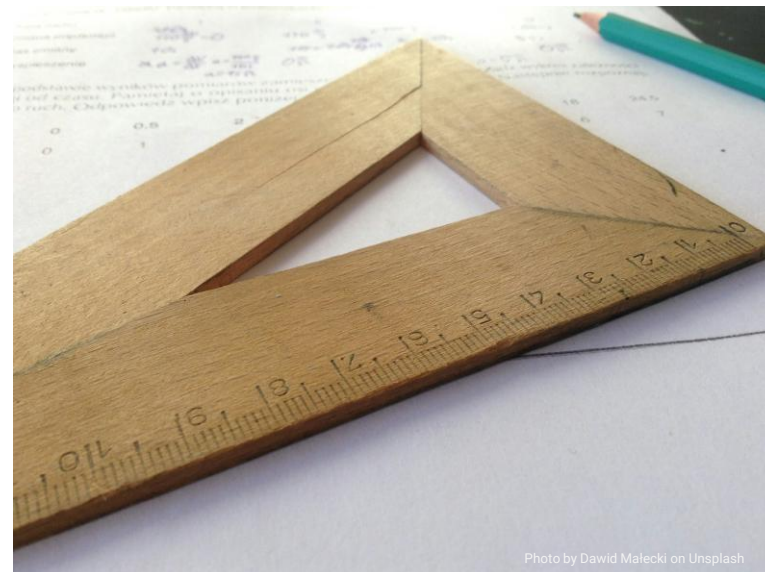


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Economic Impact Measurement

4. Scenario Analysis

Description: Compares potential outcomes of different implementation approaches or levels of resource integration.

Application to I-US: Evaluate economic implications of scaling up from one industrial cluster to multiple clusters or adding additional resource exchanges.

Metrics: Total cost savings, revenue growth, investment needs under alternative scenarios.

Benefits: Helps stakeholders understand trade-offs and make informed strategic decisions.

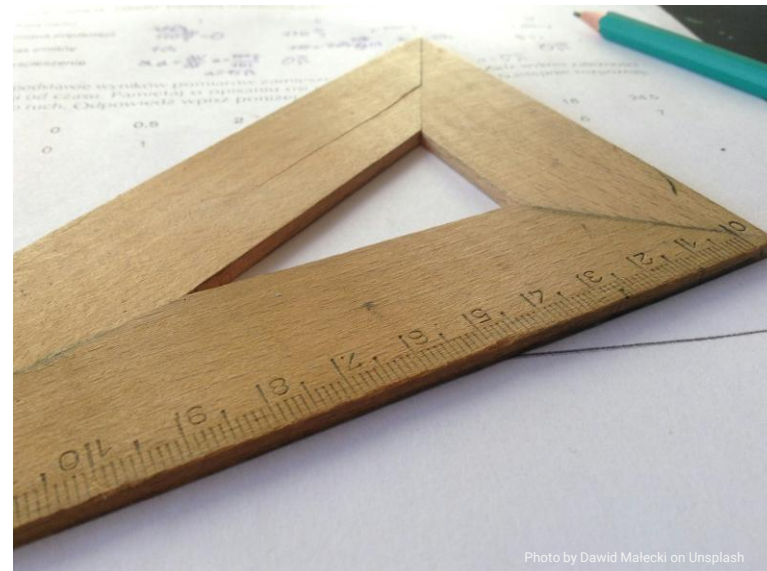


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Economic Impact Measurement

5. Economic KPIs

Description: Simple, practical indicators to track economic performance.

Metrics: Cost savings per ton of material reused, revenue from by-products, reduction in municipal waste management expenses, avoided energy costs, number of new business ventures.

Benefits: Easy to communicate and monitor across stakeholders.

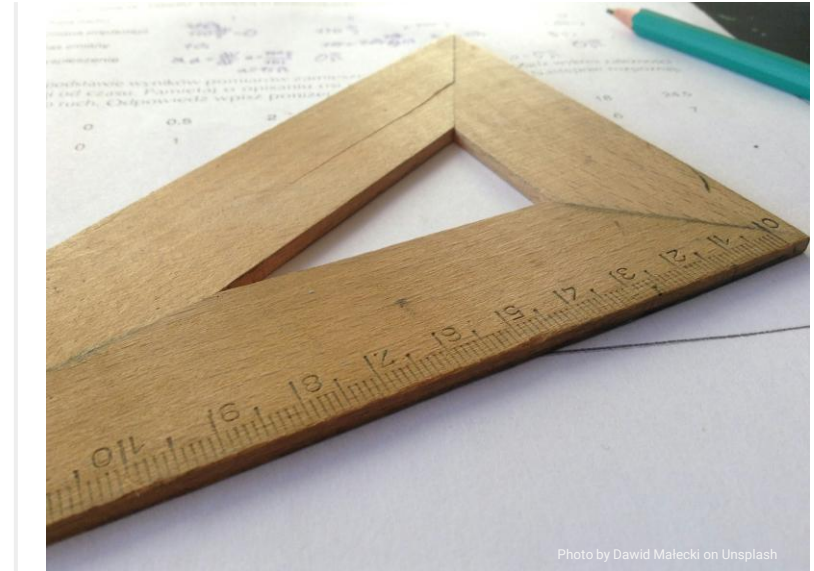


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Social Impact Measurement

Social assessment evaluates **community well-being, employment, skills development, stakeholder engagement, and urban livability**. Social benefits are often less tangible but can be measured using a mix of qualitative and quantitative methods.

1. Social Key Performance Indicators (KPIs)

Description: Quantitative metrics tracking social outcomes.

Metrics: Number of jobs created, number of people trained, reduction in local air or noise pollution exposure, households benefiting from industrial waste heat.

Benefits: Provides clear indicators of community impact that are easy to monitor and report.

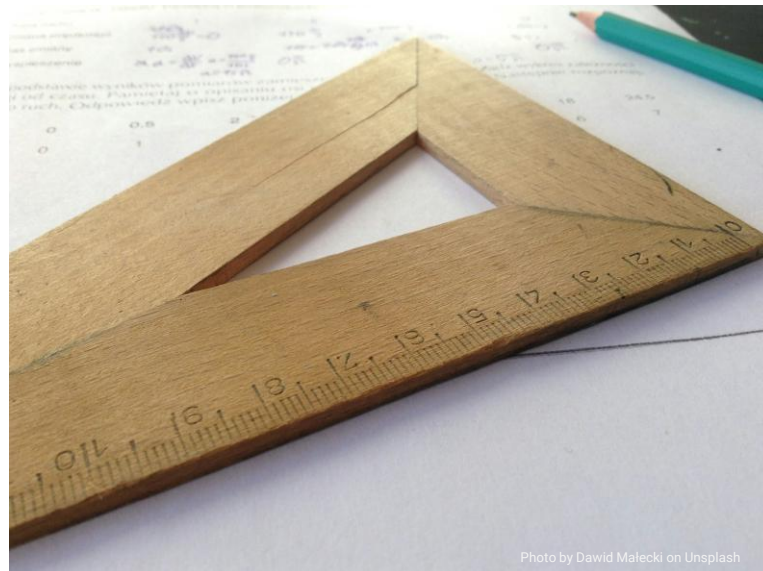


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Social Impact Measurement

2. Stakeholder Surveys and Interviews

Description: Collect qualitative and semi-quantitative data on perceptions, satisfaction, and social acceptance.

Application to I-US: Understand resident attitudes, employee satisfaction, and perceived improvements in quality of life.

Benefits: Captures benefits not easily measured by traditional KPIs, such as trust, engagement, and community support.

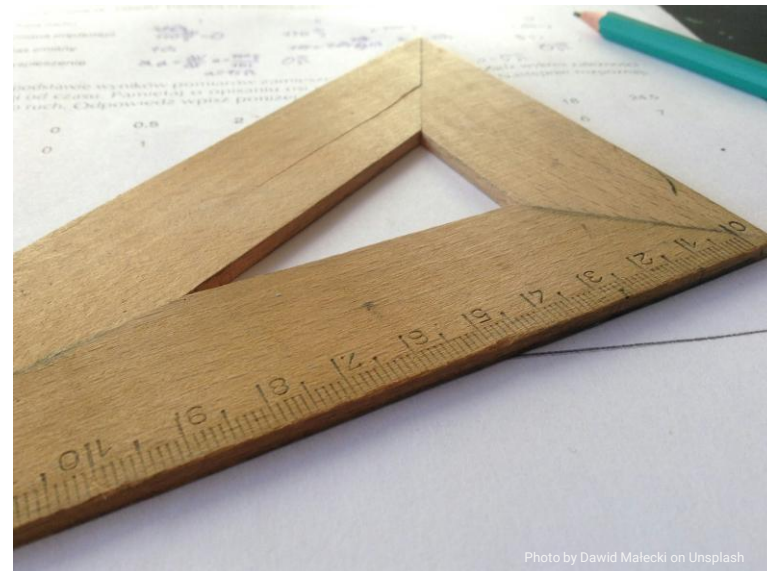


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Social Impact Measurement

3. Social Return on Investment (SROI)

Description: Converts social outcomes into monetary terms to assess value created relative to investment.

Application to I-US: Assign economic value to job creation, health benefits from pollution reduction, or improved access to resources.

Metrics: Ratio of social value generated per currency unit invested.

Benefits: Supports decision-making and demonstrates the broader societal value of symbiosis projects.

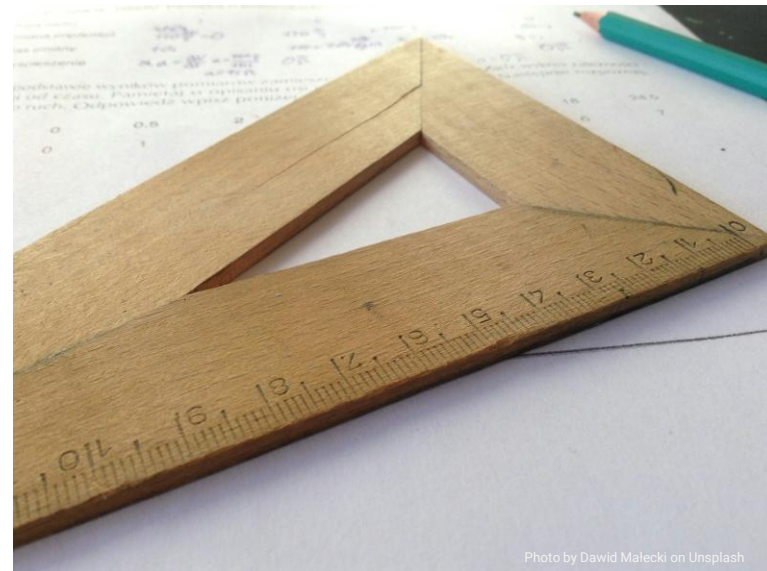


Photo by Dawid Malecki on Unsplash





Social Impact Measurement

4. Participatory and Community-Based Assessment Methods

Description: Engage local residents and stakeholders in assessing social impacts.

Application to I-US: Co-develop indicators, prioritize benefits, and evaluate satisfaction with initiatives.

Benefits: Strengthens community ownership, builds trust, and ensures that projects meet local needs.

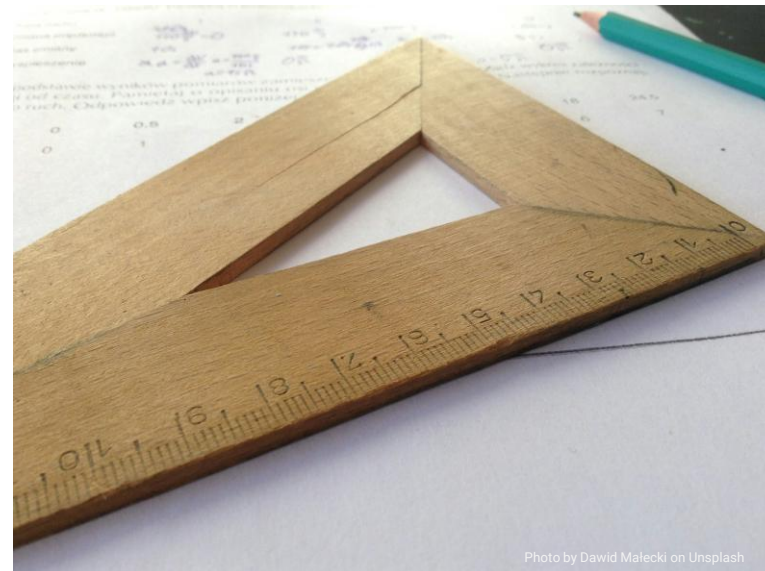


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Social Impact Measurement

5. Composite Sustainability Indicators

Description: Combine environmental, economic, and social metrics into integrated indices.

Application to I-US: Provide a holistic view of sustainability performance across all impact dimensions.

Metrics: Sustainability index scores, circularity performance indicators, or multi-criteria decision analysis outputs.

Benefits: Enables policymakers and companies to compare alternative symbiosis strategies and make evidence-based decisions.

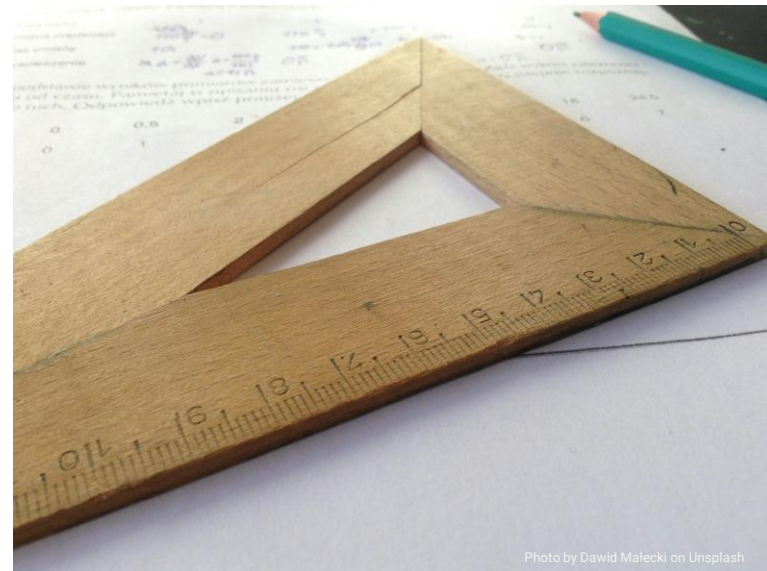


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CONSORTIUM MAP

